GUIDELINES FOR LABORATORY DESIGN

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Health, Safety, and Environmental Considerations

Fourth Edition

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Dr. Melvin W. First, ScD, M.S., C.I.H. P.E.

The fourth edition of Guidelines for Laboratory Design *is dedicated in memory of Dr. Melvin W. First, who died on June 13, 2011, at the age of 96. He was our inspiration, moral compass, trusted scientific expert, and devoted co-author during the writing of this book. Dr. First was a scholar, teacher, mentor, author, valued colleague, family man, friend, and a true gentleman. We are honored to have worked with this truly remarkable individual, feel privileged to have known him, and will forever miss his wit, kindness, loyalty, grace, and friendship.*

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FOREWORD

Today's laboratories are the incubators for tomorrow's discoveries. The very nature of laboratory work requires the use of potentially hazardous materials, complex equipment that must be integrated with building systems, and highly technical procedures and operations. It is therefore essential that the laboratory be designed with safety and health at the forefront.

The design, construction, and operation of laboratory buildings and the individual laboratories can be a complex and difficult task with the need to balance efficiency of space, cost, and flexibility while providing the users with the ability to conduct their work in a safe and efficient manner. As new technologies emerge and new discoveries are made, laboratories must evolve to keep one step ahead of the science. An important part of that evolution is to perform a risk assessment that addresses the various aspects of the laboratory in question. A risk assessment should be performed to determine the potential hazards and the engineering requirements or safety protocols that will have to be used to ensure personnel and environmental safety. Risk assessment is a site-specific and iterative process that addresses the goals appropriate to the risk of the agent(s) and the laboratory activity. The results of the risk assessment should be documented and maintained as part of the permanent record of the facility. The deficiencies that are identified in the risk assessment should be captured in a Corrective Action Plan that should be used in tracking remedial actions. Successive risk assessments should be performed until remedial actions are resolved.

Commissioning is a quality process for validating and documenting that a facility and its systems are planned, designed, installed, tested, and capable of being operated and maintained to perform in conformity with the design intent. Commissioning begins with the planning phase of a given project and proceeds through design, construction, start-up, training, acceptance, and into early occupancy. The commissioning process is designed to ensure compliance with the design intent of the facility. Commissioning partially focuses on how the engineering controls comply with the overall building operations.

There are numerous other processes that may be considered as part of the design and continuing operation of a safe laboratory. These include development of standard operating procedures, verification of individual and integrated systems, certification of specialized laboratories, and compliance to national and international standards or applicable local regulations.

This book provides an easy to use roadmap for owners and designers to meet the many challenges inherent in laboratories from the simplest to the most complex. It brings together the varied professionals who are critical to a successful design: architects, engineers, health and safety professionals, and end users. It provides the design team with the necessary information for them to ask the correct questions and determine what is the best design for the particular types of laboratories desired, while guiding them in the compliance with the relevant regulations and current best practices.

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PREFACE

The first edition of *Guidelines for Laboratory Design: Health and Safety Considerations* emerged from a contract in 1978, between five original authors (DiBerardinis, Baum, Gatwood, Groden, and Seth), with the Exxon Corporation. The authors prepared corporate guidelines for the design of new laboratory buildings around the globe, where Exxon scientists would conduct petrochemical testing and research. Dr. Melvin (Mel) First a professor at Harvard School of Public Health joined the authors of the Exxon document to write the first edition.

Good laboratory designs allow researchers to conduct their work in the most efficient and safe manner, and in laboratories that will be in compliance with all relevant regulations. The foundation for the book was to bring together the key disciplines—architecture, facility engineering, industrial hygiene and safety engineering—that need to be involved in designing laboratories. During the first and second editions all the authors worked together at Harvard University at the Medical School and at the School of Public Health. Louis DiBerardinis is a certified industrial hygienist and certified safety professional, who worked at Harvard University, and later at Polaroid Corporation. He is currently Director of Environment, Health and Safety at the Massachusetts Institute of Technology. He is also a Visiting Lecturer at the Harvard School of Public Health and an Adjunct Professor in the Department of Work Environment at the University of Massachusetts Lowell. He is president of his consulting company DiBeradinis Associates Inc. Janet Baum is a licensed architect specializing in laboratory design. She was a laboratory architect at Harvard Medical School and practiced architecture at firms in Boston and St. Louis. Janet then cofounded the laboratory design firm, Health, Education + Research Associates (HERA, Inc.). She currently teaches architecture and in the public health program at Washington University in St. Louis. Mel First, PhD, deceased, was Professor of Air Quality Engineering who conducted research and taught at the Harvard School of Public Health for over 50 years. Gari Gatwood is a mechanical engineer, and before retirement, was board certified as a safety professional (CSP) who worked for Hercules Inc., Harvard University, and Bell Laboratories. Gari served for many years on the Executive Committee of the Research and Development Section of the National Safety Council. In retirement, he pursues ocean sailing along the East Coast. Ed Groden, deceased, was a facilities engineer with extensive laboratory design and operating experience who worked for many years at Harvard Medical School. Anand Seth is a professional mechanical engineer, formerly at Harvard Medical School, then Director of Utilities & Engineering at Massachusetts General Hospital and Partners HealthCare System in Boston for many years. He left that institution to become regional president of a national engineering firm Sebesta Blomberg. He is currently in private practice with Cannon Design, an international architectural/engineering firm. Although the authors bring different perspectives to laboratory design, all have a common goal to design, build, and operate laboratories in the safest manner possible, while stressing the need for communication and cooperation among all the disciplines involved.

In subsequent editions of the book, the authors have added chapters to address renovations of existing laboratories as well as several types of laboratories that reflect the changing trends in scientific research and science teaching. In this fourth edition, the text has been

expanded and updated to reflect current trends, changes that have occurred during the past decade, and emerging technologies. Many new drawings, photographs, and graphics have been added in this edition to aid the readers' understanding. Six new chapters have been added of which three are new laboratory-type chapters. The first, "Nanotechnology Laboratories," Chapter 7 addresses an increasing trend to work with nanoparticles in all areas of research. The second, "Engineering Laboratories," Chapter 8 discusses unique aspects of a number of engineering disciplines. The third, "Autopsy Laboratory," Chapter 19 defines the differences in design of this type laboratory from general morgue facilities. "Imaging and Photographic Facilities," Chapter 25 has been expanded to introduce design considerations for several digital imaging modalities commonly used in scientific research, in addition to traditional light photography darkrooms. A new chapter, "Laboratory Storerooms," Chapter 28 addresses challenging safety and design issues presented by the storage of hazardous materials. "Commissioning and Final Acceptance Criteria," Chapter 37 assists readers to learn how to assess and verify that laboratories are constructed and operating as designed. "Sustainable Laboratory Design," Chapter 38, focuses upon design methods and materials to build sustainable laboratories without compromising the environment or occupant safety and health. Although energy conservation strategies have always been discussed, sustainable design strategies have been added in several chapters throughout this edition.

In Chapters 1 to 24, the sections covering building and laboratory layouts; safety and industrial hygiene; heating, ventilating, and air-conditioning; and special services have been expanded to include a discussion of the latest trends in these areas as well as emerging technologies and systems.

The authors expect this fourth edition to become a valuable resource for laboratory design teams and owners or operators of laboratory facilities who may consider constructing new or renovating old laboratories. This edition contains critical information on the entire project development process from the predesign and feasibility phases, through design and construction phases, to commissioning and final acceptance.

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Melvin W. First
Gari T. Gatwood
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Mr. DiBerardinis is the Director, Environment, Health and Safety at MIT. This includes oversight responsibility for safety, industrial hygiene, radiation protection, biosafety, and environmental management. Prior to that, he was an industrial hygienist at Polaroid Corporation and Harvard University.

Mr. DiBerardinis received his BS degree in Chemical Engineering from Northeastern University and a Master of Science degree in Industrial Hygiene from Harvard University.

He is a visiting lecturer at Harvard University School of Public Health where he currently teaches in several graduate courses and continuing education programs. He is Adjunct Professor at the University of Massachusetts Lowell in the Department of the Work Environment. He is editor of the *Handbook of Occupational Safety and Health* (Wiley). He served as chair of the ANSI Z9.5 subcommittee on Laboratory Ventilation from 1984 to 2006. He also chairs ANZI Z9.7 (Recirculation of Air from Industrial Process Systems) and co-chairs ANSI Z9.11 (Laboratory Decommissioning) and Z9.14 (Testing and Performance Verification Methodologies for Ventilation Systems for Biological Safety Level 3 (BSL-3) and Animal Biosafety Level 3 (ABSL-3) Facilities. He serves on the editorial board of the American Chemical Society's journal *Chemical Health and Safety* and the journal *World Review of Science, Technology and Sustainable Development*.

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Janet S. Baum, Master of Architecture, is an American Institute of Architects (AIA)-licensed architect. Ms. Baum earned her BS in Architectural Sciences at Washington University in St. Louis and her Master of Architecture at Harvard University, Graduate School of Design.

After several years of general architecture practice, she began her over 40-year laboratory design career as a Senior Planner at Harvard Medical School. After Harvard she continued in private architectural practice in Boston and later in St. Louis, MO. She founded the laboratory planning and design firm HERA, Inc., and led its architectural practice for 12 years. She co-authored or contributed chapters to 17 books on laboratory planning, design, and safety and has written numerous articles published in peer-reviewed journals. Ms. Baum is an American Chemical Society member and was awarded the Howard Fawcett Chemical Health and Safety award.

Ms. Baum currently teaches part-time at Harvard University's School of Public Health and at Washington University in St. Louis, in the Graduate School of Architecture and Urban Design and in the Institute of Public Health. Ms. Baum consults on laboratory building programming, planning, and design for academic and healthcare institutions, corporations, and government agencies. Ms. Baum participates on the National Institutes of Health (NIH) construction grant review panel and is a former advisory committee member and chairperson for the National Institute of Standards and Technology (NIST)'s Building and Fire Research Laboratory. She is a current member of the AIA's Academy of Architecture for Health and a former board member. She is a board member of the St. Louis Academy of Science.

The late MELVIN W. FIRST, Sc.D., CIH, PE

Melvin W. First was a researcher and Professor of Environmental Health Engineering at the Harvard School of Public Health for almost 60 years and was actively involved in research until a week before his death.

He earned a degree in biology and public health at MIT in 1936, then worked as a toxicologist and an industrial hygiene engineer in Michigan until 1941 when he entered the armed services. After World War II, he enrolled at Harvard, where he earned a Master's degree in sanitary engineering in 1947 and a Sc.D. in industrial hygiene engineering in 1950.

In 1956 he joined the Department of Industrial Hygiene at Harvard School of Public Health, rising through the ranks to become Professor of Environmental Health Engineering in 1971. He became an emeritus professor in 1985 but continued to work daily on the Harvard faculty for the next 26 years.

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Gari T. Gatwood, Bachelor of Science in Mechanical Engineering (CSP retired), is a consultant in safety engineering. For 25 years Mr. Gatwood served as Manager of Safety Engineering and Environmental Services for the Department of Environmental Health and Safety of Harvard University. Prior to that he was the Manager of Safety for the Cambridge Electron Accelerator, an Atomic Energy Commission–funded laboratory run jointly by the Massachusetts Institute of Technology and Harvard. Earlier, he was a Senior Weapon Systems Safety Engineer for the Hercules Inc. Intercontinental Ballistics Missile program.

Mr. Gatwood has lectured widely and has taught courses in laboratory safety and design and in process safety engineering for Bell Laboratories, Harvard University, the American Chemical Society, and other organizations in the United States and abroad. Mr. Gatwood served as Chairman of the Board of the Massachusetts Safety Council and has served in officer positions within the National Safety Council and the American Society of Safety Engineers. He was presented the American Society of Safety Engineers Safety Professional of the Year award for Northeastern United States in 1981.

Mr. Gatwood received his degree in Mechanical Engineering from Missouri School of Mines and Metallurgy in Rolla, Missouri (presently known as Missouri University of Science and Technology).

ANAND K. SETH, BS, MS, PE, CEM, CPE

Anand K. Seth is currently a Principal in Cannon Design, an international architectural/engineering/commissioning firm. Before Cannon Design, Mr. Seth was the U.S. North East Sector regional president for Sebesta Blomberg and Associates, Inc. Prior to that, he was Director of Utilities and Engineering for Partners Healthcare Systems, Inc. (PHS), which operates several hospitals in Massachusetts. In that role, he was in charge of all engineering systems for its large multi-building, multi-campus complex. Before joining PHS, Mr. Seth worked at Massachusetts General Hospital and Harvard University with similar functions.

Mr. Seth holds a Master of Science in Mechanical Engineering from the University of Maine and has done postgraduate work at other universities. Mr. Seth is a registered Professional Engineer in several states and has national credentials as a Certified Energy Manager and Certified Plant Engineer.

Mr. Seth has been active in the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). He chaired the ASHRAE SP 91 committee to write a manual on hospital air conditioning systems. He is the author of numerous technical papers, and is one of the editors of the book *Facilities Engineering and Management Handbook an Integrated Approach* (2000).

Mr. Seth has taught at the Franklin Institute of Boston and Cambridge College in Cambridge, Massachusetts, and since 1981 has taught several continuing education courses at Harvard University School of Public Health. He has been and continues to be a frequent lecturer at professional conferences.

ABBREVIATIONS

ACD	allergic contact dermatitis
ACH	air changes per hour
ACM	asbestos-containing material
ACR	air changes rate
ACZ	adjustable current sensor inverter
A/E/C	architecture/engineering/construction
AFFF	aqueous film-forming foam
AHJ	authority having jurisdiction (see also JHA)
AHU	air-handling unit
ALARA	as low as reasonably achievable
AM	as manufactured
ASD	aspirating smoke detection
AVI	adjustable voltage inverter
BIM	building information management
BOD	basis of design
BOQ	Bill of Quantities
BSC	biological safety cabinet
BSI	British Standards Institute
CA	commissioning agent
CADD	computer-aided design and drafting
CFC	chlorofluorocarbon
CFD	computational fluid dynamics
CHO	chemical hygiene officer
CNC	computer numeric control
CO_2	carbon dioxide
COI	chemicals of interest
COP	coefficient of performance
CRF	condensation resistance factors
CSF	cerebrospinal fluid
DC	direct current
DD	double-duct system (ventilation)
DEAE	(diethylamino)ethanol
DI	deionized
DNA	deoxyribonucleic acid
DOP	dioctylphthalate
DOT	Department of Transportation
DX	direct expansion refrigeration cooling system
EA	environmental assessment
EH&S	environmental health and safety professionals
EHS	environmental health and safety
EIS	Environmental Impact Statement
ELISA	**e**nzyme-linked immunosorbent assay
ETRAF	enclosure for toxins using recirculating air filtration
EUI	Energy Use Index
FCA	facility conditions analysis
FCCV	fan coil constant-volume reheat system (ventilation)
FCVAV	fan coil variable air volume reheat system (ventilation)
FM	Factory Mutual (casualty insurance group)
FP	fire protection
FRP	fiberglass-reinforced polyester
FTE	full-time equivalent
GFCI	ground fault circuit interrupter
GHG	greenhouse gas
GM	Geiger Muller
GPR	green performance ratings
HEPA	high-efficiency particulate air (filters)
HHS	U.S. Department of Health and Human Services
HIV	human immunodeficiency virus
HPM	hazardous production materials
HVAC	heating, ventilating, and air-conditioning

IARC	International Agency for Research on Cancer
IAQ	indoor air quality
IBC	International Building Code
I.D.	inner diameter
ID	ionization products of combustion detection
IFC	International Fire Code
IHO	Industrial Hygiene Office
IPD	integrated project delivery
IT	information technology
JCAHO	Joint Commission for Accreditation on Hospitals Organization
JHA	jurisdiction having authority (see also AHJ)
JIT	just-in-time
LANL	Los Alamos National Laboratory
LCA	life-cycle assessment
LD_{50}	lethal dose that kills 50% of the exposed population, usually in animal toxicology studies
LED	light-emitting diode
LEL	lower explosive limit
LEV	local exhaust ventilation
LPD	lighting power density
LTS	linear temperature sensing
MAA	main accumulation area (for hazardous waste)
M.E.	medical examiner
MEP	mechanical, electrical, and plumbing
MERV	Minimum Efficiency Reporting Value
MIT	Massachusetts Institute of Technology
MMF	manmade fiber
MRI	magnetic resonance imaging
NAS	National Academy of Sciences
N.C.	normally closed (control valve)
NCCLS	National Committee for Clinical Laboratory Standards
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NMR	nuclear magnetic resonance
N.O.	normally open (control valve)
NRC	U.S. Nuclear Regulatory Commission
NSC	National Safety Council
NSF	National Sanitation Foundation
NTP	National Toxicology Program
OEL	occupational exposure limit
OFD	optical flame detection
OMCVD	organometallic chemical vapor deposition
OPR	owner's project requirement
OSD	optical smoke detection
OSHA	Occupational Safety and Health Administration
PCOC	potential contaminants of concern
PCR	polymerase chain reaction
PEL	permissible exposure limit
PI	principal investigator
PPE	personal protective equipment
PWM	pulse-width modulator
PVC	polyvinyl chloride
RCR	room cavity ratio
RH	relative humidity
ROR	rate of rise thermal detection
RPO	Radiation Protection Office
SA	select agents
SAL	special autopsy laboratories
SCBA	self-contained breathing apparatus
SF_6	sulfur hexafluoride
STEL	short-term exposure limit
TAT	turnaround time
TDS	total dissolved solid (water)
TLA	total lab automation
TLV	threshold limit value (air contamination)
TMR	terminal reheat system (ventilation)
TRH	constant-volume terminal reheat system (ventilation)
UFAD	underfloor air supply distribution
UL	Underwriters Laboratory
ULPA	ultralow penetration air (filter)
UPSs	uninterruptible power supplies
VAV	variable air volume
VHP	vaporized hydrogen peroxide
VOC	volatile organic compounds
VVTRH	variable-volume terminal reheat system (ventilation)

UNITS

A	Ampere
ACH	air changes per hour (ACPH) also acceptable
°C	degrees Centigrade
cm^3	cubic centimeter
CFM	cubic feet per minute (air volume rate); ft^3/min also used
cm	centimeter
dB	decibels
°F	degrees Fahrenheit
FPM	feet per minute (air velocity); ft/min also used
ft	feet
ft^2	square feet
ft^3	cubic feet
ft-c	foot candles (illumination) fc also used
g	gram
gal	gallon
gpm	gallons per minute
GSF	gross square feet
GSM	gross square meters
h	hour
Hz	Hertz
in. w.g.	inches water gauge (pressure)
in.	inch
kPa	kilopascal
L	liter
lbs	pounds
lf	linear feet
lpm	liters per minute
lx	illuminance
m	meter
m^2	square meters
m/s	meters per second (1 m/s = 197 FPM)
m^3/min	cubic meter per minute
m^3/min/m^2	cubic meters per minute per square meter
m^3/s	cubic meters per second (1 m^3/s = 2120 CFM)
mA	milliampere
min	minute
mL	milliliter
mrem	millirem
mW	milliwatt
NASF	net assignable square feet
NASM	net assignable square meters
nm	nanometer
NSF	net square feet
NSM	net square meters
oz	ounce
Pa	pascal (250 Pa = 1 in. w.g.)
ppb	parts per billion
ppm	parts per million
PSF	pounds per square foot
psig	pounds per square inch gauge (pressure)
rad	unit of ionizing radiation (dose)
s	second
V	volt
vac	volts alternating current
W/ft^2	Watts per square foot (illumination allowance)
µCi	microcurie (ionizing radiation)
µg/m^3	micrograms per cubic meter
µin./s	micro-inches per second
µm	micrometer
Ω-cm	ohm-centimeter (water conductivity)

ORGANIZATIONS REFERENCED

AAALAC	American Association for Accreditation of Laboratory Animal Care
AAMA	American Architectural Manufacturers Association
ACGIH	American Conference of Governmental Industrial Hygienists
AGS	American Glovebox Society
AIA	American Institute of Architects
AMCA	Air Movement and Control Association
ANSI	American National Standards Institute
ASEA	American Solar Energy Society
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
BOCA	Building Code Officials' Association
BOMA	Building Owners Management Association
BSI	British Standards Institute
CDC	Centers for Disease Control and Prevention
CETA	Controlled Environmental Testing Association
DHS	Department of Homeland Security
DOT	Department of Transportation
EPA	U.S. Environmental Protection Agency
FGI	Facility Guidelines Institute
FM	Factory Mutual
GBI	Green Building Initiative
GSA	General Services Administration
IAIA	International Association for Impact Assessment
IARC	International Agency for Research on Cancer
IEEE	Institute of Electrical and Electronics Engineers
IESNA	Illuminating Engineering Society of North America
ILBI	International Living Building Institute
ISPE	International Society for Pharmaceutical Engineering
LBL	Lawrence Berkeley Laboratory
LEED®	Leadership in Energy and Environmental Design
MPI	Master Painter Institute
NAME	National Association of Medical Examiners
NCES	National Center for Education Statistics
NEBB	National Environmental Balancing Bureau
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NFRC	National Fenestration Rating Council
NIBS	National Institute of Building Sciences
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology Building and Fire Research Laboratory

NSF	National Sanitation Foundation
OSHA	Occupational Safety and Health Administration
SBIC	Sustainable Buildings Industry Council
SCAQMD	South Coast Air Quality Management District
SCS	Scientific Certification Systems
SEFA	Scientific Equipment and Furniture Association
SFI	Sustainable Forest Initiative
SMACNA	Sheet Metal and Air-Conditioning Contractors' National Association, Inc.
UL	Underwriters Laboratory
USGBC	U.S. Green Building Council

INTRODUCTION

NEED FOR THIS BOOK

The design and construction of new laboratory buildings and the renovation of old ones require close communication between laboratory users, project engineers, architects, construction engineers, and environmental health and safety personnel. With a multitude of needs to be addressed, all too often safety and health conditions and environmental impact, are overlooked or slighted, and laboratories may be built with unanticipated safety and health hazards or adverse effects to the environment. It is clear that one of the principal objectives of laboratory design should be to provide a safe place in which scientists, engineers, and their staff can perform their work. To fulfill this objective, all safety and health considerations must be evaluated carefully and protective measures must be incorporated into the design wherever needed.

Over many years, chemists, physicists, biologists, research engineers, and their technicians and assistants have met with injury and death in their laboratories by fire, explosion, asphyxiation, poisoning, infection, and radiation exposure. Injury and death have also resulted from more common industrial accidents, such as falls, burns, electrocution, and encounters with broken glassware and falling objects. Emphasis on safety should begin in well-organized high school science classes and continue with increasing intensity and sophistication through colleges and graduate schools for the express purpose of educating scientists and laboratory workers to observe safe laboratory procedures while learning and to carry this knowledge and experience into their careers. Often, however, the very laboratories in which they later practice their profession are obsolete or, when modern, fail to incorporate safe design principles. Unless such scientists have had the good fortune to observe well-designed laboratories, they may be ill equipped to assist architect-engineers with safety design when new or renovated laboratories are being prepared for their use. Few architect-engineers are specialists in laboratory safety, and they usually need and welcome the active participation of the scientists to whom the laboratories will be assigned in designing for laboratory safety.

Because laboratory scientists tend to do their work alone or in very small clusters, the dire effects of serious breaches of good safety and health practices seldom result in numerous casualties and for this reason are poorly reported in the popular and professional news media. This may give the impression that the dangers of laboratory work have been exaggerated and perhaps may lull scientists into a false sense of security. Accident statistics, however, confirm that laboratories can become dangerous workplaces. Careful thought for worker safety remains an essential part of the laboratory design process.

This book is organized to provide, in a concise, easy-to-use format, the information needed by architects, project engineers and environmental health and safety professionals to design safe and efficient laboratories. It includes safety considerations that must be addressed to comply with governmental regulations as well as recognized good practice standards. Although the book emphasizes U.S. regulations, it is expected that application of the safety principles recommended here will provide safe and efficient laboratories wherever they may be needed.

OBJECTIVES OF THIS BOOK

The purpose of this book is to provide reliable design information related to specific health and safety issues that should be considered when planning new or renovated laboratories. The objective is approached within the framework of other important factors such as efficiency, economy, sustainability, energy conservation, and design flexibility. Although precise specifications are provided in some cases, the general intent is to review the relevant environmental, safety, and health issues and then to recommend appropriate design action, including, where possible, a range of alternatives. In those cases in which there are specific U.S. code requirements, the appropriate section of the code is referenced. In many cases, consultation between project engineers, laboratory users, and environmental specialists, industrial hygienists, and safety experts will be required at one or more design stages. These instances are noted in the text, and it is the hope of the authors that a relationship characterized by close cooperation and understanding will develop among these groups as a result of the use of this book.

The book seeks to address at the design stage the many issues that have a direct bearing on the occupational health and safety of those who work in laboratories. It makes no attempt to address all the building structural service requirements that are normal architectural and engineering design considerations, nor does it intend to define good practice laboratory health and safety programs in operating laboratories. It recognizes that all these matters should have an important influence on design considerations and addresses them solely in that context. Instances where enhanced design features can facilitate compliant and efficient operation are noted.

It is always important for project managers to communicate frequently with all laboratory users to keep current with their specific needs. Experience has amply confirmed that there is a steep learning curve whenever laboratory personnel enter into the design phase of their own laboratories, and changing requirements are the norm at the start. Because many safety considerations are specific to certain laboratories but absent in others, it is extremely important that the typical laboratory chosen for design purposes be identified unequivocally as the one the user needs.

In renovation projects, the original building layout and engineered systems design must be evaluated very carefully to determine its compatibility with the needs of the intended occupants as well as with the good practice layouts recommended in this book. Therefore, it will be essential to review each laboratory design recommendation to investigate its compatibility with the building that has been selected for renovation. This must be done cooperatively with the user, the architect, and management because critical compromises are almost inevitable when an existing building is adapted to new uses.

HOW TO USE THIS BOOK

Subject Matter Organization

All of the laboratory specific technical matter in this book is divided among five parts and several appendixes in a manner designed to provide easy access to all the occupational safety and health information needed to complete a specific design assignment. This has been accomplished in two ways. First, Chapters 1 and 2 (Part 1, Section A), contain technical information that applies to all, or nearly all, laboratory buildings (Chapter 1) and laboratory modules (Chapter 2) regardless of the precise nature of the work that will be conducted in each. The purpose of placing all generally applicable information into two early chapters is to avoid repeating it when each of the distinctive types of laboratories is discussed in the individual laboratory type chapters contained in Part II. Part I, Section B (Chapters 3 and 4) performs a similar mission for the subject of preparing existing laboratories for renovation and construction of replacement facilities. The general technical information contained in Sections A and B is also intended to present to the reader a unified body of design principles that will be instructive as well as easily accessible as a reference source.

The second method used to coordinate the information in the several technical chapters is the use of an invariant numerical classification system throughout the chapters in Parts I, II, III, and IV, whereby identical topics are always listed under the same numerical designation. For example, in every chapter in these four parts, all space requirements and spatial organization information will be found in sections containing the number 2 after the chapter number. Therefore, the section numbered 1.2 is in Chapter 1 and is concerned with the technical aspects of building layout, whereas the section numbered 2.2 is in Chapter 2 and refers to the general technical aspects of laboratory module layout. Similarly, these same numbers have been assigned to the chapters that cover each unique type of laboratory. For easier understanding by the reader, the numerical classification system that is used in each chapter throughout Parts I through IV of the book are summarized below under "Book Organization."

Part II of this book contains information on detailed specifications, good practice procedures, and cautionary

advice pertaining to 20 specific types of commonly constructed laboratories for academic, commercial, government, and industrial research and for testing and educational purposes. Some laboratories are intended for general purpose usage (for example, undergraduate chemistry teaching), whereas others are intended for very specific and well-defined research activities (for example, work with biological hazards).

The safety and health design recommendations for each laboratory are based on the operations that are to be performed as well as on the materials and equipment that will be used. It is recognized that laboratory usage patterns tend to change over time, and therefore it is prudent to try to provide for unique functions with as much design flexibility as possible. In some cases, a predictable changing pattern of usage may call for what we refer to as *a general purpose laboratory*. We therefore treat the general purpose laboratory as one of the special laboratory design categories.

No attempt has been made to treat every conceivable type of laboratory in a separate chapter because some are highly specialized and have too restricted a range of usage to make this worthwhile (for example, total containment biological safety laboratories), whereas others are offshoots of one or more of the laboratories that are described in detail and the transference of information will be obvious. Where gaps of coverage remain, it is hoped that the general principles enunciated in Part I, plus the specific information contained in Parts II through IV, will provide adequate guidance for those confronted with a need to design and construct unique and innovative types of laboratories.

Part III contains four chapters that are concerned with support facilities commonly needed by laboratories of all types. They include imaging and photographic suites, research model shops, laboratory storerooms, and special waste-handling facilities designed for the collection, temporary storage, consolidation, and shipping of chemical, biological, and radioactive wastes. All aspects of hazardous wastes are rigidly regulated by the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission. In the field of biological hazards, the U.S. National Institutes of Health and Centers for Disease Control and Prevention issue guidelines that have the practical force of regulations.

Part IV is devoted to a number of general and specific topics associated with the job of heating, ventilating, and air-conditioning laboratories. Background information is presented on comfort perception and on important system components such as fans and filters. A major emphasis of Part IV is on laboratory hoods of all kinds and on variable-air-volume systems designed to conserve energy by automatically reducing emissions of air from the laboratory when exhaust air services are not needed at their maximum design capacity. Other energy conservation techniques are also reviewed.

Part IV also contains commonly consulted consensus standards, good practices, and institutional bid documents and procedures found to be useful in the design of well-functioning HVAC systems.

Part V contains administrative matters pertaining to bidding procedures, final acceptance inspections, and sustainability considerations. Although sustainability strategies are discussed and incorporated throughout the book, they are treated as a major topic in Part V. These strategies emphasize (1) designing sustainable buildings (see Chapter 38); (2) selection of materials; (3) heating, cooling, and ventilation systems that minimize the discharge of uncontaminated air; (4) recommendations for the installation of exhaust air devices (for example, fume hoods) that discharge the least air volumes consistent with safety, and (5) the use of fully modulated HVAC systems that supply tempered air consistent with exhaust requirements, but no more (see Chapters 37 and 38); and (6) strategies for water conservation. It is anticipated that all ordinary energy conservation measures associated with the laboratory structure will be familiar to architects and engineers and that they will be incorporated into the design of the building. Therefore, these important energy conservation methods are not discussed in this book. Instead, only those conservation techniques closely associated with the functioning of occupational health and safety matters are covered.

Part VI contains (1) appendixes related to universally used laboratory safety items (emergency shower and eyewash stations, and warning signs), and (2) a matrix table intended to be used as a handy checklist for health and safety design items and to inform the reader where pertinent sections are located in the book.

Book Organization

This book is organized with sufficient flexibility to guide the user in the design of a complete new, multistory laboratory building as well as in the renovation of a single laboratory module. It is arranged in a format that allows the user to start with the building description and then to proceed in a logical sequence to the development of each individual laboratory module. The safety and health considerations that must be addressed in every laboratory design assignment are explained and illustrated in five broad categories.

1. Guiding Concepts. This section defines each type of laboratory by (1) the nature of the tasks normally

performed there, (2) the special materials and equipment used, and (3) the nature of the requirements that contribute to making this laboratory unique. In some instances, hazardous or specialized materials and equipment that should not be used in a particular laboratory are listed to aid in making certain that the architect, project engineer, and laboratory user all have the same laboratory type under consideration. When the laboratory type first selected has serious contraindications for some of the projected activities, an alternative type that does not have such exclusions should be identified and those design guidelines followed. There may be instances where the type laboratories designated here is a combination of several of the type laboratories designed here. In this case, the relevant parts of the following Sections 2 through 5, must be determined and applied.

2. Laboratory or Facility Layout. This section discusses and illustrates the area requirement and spatial organization of each type of laboratory with special regard to egress, equipment and furniture locations, ergonomics, and ventilation requirements. Typical good practice layouts are illustrated, and a major effort is directed toward calling attention to those layouts that are clearly undesirable. The location of exhaust hoods, biological safety cabinets, clean benches, and items of similar function are given special attention. Materials of construction are discussed with respect to sustainability.

3. Heating, Ventilating, and Air-Conditioning. This section describes the desirable elements of a laboratory HVAC system that is designed for comfort and safety. Wherever unique requirements have been recognized because of the critical nature of the work or equipment, they are given consideration and definition in a special requirements section. Usually, minimum performance criteria are specified in bid documents, but it should be recognized that somewhat better performance ought to be provided by the design to allow for inevitable system deterioration while in use. This is needed because health and safety equipment installed in laboratories and laboratory buildings must perform its design function with a high level of reliability throughout an assigned service life that may be the same as the life of the building. Some loss of efficiency and effectiveness over long time periods is usual for machinery and structures. Therefore, a factor to account for normal deterioration must be included in procurement specifications so that, at the end of the expected service period, performance will be adequate to accomplish the assigned health and safety functions with an adequate margin of safety. Procurement documents often specify minimum performance criteria, which can diminish with time, thereby ensuring less than desired performance over a major portion of the service life of the items. Thus, minimal acceptance criteria for procurement must take into account (1) lesser performance experienced after installation than contained in manufacturers' performance tables developed under ideal test conditions plus (2) an additional factor for normal deterioration over long-term usage to ensure acceptable health and safety protection initially and over the life of the facility. Special attention is given to providing adequate makeup air for exhaust-ventilated facilities and to the pressure relationships between laboratories, offices, and corridors. When construction requirements for laboratory systems differ substantially from those that apply to ordinary HVAC installations, the differences are made explicit and appropriate codes and standards are cited in the text.

4. Loss Prevention, Industrial Hygiene, and Personal Safety. This section presents checklists of items that must be evaluated for their inclusion during the design stages. They encompass a wide variety of safety devices and safety design options intended to protect workers, property, and the environment. The important subjects of fire safety, handling dangerous substances and disposal of laboratory waste, are included.

5. Special Requirements. This section deals with the unique aspects of each identified laboratory type. Not all of the noted special requirements may be needed exclusively for safety reasons, but their presence in a laboratory may affect overall safety considerations and are important for that reason. This section evaluates their potential impact and presents appropriate safety measures when required. In Part II, this section contains unique references to renovation requirements pertaining to specific laboratory types.

CODES AND STANDARDS

Governmental and code requirements that pertain to specific safety items are stated, and the sources are referenced. In the United States, the major codes, regulations and standards that must be met for new construction and major renovations are those of the latest editions of the Occupational Safety and Health Administration (OSHA), the Environmental Protection Agency (EPA), the National Fire Protection Association (NFPA), and the International Buildings Code (IBC) or equivalent national building code adopted by the jurisdiction having authority. In addition, there are many local codes, ordinances, and state laws that must be observed. In the absence of specific regulations or code requirements, numerous safety-related topics are treated with special detail because we are of the opinion that our recom-

mendations will have an important impact on improved safety in areas not now adequately addressed elsewhere. In these instances, considerable pains have been taken to justify the recommendations. Whenever possible, alternative recommendations are made to permit flexibility of design and construction, especially for renovation projects, in which physical constraints are encountered frequently. Even when no specific recommendations are made, a checklist of items to be considered is often presented. When additional interpretation of recommendations or further explication of design cautions is considered desirable, it is highly recommended that the project engineer and architect work closely with environmental specialists, industrial hygienists, and safety professionals in an endeavor to design and build the safest and most sustainable laboratories feasible.

INFORMATION SOURCES

Applicable federal and state regulations, codes and standards, textbooks, and published articles on the safe design of laboratories are referenced throughout the book to provide the user with more detailed information. Close communication with environmental specialists, industrial hygienists, and safety professionals throughout the planning phases is recommended. In the absence of qualified staff personnel, certified professional guidance may be obtained in several ways.

1. *Consultants.* The American Industrial Hygiene Association, the American Society of Safety Engineers, Association of Fire Protection Engineers, and the American Academy of Environmental Engineers maintain current lists of consultants, which can be obtained on request.
2. *Government Agencies*
   (a) Many state departments of occupational health (or industrial hygiene) receive federal assistance for the express purpose of providing professional help for occupational health and safety needs, and they can be called or visited for advice.
   (b) Regional offices of the National Institute for Occupational Safety and Health (in the U.S. Department of Health and Human Services) as well as the Occupational Safety and Health Administration (in the U.S. Department of Labor), can also be requested to provide answers to specific health and safety issues and interpretation of federal regulations.
   (c) Local fire departments usually review large renovations and new building plans with respect to fire regulations.
   (d) Regional offices of the Environmental Protection Agency and state departments of environmental protection are prepared to interpret regulations regarding permissible emissions to air and water and disposal of hazardous solid wastes.

Note. Because it is expected this book will be used by people with diverse technical backgrounds (for example, architects, engineers, laboratory scientists, health and safety professionals and nontechnical administrators), many terms and concepts are defined and explained with a degree of detail that may seem excessive to one or another of these professional groups. Should this occur, we hope that the reader will be patient and understanding of the knowledge limits of others on the design team.

THE USE OF COMPUTATIONAL FLUID DYNAMICS IN THE DESIGN OF LABORATORIES

Over the past 35 years computational fluid dynamics (CFD) techniques have been used extensively and successfully in the nuclear and aerospace industries. The concept of combing CFD software with the expertise of the HVAC engineer has made it possible to apply these powerful methods to obtain fast and accurate results by designers under severe time and budgetary constraints. Airflow modeling based on CFD is now well established and widely applied to study building ventilation, heating/cooling, and contaminant control.

CFD technology involves numerically solving a set of conservation of momentum, energy, and mass equations by superimposing a grid of many tens or even hundreds of thousands of cells, which describe the physical geometry of heat flow, contamination sources, and of the air itself. Three methods are typically used for this, namely, the finite volume, finite element, and finite difference methods. The first two are the most popular and a good description of them can be found in Patankar (1981). Reddy and Gaitling (1994) is a good reference for the finite element approach.

Although CFD is unlikely to replace experimental procedures completely (and there is a good argument that it should not replace them completely), there are several advantages in the use of CFD over experiment:

- CFD can provide a wealth of information at literally hundreds of thousands of spatial locations within the volume of interest. To achieve the same

level of experimental information would cost many times the effort associated with the CFD study.
- CFD allows one to consider systems that would otherwise be very difficult to consider experimentally, for example, simulation of a fire scenario.
- Parametric studies can be evaluated very effectively using CFD compared with more traditional methods.
- The use of experimental measuring devices, which can be obtrusive in physical scenarios and can distort results, are not necessary with CFD.

A rise in the use of CFD can be attributed to three main reasons:

1. Computer power is getting cheaper, meaning that useful simulations can now be run on PCs.
2. With the steady accumulation of published CFD success stories, it is becoming a recognized form of analysis, i.e., the air of mystery, and therefore caution, surrounding CFD is diminishing.
3. CFD tools are now being designed with the CAD/CAM engineer in mind and so are much friendlier to use.

Although there are still some classes of problems that are not well understood from a CFD sense, CFD is becoming a widespread tool in many HVAC studies, especially those where the cost of experimentally creating prototypes would be prohibitive.

A few examples of how CFD can benefit for the HVAC engineer and health and safety professional follow.

- Developing ventilation systems for virtually any built environment, such as atria, health care facilities, animal care facilities, laboratories, cleanrooms, and manufacturing areas.
- Developing smoke extraction systems, especially in built environments in which experimental tests are not possible, for example, in atria.
- Consider external flows, and their possible impact on internal regions. An example of this is considering whether smoke and other contaminants from stacks can be reentrained into nearby building air intakes.
- Considering conjugate heat transfer problems in buildings, where the effect of conduction through wall materials is combined with convective flow patterns.
- Balancing supply or exhaust plenums in cleanrooms.
- Considering airflow in ductwork and other ventilation system components.

Research utilizing CFD to assist laboratory design is still relatively rare. However, Memarzadeh (1996, 1998) used CFD as a method to optimize laboratory hood containment and design of animal research facilities. Hundreds of different ventilation system scenarios were considered in CFD models and conclusions were drawn for selecting design guidelines to ensure containment. The same author used CFD to verify the effectiveness of the design for thermal comfort, uniformity, and ventilation effectiveness in laboratories in a chemical research center in Bethesda, MD.

It should be clear from the above that CFD offers a wealth of advantages to the HVAC engineer and health and safety professional. Although it does not completely eliminate the need for experimental procedures, it can drastically reduce the amount of experimental study needed to solve many classes of laboratory design.

PART IA

COMMON ELEMENTS OF LABORATORY DESIGN

The first two chapters of this book address several elements of the design process, starting with essential decisions regarding building size and function, progressing to structural and modular design choices, and then on to individual laboratory requirements for space, utilities, clustering, and the auxiliary facilities that allow laboratories to function safely and productively.

For the most part, the subjects covered in these two chapters apply to all laboratories and to all buildings primarily devoted to housing laboratories. Therefore, they cover the general principles of modern laboratory building and laboratory module design, with a special focus on the health and safety of those who will occupy the finished structures and work there. The diverse nature of present-day science and engineering activities calls for unique features and equipment in most special-function laboratories. These special needs generally call for additions to the basic requirements covered in these two chapters rather than substitutions; these special requirements are covered in considerable detail on an individual laboratory-by-laboratory basis in Part II.

The information contained in Part I, Section A is directed toward new construction. The varieties of structural constraints that can be associated with the renovation of existing buildings and laboratories are covered in Part 1, Section B. Nevertheless, it is anticipated that most of the material in Section A can be applied to renovations and reconstructions. Certainly, the same modern principles of laboratory health and safety protection serve new and renovated laboratory facilities alike and can be applied to both.

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

1

BUILDING CONSIDERATIONS

1.1 GUIDING CONCEPTS

This chapter deals principally with alternative building layouts for the design and construction of new laboratory buildings. The advantages and disadvantages of a variety of alternative building design strategies are presented, as are preferred design choices. Laboratory requirements based on the various preferred building layout strategies are discussed. During the useful life of a building, laboratories may be renovated several times. Therefore, as much flexibility as possible has been provided so that the health and safety concepts given here may be applied to the renovation of existing buildings as well as to original construction. Facilities undergoing simple upgrading need not be substantially revised to meet the requirements given in this chapter if no safety hazards are present, but close consideration of the precepts detailed in this chapter is warranted when substantial modifications are to be made. Because laboratories may be constructed within building layouts that are less than ideal for the purpose, careful review and application of health and safety requirements will be required. Nevertheless, most safety and health requirements can be applied to many different laboratory and building layouts: It should always be possible to meet essential safety requirements.

1.2 BUILDING LAYOUT

1.2.1 The Building Program

The architect, project engineer, and laboratory consultant, with the assistance of the owner's administrators and laboratory users, develop the building program from analysis of data collected on (1) the number and types of personnel who will occupy the building; (2) the research, teaching, production, or industrial functions to be housed; and (3) the interrelationships of functions and personnel.

1.2.1.1 Program Goals. A building program of requirements is a written document that describes and quantifies the design goals for a building. The goal of a good program is to define a building that will have ample space for the number of occupants and functions it will house, that will function safely, and will realistically meet the owner's needs and budget. A program project team of programmers and design architects and engineers, users, administrators, facilities management, and health and safety professionals from within the organization prepare a building program. The program describes where and for whom the building will be constructed and what building functions and performance levels that

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owners and users require to meet their goals. Architects and engineers use building programs to learn for whom they are designing the facility, what spaces and facilities are required, where functions should be located in relation to each other, and the performance level that will meet the owners' needs. The programming process described in detail below is a consensus-based process. Consensus-based processes actively engage all stakeholders in developing the program of requirements for the program project team to gain as much balanced and comprehensive information as possible. There are other methods that engage only top administrators and scientists, and not stakeholders or health and safety professionals. Using this approach, the owner expedites the program process. It may also be warranted when the project is a start-up research or scientific product development organization, a new government agency, or a new academic department and it is too early for other stakeholders or health and safety professionals to be involved. Basically, the program project team accomplishes the same tasks, but when fewer individuals provide data and opinions, with no input from health and safety authorities and facilities management professionals to interpret data and inform the team of the organization's policies and standard operating procedures, the document may be more generic as a result of the depth of experience of the program project team in place. This is a risk the owner takes.

1.2.1.2 Types of Program Documents. There are three primary types of building programs, categorized based on the owner's project team objectives.

1. A conceptual program, used to test feasibility of a building or renovation project, can also be used for fund-raising and for convincing potential funding sources of the merit and utility of the project. A conceptual program quantifies net usable area or gross area for each department or generic space type. Generic space categories are laboratory, laboratory support, and specialized areas that include office and administration, personnel support, and building support.
2. An outline program lists the specific room types and the number and areas of each, and can be used as a tool for recruiting additional research scientists and for fund-raising.
3. A detailed functional program, the most common program document, is used to estimate construction cost and to build consensus within the proposed group of laboratory occupants and stakeholders. A detailed functional program describes architectural, mechanical, electrical, plumbing, information technology, and fire protection performance criteria for all building functions that must be accommodated. A detailed functional program identifies areas of special concern for safety, such as high-hazard areas that use flammable, toxic, and pathogenic materials or processes; the program also includes the waste removal implications of and facilities for these sensitive materials. The detailed functional program does not need to be written with any preconceived formal design philosophy in mind, except as may be required to incorporate health and safety guidelines. A detailed functional program is intended to enable owners and users to evaluate the building plan, and the engineering and architectural design that the consultant design team ultimately develops.

1.2.1.2.1 Completing the Program Documents. Table 1-1 lists the tasks required for completing the three types of programs. The remainder of this section details the steps and the preferred sequence necessary for the successful completion of the program documents.

STEP 1: EXISTING FACILITY OCCUPANCY ANALYSIS. Beginning the program process with the program team understanding of how the owner uses existing laboratory building(s) that will be replaced by the proposed new or renovated laboratory facility is very important to the outcome of the program document. Existing facility analyses gather and document observations and hard data on occupancy patterns from where the occupants currently work. Factors investigated may include population density, major equipment housed in laboratories, processes conducted in laboratories that impact the size of labs, linear feet (meters) of lab bench, chemical fume hood quantities and distribution, and management of hazardous materials and waste, for example. If future occupants come to the new or renovated laboratory from a number of different buildings or existing laboratories, a sampling of a few laboratories from each relevant department or organizational unit will suffice to enlighten the program team on the manner in which the users organize their space and the efficiencies the owner is able to achieve, or not. It is important to use the owners' facility or space assignment database(s) to analyze occupancy factors such as population density (net area per laboratory full-time equivalent [FTE] positions), average net area of assigned laboratories, proportion of net area for assigned labs to support and shared labs, proportion of net area for nonlaboratory use in the existing building(s), and net to gross area ratio of the existing building.

TABLE 1-1. Program Tasks and Sequence for Types of Program Documents

Step	Task	Conceptual	Outline	Detailed Functional
1	Perform an existing facility occupancy analysis or comparison to a similar facility	Yes	Yes	Yes
2	Perform any special studies or analyses required to help define the project scope	No	Optional	Yes
3	Conduct interviews and meetings with all stakeholders	Yes	Yes	Yes
4	Estabilish new or revised area standards	Yes	Yes	Yes
5	Develop a room type list	No[a]	Yes	Yes
6	Develop room performance specifications	No	No	Yes
7	Diagram typical lab module and all major room types	No	No	Yes
8	Estimate the quantities and net areas for each room type	Yes[a]	Yes	Yes
9	Calculate building net and gross area	Yes	Yes	Yes
10	Diagram spatial relationships of functions	No	Yes	Yes
11	Describe building basis of design for architectural, utlities, electrical, IT, mechanical, plumbing, and FP systems	No	Optional	Yes
12	Model or estimate cost of construction	Yes	Yes	Yes

[a]Conceptual programs have only generic room types: laboratory, lab support, administration, personnel support, and building support. There is no detail.

A second purpose for completing an existing-facility occupancy analysis is to objectively inform the owner and users of their current occupancy pattern, using numerical data and actual photographic documentation of the current status of the existing building, not just the programming team's subjective opinions. This process is like holding a clear, undistorted mirror for both owner representatives and users to look at themselves and how they currently use laboratory buildings. It informs them in new ways of what their goals and expectations could be for the new or renovated laboratory or building. It reduces the number and impact of preconceived notions and political ploys that inevitably arise within group interactions.

If the owner has no existing laboratory facility in which to perform the analysis, the program team with the owner's participation, should select another facility of similar use at a similar organization to analyze. The other facility should be occupied for a minimum of 2 years; otherwise, the analysis may be unrealistic and not helpful. This facility functions as a stand-in for the owner's "in process" laboratory building.

Step 2: special analyses and studies. Programming of some laboratory facilities requires additional expert knowledge to be brought to the owner and program project team. These special areas of analysis for some research and development laboratory buildings include threat and security, site selection, and environmental impact. Specifically for laboratory buildings undergoing renovation, an analysis of existing facility conditions is very important to complete prior to or during the period of the program process. The following paragraphs will offer perspective on applications of these special analyses and studies on programming laboratory buildings.

Threat and Security Analysis. Because most research, development, testing, and educational laboratories use chemicals and some laboratories also use hazardous pathogenic materials, security and safety of laboratory facilities and occupants are of concern to many laboratory owners, occupants, and users. The National Institute of Building Sciences (NIBS) recommends "Designing buildings for security and safety requires a proactive approach that anticipates [in the programming process] and then protects the building occupants, resources, structure, and continuity of operations from multiple hazards. The first step in the process is to understand the various threats and the risks they pose. . . . This effort identifies the resources or 'assets' to be protected, highlights the possible 'perils' [major natural disasters for example] or 'threats' [terrorism, vandalism, arson for example] and establishes a likely consequence of occurrence or 'risk'" (NIBS, 2010, p. 1).

Building owners who represent corporate, government, and academic organizations need to engage a qualified consultant, an expert in laboratory facilities, to provide "recommendations from a comprehensive threat assessment/ vulnerability assessment/ risk-based security analysis" (NIBS, 2010, p. 1). This limits the potential liabilities of the owner and provides practical design guidelines for the program project team to integrate into the scope of the laboratory building program of requirements. Laboratory buildings for

many government agencies require this analysis. The best time to provide for security guidance for a project is before or during the programming process.

Site Selection Analysis. Laboratory owners may not have identified land or a site for the proposed building(s) during the programming phase of the project. Owners may not know which existing building or portion of a building would be the best to renovate by the time a program process commences. This does not pose an insurmountable difficulty for the program project team to successfully complete a program. However, many site issues have a direct impact on estimates of the net-to-gross area ratio and on construction and project costs to owners—Step 12 in the program process. Some decisions owners normally make during the programming process may have to be deferred until the owner selects a site. Owners may elect to conduct a two-stage programming process starting with a conceptual program followed by either an outline or detailed functional program documents performed when the site is selected.

Several site selection issues critical to the health, safety, and environmental aspects of laboratory buildings include the following:

- Availability of and capacity of major utilities at the site
- Safety and security of the facility
- Vehicular and service access to and within the site
- Pedestrian circulation to and on the site
- Subsurface conditions that impact building structure and site drainage
- Surrounding buildings and/or landscape features that impact supply air quality to and dispersion of exhaust effluent from the laboratory building
- Contamination of the soil or water on the site by previous use of the site

Environmental Assessment. If a site is selected or a building identified for renovation, the jurisdiction having authority over that site may require the owner to provide an Environmental Impact Statement (EIS). An environmental assessment (EA) is the process required to produce an EIS. Federal and many state or local government agencies also require an EA to be performed and EIS submitted as part of the official project approval process.

An EA, as defined by the International Association for Impact Assessment (IAIA) is "the process of identifying, predicting, evaluating, and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made" (IAIA, 2012, p. 2). The project program phase is the preferred time to start Step 1, Preliminary Assessment for development of the EA because information is being gathered and initial assumptions are being made that will impact the environment of the site. The second step of the EA, Detailed Assessment, is developed during the project planning phase, and upon completion will be issued in the EIS.

Several components of environmental assessments that influence the development of the building program of requirements include the following adapted from the National Environmental Policy Act, 1978 (40 CFR Part 1500, NEPA Regulations, Section 1508.9):

- Description of the proposed building, construction activity, and an analysis of the need
- Analysis of the site selection procedure and alternate sites
- Baseline [site] conditions and major concerns
- Description of potential positive and negative environmental, social, economic and cultural impacts including cumulative, regional, temporal and spatial considerations
- Identification of human health issues

Facility Conditions Analysis (for Renovations and Additions to Existing Lab Buildings). An existing facility conditions analysis (FCA) should be conducted on laboratory buildings proposed for renovation, whether it is a few laboratories, a floor of the building, or the entire building. Projects where existing buildings will be expanded with laboratory additions also benefit from FCA. FCA offer owners objective, thorough technical knowledge of all major systems of a building with regard to changes in function since the building was constructed, compliance to current building codes, and replacement of equipment and materials based on specific life-cycle data and existing conditions. FCAs are part of successful facilities management practice in operating technically complex laboratory buildings. Especially in times of economic stress or where deferred maintenance is routinely practiced by an organization, an FCA provides the only comprehensive, objective information on building deficiencies. This analysis will guide the owner and design team in making decisions on the scope of the renovation and setting priorities in a rational, well-informed manner, rather than solely by political pressure. It is advisable that the owner makes the full document available for the program project team's review.

Step 3: interviews and stakeholder meetings. The program project team of consultants and in-house members of the organization conduct interviews with

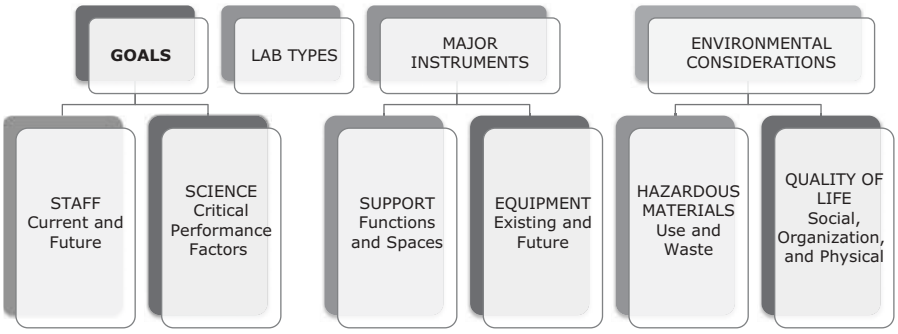


FIGURE 1-1. Sample principal investigator interview agenda.

department heads, principal investigators (PIs), administrative leaders, and laboratory managers for information on current population numbers and functions, and their projections for future capacities. (See Figure 1-1 for a sample agenda for meetings with PIs.) In addition, meetings are held with critical operations and support staff including key laboratory technicians (on PI research teams), facilities management representatives, environmental health and safety professionals, chemical hygiene officers, chemical and supply stockroom staff, materials' handling personnel, housekeeping staff, and any other individuals and operations managers who are involved in operating the proposed building, even if they will not be occupants. In educational institutions, student representatives may participate in meetings or surveys to share their perspectives on building requirements with the program project team. This inclusive approach brings out critical health, safety, environmental, and operations information, as well as hidden assumptions that might otherwise not be revealed to the program project team.

An effective method to manage large and diverse groups of stakeholders is to conduct discussions in well-structured "*Problem Seeking*" (Pena, 2001) workshops. The primary outcome of Problem Seeking is that stakeholders from top to bottom of the organizational hierarchy are placed, at least temporarily, on equal footing to express their observations and opinions about the existing conditions, and more importantly, about the proposed new or renovated facility. Stakeholders hear and see what others in the organization think and share. Comments are recorded graphically, but are unattributed to individuals. Comments then are posted physically and distributed electronically for all stakeholders to review and discuss further. Problem-Seeking workshops are most effective when conducted near the beginning of the programming phase.

When the persons who will be responsible for managing the laboratories, PIs, and occupants are not yet known, the program project team consults with the administrative leaders of the organization who are to hire these primary staff members. The leaders establish what functions will be carried out in the building and define the owner's goals. When no better information is available to the program project team, allocations of the major divisions of space can be estimated based on the occupancy patterns of well-functioning buildings of similar purpose. Information from such indirect sources may (1) be nonspecific to the actual project, and (2) produce less precise estimates of needs than information that otherwise would be obtained directly from future occupants, building operators, and administrators.

To estimate a laboratory building population for a conceptual program when specific numbers of FTEs are unobtainable, the programmer can construct a model to estimate population based on an understanding of the most commonly observed laboratory working groups as given in Table 1-2. These figures refer to FTE positions, not head count. FTE positions are often a lower number than head counts. FTE calculation aggregates part-time workers to the 40-hour, or other, workweek equivalent of a full-time worker. For example, two part-time technicians equal one FTE. According to the total amount of time four to six undergraduate students work with a research team, they may equal 1 FTE. This can become a major adjustment for actual laboratory and building population figures.

The example used here is based on a typical research laboratory at a medium-sized higher-education academic institution: Staffing for different laboratory types and for other sizes of research organizations will differ. In the research and development industry, there are wide variations based on the science discipline pursued and the type of organization: academic, corporate, or government. Using the team sizes given in Table 1-2, administrative and scientific leaders can estimate the optimal population of scientists in the facility that they feel will meet the operational research and development objectives for the organization. They may propose several variations to investigate the implications for the

TABLE 1-2. Conceptual Program: Research Team FTE Population Estimates

Team Members	Very Small Team FTE	Small Team FTE	Medium Team FTE	Large Team FTE	Very Large Team FTE
Principal Investigator	1.00	1.00	1.00	1.00	1.00
Research Assistant		1.00	1.00	2.00	2.00
Postdoctoral Student		1.00	2.00	2.00	4.00
Technician			1.00	2.00	4.00
Graduate Student	1.00	1.00	1.00	3.00	6.00
Undergrad Student[a]			0.50	1.00	2.00
Clerical Assistant	0.25	0.25	0.50	1.00	1.00
Total Team Population	2.25	4.25	7.00	12.00	20.00

[a]Undergraduate (UG) students are part time in laboratories. FTE = full-time equivalent. 4 UG = 1 FTE

net area required just to accommodate the scientists. Area allotments for extra-large groups of over 20 persons that are encountered in some laboratory settings can be roughly extrapolated from the values given in Tables 1-2 through 1-5.

It is our experience that even when a new facility is well planned and well constructed, demand on it can go far beyond conservative estimates that were established during the programming phase. Within a few years, occupancy of a successful new laboratory can reach 120–150% of the original population envisioned in the building program. Therefore, organizational leaders should carefully consider the total FTE population with input from the program project team.

Step 4: new or revised net area standards. The next step is to establish research net assignable area standards or to revise current standards, if they exist. The definition of *net area* as established by the Building Owners Management Association (BOMA) is "the total floor area within the walls of a space. Measure length and width from centerline-to centerline of walls (except the exterior walls)" (BOMA Z65.1, 1996). "Net assignable area does not include area used for public corridors, structural elements, exterior walls, mechanical equipment rooms, or duct and pipe shafts, toilets, and other building support facilities. Those elements are accounted for in building *gross area*" (BOMA Z65.3, 2009). Area standards are calculated from the existing laboratory population density by making an analysis of current and more desirable laboratory occupancy patterns, assessing the adequacy of existing conditions and net assignable areas, and then setting realistic but safe area goals for the new facility. Laboratory parameters useful to establish standards per FTE are bench length, shared equipment wall length, computational station length, length of chemical fume hood(s), hazardous waste storage area, and linear feet of sink.

For example, in Table 1-3, these parameters are applied to a typical biochemistry and an organic chemistry research laboratory, respectively. As illustrated in the table, data from existing conditions can be used for developing new standards. For some parameters, the recommended new standards are adjusted up or down from current existing laboratory averages in linear measure then converted to net area.

For conceptual programs, an alternative method based on commonly observed laboratory settings must be resorted to when there is no existing facility to analyze. The example of area standards calculated per FTE research occupant shown in Table 1-4 is derived from a database of areas for several functions typical for a range of general chemistry and biomedical research laboratories in higher-education academic facilities. Because research in academic institutions relies on availability of cheap student labor, area allotments or standards per FTE occupant for academic research laboratories are factors of 2 to 3 lower than for corporate, industry, and some government agency facilities. The estimated total net area divided by the total FTE research population establishes the area per FTE researcher figures shown in Table 1-5.

Definitions of the major functional categories listed in Tables 1-4 and 1-5 follow.

Laboratory is a category of net assignable area in which diverse mechanical services and special supply and exhaust ventilation devices are available. Laboratories are often modular, that is, designed on a standardized size or a precise multiple or simple fraction of that standard size. See Step 7 and Chapter 2, Section 2.2.1 for a discussion of the laboratory module.

Laboratory support area is a category of net assignable area that contains the same services and ventilation facilities as the laboratory area, but may or may not conform to the same modular laboratory size or configuration. Dedicated laboratory support areas are assigned to individual PIs, and may adjoin the modular laboratory

TABLE 1-3. Examples of Current and Recommended New Standards for Biochemistry and Organic Chemistry Laboratory Facilities[a]

Workstation	Biochemistry Research								Organic Chemistry Research							
	Existing Lab Averages				Recommended New Standards				Existing Lab Averages				Recommended New Standards			
Component Measure	lft	m	NASF	NASM	lft	m	NASF	NASM	lft	m	NASF	NASM	lft	m	NASF	NASM
Bench	5	1.52	27.5	2.55	7	2.13	38.5	1.76	8	2.44	44.0	1.21	6	1.83	33.0	3.07
Equipment Wall	2	0.61	11.0	1.02	4	1.22	22.0	1.00	2	0.61	11.0	0.48	4	1.22	22.0	2.04
Chemical Hood	1	0.30	5.5	0.51	2	0.61	11.0	0.50	5	1.52	27.5	0.24	8	2.44	44.0	4.09
Lab Sink	1	0.30	5.5	0.51	1	0.30	5.5	0.25	1	0.30	5.5	0.24	1	0.30	5.5	0.51
Waste Material Handling & Stg	0	0.00	0.0	0.00	1	0.30	5.5	0.25	0	0.00	0.0	0.00	2	0.61	11.0	1.02
Write-up Bench	3	0.91	16.5	1.53	4	1.22	22.0	1.00	3	0.91	16.5	0.72	4	1.22	22.0	2.04
Dedicated Support	4	1.22	20.0	1.86	7	2.13	40.0	3.72	4	1.22	20.0	1.86	4	1.22	20.0	1.86
Shared Support	6	1.83	30.0	2.79	7	2.13	40.0	3.72	4	1.83	20.0	2.79	8	2.44	40.0	3.72
Common Support	2	0.61	10.0	0.93	2	0.61	10.0	0.93	2	0.61	10.0	0.93	2	0.61	10.0	0.93
Assigned Desk[b]	0	0.00	0.0	0.00	5	1.52	30.0	2.79	0	0.00	0.0	0.00	6	1.83	30.0	2.79
BIOCHEM TOTALS	**24**	**7.31**	**126**	**11.70**	**40**	**12.19**	**224.5**	**15.92**	**29**	**9.45**	**155**	**8.47**	**45**	**13.71**	**237.5**	**22.07**

[a]All net areas include half module sf per linear foot, or 5.5 sf per 1 lft (1.67 sm per 1 m length), includes the width of the work zone and lab aisle in front.

[b]Office area for staff and students is recommended to be located outside and separate from laboratories.

units or may be elsewhere. Shared laboratory support is assigned to and used by more than one PI or department. Laboratory support services assigned to a specific department may function as specialized common resources by researchers throughout a building.

Administration area is a category of net assignable area that contains only standard commercial electrical, telecommunication, and office ventilation services. Ventilation air from these areas may be recirculated. If the new laboratory building is one of a number of similar buildings on a well-established campus or industrial complex, administrative and most clerical personnel may be located in an entirely separate building. When administrative personnel are located within a building that is principally devoted to laboratories, their room types must be listed and the areas estimated in the program tabulation.

Personnel support area is a category of net usable area that is similar in function to an administration area, but may contain added mechanical and HVAC services to provide for special functions, such as toilets, shower and locker rooms, cafeterias and kitchens, etc. Personnel support requirements can be estimated in the same way as administrative functions. However, building codes regulate capacities requirements for restrooms and other personnel support functions. When certain needed facilities exist nearby (e.g., a cafeteria), they may not need to be duplicated in the new or renovated laboratory building.

Building support area is a category of net usable area or gross area that may contain special mechanical and HVAC facilities to provide for special needs. Every laboratory building requires adequate areas for materials handling, maintenance, housekeeping, and special storage. These room categories also should be listed in the program tabulation. When a loading dock and temporary storage room(s) for daily deliveries and shipments are not conveniently close, alternative facilities must be provided for these activities in the building. Dedicated storage rooms for maintenance equipment and supplies are as important as storage space for scientific apparatus and materials. Table 1-4 shows a minimum estimated area of 10 net area square feet (NASF) (0.93 net area square meters [NASM]) per FTE researcher for building support. The program project team should consider carefully investigating and revising this estimate as the program process proceeds and as more detailed information emerges.

Animal facility area requirements may be the most difficult research function to estimate. The net area planned for animal facilities per FTE researcher may vary from 0 to 150 NASF (13.94 NASM) and greater. Very careful consideration must be given to the anticipated research animal demands to develop facilities of appropriate size within new or renovated laboratory buildings. See Chapter 22, Animal Research Laboratory, for more information.

Area standards are used to estimate the net assignable area of research and other building functions for each research team size, as shown in Table 1-5.

As shown in Table 1-6, different activities and scientific disciplines have different area requirements per

TABLE 1-4. Minimum Net Area Standards for Typical Academic Research Laboratories

Laboratory Area Category	Very Small Team		Small Team		Medium Team		Large Team		Very Large Team	
	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE
Total FTE Population	**2.25**		**4.25**		**7.00**		**12.00**		**20.00**	
PI Office	54	4.65	29	2.79	18	1.86	12	1.39	12	0.93
Clerical Office	20	1.86	20	1.86	10	0.93	5	0.46	5	0.46
Staff/ Student Offices[a]	30	2.79	30	2.79	30	2.79	30	2.79	30	2.79
Modular Laboratory	130	12.08	130	12.08	130	12.08	120	11.15	120	11.15
Dedicated Lab Support	40	3.72	40	3.72	40	3.72	30	2.79	20	2.79
Shared Lab Support	40	3.72	40	3.72	40	3.72	30	2.79	20	2.79
Common Lab Support	20	1.86	20	1.86	10	0.93	10	0.93	5	0.46
Animal Housing Facility[b]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Subtotal NASF per FTE	334	30.68	309	28.82	278	26.03	237	22.3	212	21.37
Administration Offices[c]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Personnel Support[d]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Building Support	10	0.93	10	0.93	10	0.93	10	0.93	10	0.93
Total Net Area/FTE Laboratory Occupant	**344**	**31.61**	**319**	**29.75**	**288**	**26.96**	**247**	**23.23**	**222**	**22.30**
	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE	NASF/ FTE	NASM/ FTE

[a]Office area for staff and students is recommended to be located outside and separate from laboratories.
[b]Estimates of animal housing must be calculated on factors other than count of laboratory full-time equivalents (FTEs). See Chapter 22, Animal Research Laboratory.
[c]Estimates of administrative offices and support depend on organizational factors not count of laboratory FTEs. Prepare a separate program accounting of administrative requirements.
[d]Estimates of personnel support depend on building code and factors other than count of laboratory FTEs. Prepare a separate program accounting of personnel support requirements.

TABLE 1-5. Estimated Net Areas for Typical Academic Research Laboratories

Laboratory Area Category	Very Small Team		Small Team		Medium Team		Large Team		Very Large Team	
	NASF	NASM	NASF	NASM	NASF	NASM	NASF	NASM	NASF	NASM
Total FTE Population	2.25		4.25		7.00		12.00		20.00	
PI Office[a]	122	10.46	123	11.86	126	13.02	144	16.68	240	18.60
Clerical Office (shared)	45	4.19	85	7.91	70	6.51	84	7.73	120	11.04
Staff/ Student Offices[b]	68	6.28	128	11.86	210	19.53	360	33.48	600	55.80
Modular Laboratory	293	27.18	553	51.34	910	84.56	1,440	133.80	2,400	223.00
Dedicated Lab Support	90	8.37	170	15.81	280	26.04	360	33.48	400	55.80
Shared Lab Support	90	8.37	170	15.81	280	26.04	360	33.48	400	55.80
Common Lab Support	45	4.19	85	7.91	70	6.51	120	11.16	100	9.20
Animal Housing Facility[c]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Subtotal NASF per FTE	752	69.03	1,313	122.49	1,946	182.21	2,868	269.81	4,260	429.24
Administration Offices[d]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Personnel Support[e]	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies
Building Support	23	2.09	43	3.95	70	6.51	120	11.16	200	18.60
Total Net Area	**774**	**71.12**	**1,356**	**126.44**	**2,016**	**188.72**	**2,988**	**280.97**	**4,460**	**447.84**
	NASF	NASM	NASF	NASM	NASF	NASM	NASF	NASM	NASF	NASM

[a]Office area for principal investigator (PI) of large and very large teams includes area for team meetings within or adjacent to PI office.
[b]Office area for staff and students is recommended to be located outside and separate from laboratories.
[c]Estimates of animal housing must be calculated on factors other than count of laboratory full-time equivalent positions (FTEs). See Chapter 22, Animal Research Laboratory.
[d]Estimates of administrative offices and support depend on organizational factors not count of laboratory FTEs. Prepare a separate program accounting of administrative requirements.
[e]Estimates of personnel support depend on building code and factors other than count of laboratory FTEs. Prepare a separate program accounting of personnel support requirements.

TABLE 1-6. Sample Research Net Area Standards per FTE Occupant for a Variety of Science Disciplines

Primary Activity	Office Use				Laboratory				Lab Support				Total Net Area/FTE[a]			
	SF	SF	SM	SM	SF	SF	SM	SM	SF	SF	SM	SM	SF	SF	SM	SM
	min	ave	min	ave	min	ave	min	ave	min	ave	min	ave	min	ave	min	ave
Analytical Chemistry	57	90	5.3	8.4	110	150	10.2	14.0	20	35	1.9	3.3	187	275	17.4	25.7
Biochemistry	57	90	5.3	8.4	130	175	12.0	16.3	60	80	5.6	7.4	247	345	22.9	32.1
Cell/ Tissue Culture	57	90	5.3	8.4	95	130	8.8	12.0	95	100	8.8	9.3	247	320	22.9	29.7
Molecular Biology	57	90	5.3	8.4	120	130	11.1	12.0	100	120	9.3	11	277	340	25.7	31.5
Organic Chemistry	57	90	5.3	8.4	150	190	14.0	17.7	40	50	3.7	4.6	247	330	23.0	30.7
Physical Chemistry	57	90	5.3	8.4	170	200	15.8	18.6	30	40	2.8	3.7	257	330	23.9	30.7
Physiology	57	90	5.3	8.4	150	170	14.0	15.8	20	40	1.9	3.7	227	300	21.2	27.9

[a]*Note*. Total areas omit allocations for animal facilities, lab shops, administration, personnel or building support. FTE = Full-time equivalent.

FTE. Two primary factors that distinguish net area standards among various experimental science activities and disciplines are the recommended area per researcher for (1) modular laboratory units and (2) laboratory support categories, which may be dedicated, shared, and common support facilities, as defined earlier. There are fewer functional differences in allocation of office space attributable to the scientific discipline than there are differences that are influenced by an organization's culture and adherence to hierarchy. In some organizations, the size and qualities of an office precisely indicate the individual researcher's status to the square foot!

Step 5: room type list. Outline and detailed functional building programs provide lists of all proposed room types with information that relates the nature of the research, equipment, and activities that will take place within each of them. These programs have more specific information than conceptual programs do. However, as in the conceptual program, there are five general area and function categories, not including structural and mechanical spaces: (1) laboratories, (2) laboratory support facilities, (3) administration, (4) personnel support facilities, and (5) building support, as described in Step 4. The National Center for Education Statistics publishes the *Integrated Postsecondary Education Data System* (NCES, 2012), a list of approved room-type names for colleges and universities. Identifying room types by IPEDS numbers as well as by name and program ID is often used in university space databases and is also helpful in making data sorts and for quality control in the compilation of program tabulations.

There are many special laboratory types: general chemistry, physics, controlled environment, animal, teaching, and more. A number of types are discussed in considerable detail in Part II of this book. Various office spaces that are directly involved in research activities, such as those assigned to PIs, research staff, students, and administrative personnel, as well as research team conference rooms are included in laboratory room type list. Other types of offices are included under administrative facilities. Laboratory room types that may be used for teaching must be clearly designated as such because many states have separate building codes governing the construction of teaching facilities.

Laboratory support facilities include the following types: equipment and storage rooms, special instrument rooms, data processing and computer server facilities, glassware washing rooms, sterilization facilities, preparation rooms for media and solutions, sample processing and distribution rooms, machine shops, electronics shops, darkrooms, and a wide variety of imaging suites that may contain microscopes and their associated spectroscopy and computer equipment. Lists of support facility types are extensive.

Administration facilities that do not directly support research program activities include private offices, group offices, and clerical pools. Business offices, personnel record offices, and data processing offices are assigned to administration of the building or to general administration of the organization. Other administrative facilities include libraries; conference rooms; seminar rooms; auditoria; and supply, copy, and mail rooms.

Personnel support facilities include reception areas and lobbies, toilets, changing rooms, locker and shower rooms, health and first-aid offices, lounges, meeting rooms, vending or dining facilities, kitchens, and recreation areas that are indoors. Outdoor recreation areas are not counted in the net assignable area of a building, but need to be documented in the proposed scope for site development.

Building support facilities include shipping and receiving areas, chemical or flammable liquid storerooms, and storerooms for radioactive, chemical, and biological hazardous wastes, maintenance, equipment, housekeeping, shops, supply and stockrooms. Some

types of building support rooms are discussed in Part III of this book.

The amount of laboratory area available in a building can be increased at a later time by converting facilities for nonlaboratory functions, such as offices, stockrooms, and personnel support areas. However, to do this safely, efficiently, and cost effectively, advance planning is required to provide reserve capacity in heating, ventilating, and air-conditioning, electrical services, and piped utilities to significantly increase the delivery of building services to new labs. Demand and capacity standards for ventilation, cooling, electricity, water, waste drainage, gas, and so on are far greater for laboratories than for nonlaboratory functions (see Section 1.3). Normal commercial and residential engineering diversity factors for electrical and cooling capacity do not apply to laboratory use. Laboratory equipment may operate constantly (24/7); electrical loads are typically high. This, in turn, puts a greater and more sustained demand on building cooling equipment. Therefore, building program room lists should (1) identify all nonlaboratory rooms and spaces that are likely to be converted to laboratories when the need arises in the future and provide these spaces with reserve capacity, or (2) specify the proportion of nonlaboratory area that should be engineered for future conversion to laboratories.

STEP 6: LABORATORY PERFORMANCE CRITERIA DATA. Detailed functional programs provide comprehensive information on performance criteria for each individual laboratory and generic laboratory (or room) types, based upon what future occupants know or assume at the time of program interviews. This data can be updated at any time during programming and design phases, as more information emerges in later discussions with users. This form provides essential scope and quantity information for the entire project design team, but particularly for building design engineers. Laboratory performance criteria data sheets are a primary communications tool between laboratory design architects and engineers. In addition, owners and users refer to these data sheets throughout design and construction phases, to make sure all their requirements are addressed in the design documents and for quality assurance during construction.

Nonlaboratory room data sheets may be simplified, if desired, because generally there are far fewer technical requirements in office, classroom, and personnel support room types. The data categories often found in laboratory performance criteria data sheets are

- Laboratory (or room) type, special classification, and assignment information
- Occupancy data, such as number of occupants and estimated hours of occupancy
- Lists of requirements for mechanical and piped utility systems and fixture types
- Lists of piped utility requirements and estimates of outlets for each
- Lists of fire protection systems and safety equipment
- Lists of requirements for electrical, stand-by, and emergency power, with estimates of outlets for each service
- Lists of requirements for information technology, telecommunications, and audio visual equipment and systems
- List of probable major equipment
- Categories of chemicals that may be stored, with estimated volumes, if available
- Storage requirements for chemicals and compressed gas cylinders
- Safety equipment requirements
- Number and type of chemical hoods, biological safety cabinets (BSCs), other hoods; any other special exhaust requirements
- Number of workstations and types of benches
- Architectural, material, and finish requirements

Figure 1-2 shows a form that may be used to gather the laboratory performance criteria necessary to facilitate detailed functional program documents. In the detailed functional program document, diagrammatic plans (Step 7) may be attached to data sheets for each laboratory or room.

Chemical Inventory Data. The laboratory performance criteria shows a simple snapshot of several classes of hazardous chemicals and proposed volumes to be used and stored in each laboratory.

This information can raise "red flags" to the laboratory planner and design team on chemical use that may have a significant impact on the design of certain laboratories, e.g., safety ventilation and fire protection systems, as well as fire-resistive construction. However, the chemical inventory data as provided in the presented form is unfortunately insufficient data for the laboratory planners and design team to design the laboratory building. Full and up-to-date chemical inventories are needed from all occupants. Many organizations collect and keep this information current. If an inventory is available, the Chemical Hygiene Officer (CHO) or Environmental Health and Safety Office needs to provide the design team with lists of total volumes by chemical classification: explosives, flammable liquids,

Program ID No. **Classification**

BSL 1,2
Department BSL 3, 4
ABSL 2
Assignment ABSL 3
cGLP
Space Name cGMP
Clean Room Class

LABORATORY PERFORMANCE CRITERIA DATA SHEET

Client Name

Project Name

Recorded by Date Final

OCCUPANCY
Hrs. Occupancy No. Rooms
No. Occupants Room Area
No. Animals Species

FUNCTIONAL RELATIONSHIPS
Primary Room Activity
Secondary Activity
Room Adjacencies
Floor Adjacencies

ARCHITECTURAL
Floor Material Seamless
Base Material Height
Wall Material Finish
Ceiling Material Height
Door Material Type
Door Width Height Rating
Door Hardware
Acoustic Criteria
Window Treatment
Vibration Control Floor Load
Hoist Load Rating

CASEWORK

Standing Bench	LF	Type	Depth
Seated Bench	LF	Type	Depth
Wall Cupboard	LF	Type	Depth
Tall Cupboard	LF	Type	Depth
Mobile Bench	LF	Type	Depth
Lab Table	LF	Type	Depth
Adjustable Shelving	LF	Type	Depth
Reagent Shelving	LF	Type	Depth
Countertop Material			
Other			

LIGHTING

Fixture	Qty	Type	
Fixture	Qty	Type	
Fixture	Qty	Type	
Controls			
Timer		Type	

MECHANICAL

			Summer	Winter
Temperature	Set	Range		
Relative Humidity	Set	Range		
Filtered Supply	YES	Type		
Chemical Fume Hood	Qty	Type		Size
Biological Safety Cabinet	Qty	Type		Size
Point Exhaust	Qty	Type		Size
Snorkel Exhaust	Qty	Type		Size
Canopy Exhaust Hood	Qty	Type		Size
Other Local Exhaust	Qty	Type		Size
Filtered Exhaust	Qty	Type		
Other Consideration				

SAFETY EQUIPMENT

Flam Liq Stg Cab	Qty	Type	Size
Corrosive Stg Cab	Qty	Type	Size
Fire Extinguisher	Qty	Type	Size
SCBA	Qty	Type	
Emergency Eyewash	Qty	Type	
Safety Shower	Qty	Type	
Gas Cylinder Rack	Qty	Type	
Other	Qty	Type	

PLUMBING	Wall	Bench	Hood		Wall	Bench	Hood
Lab Sink Qty				Local Polisher Qty			
Cup Sink Qty				Process CW Qty			
Hand Wash Sink Qty				Comp Air Qty			
Open Drain Qty				Vacuum Qty			
Cold Water Qty				Nitrogen Qty			
Hot Water Qty				Steam Qty			
Purified Water Qty				Natural Gas Qty			
Floor Drain Qty		Size		Other Qty			

ELECTRIC POWER	Amps	Volts	Phase	Qty or Spacing	UPS	Emerg	Islolated Circuit
Bench Qty							
Bench Qty							
Wall Qty							
Wall Qty							
Wall Qty							
Chemical Hood Qty							
Biosafety Cab Qty							

TELECOMMUNICATIONS
Phone Qty Wireless
Internal Network Port Qty Type
Outside Network Port Qty Type

AUDIOVISUAL & SECURITY SYSTEMS
VCR & Screen Qty Type
Microphone Qty Type
PA or Loudspeaker Qty Type
Lab Entry Security Qty Type
CCTV Qty Type
Other Qty Type

CHEMICAL HAZARDS	Liquid	Solid	GAS CYLINDERS	Liquid	Gas
Combustible Qty			Combustible Qty		
Corrosive Qty			Corrosive Qty		
Oxidizer Qty			Oxidizer Qty		
Cryogenic Qty			Cryogenic Qty		
Flammable Qty			Flammable Qty		
Toxic Qty			Toxic Qty		
Highly Toxic Qty			Highly Toxic Qty		
Radioactive Qty			Pyrophoric Qty		
Select Agent Qty			Other Qty		

PHYSICAL HAZARDS
Laser Qty Type
X-Ray Source Qty Type
Accelerators Qty Type
Other Radiation Qty Type

MAJOR EQUIPMENT - Manufacturer and Model Number

1		Qty
2		Qty
3		Qty
4		Qty
5		Qty
6		Qty
7		Qty
8		Qty
9		Qty
10		Qty
11		Qty
12		Qty
13		Qty
14		Qty
15		Qty

FIGURE 1-2. Laboratory performance criteria data form.

flammable gas, combustible liquids, cryogenic oxidizers, oxidizers, water reactives, unstable reactives, organic peroxides, detonatable organic peroxides, irritants, corrosives, toxic and highly toxic chemicals. The International Building Code (IBC), and the former Uniform Building Code (UBC), and Building Code Officials' Association (BOCA) tables of maximum allowable quantities of hazardous chemicals are all based on these standard chemical classifications. A typical inventory list of 10,000 and more separate chemicals is only helpful to the design team for its standard chemical classifications. See Section 1.2.4.2 for how this data is used in the laboratory planning process.

Equipment Inventory Data. In the case of a program for a building that will be occupied by personnel relocated from another laboratory building, consider developing a comprehensive equipment inventory to supplement partial information provided on the laboratory performance specification data sheets. This type of inventory includes not only the list of existing and proposed equipment with model and manufacturer data, but photographs of existing units and cut sheets of new units, as well as equipment installation specifications that can be obtained from manufacturer's installation manuals. Providing thorough information on scientific equipment in the programming phase, aids mechanical, electrical, and plumbing (MEP) engineers to list and describe the required utilities and systems in the Basis of Design (BOD) program Step 11. During the design phase, equipment inventory data is required for engineers to provide the most accurate cooling load calculations, diversity factor estimates, and utility provisions for equipment in each laboratory.

The equipment inventory and survey are additional services and are usually contracted separately from the program document. Performing equipment inventory during the programming phase is highly recommended.

STEP 7: ROOM-TYPE DIAGRAMS AND NET AREA ESTIMATES. At this point in the programming process, the program project team has gathered considerable information on laboratory users' needs and requirements for each proposed laboratory. For outline and detailed functional programs, room lists have been generated. To estimate the net areas of each room type the programmer needs to apply two methods: (1) Generate options on laboratory module dimensions, configurations, and net area; and (2) test area estimates by generating simple line diagrams of all laboratory room types using the module template. Figures 1-3 and 1-4 are examples of single and double modules. Laboratory sizes are determined by multiples of or simple fractions of single modules. Multiple modules are generally arranged in linear arrays.

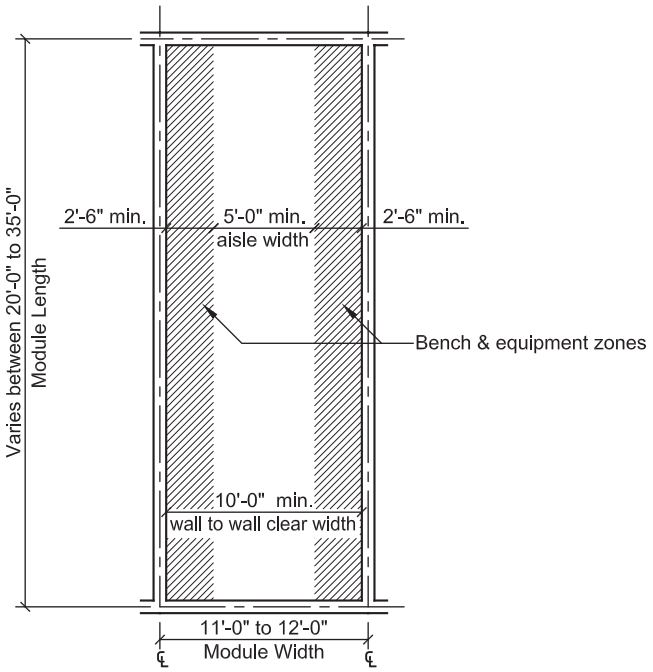


FIGURE 1-3. Plan of single module lab.

See Section 1.2.4 for a detailed description of laboratory module planning considerations. Diagrams of nonlaboratory rooms, such as offices, meeting rooms, etc., provide good tests of area estimates. Below are some basic concepts to be followed.

1. Modules for laboratory space have three dimensions, but for area estimating purposes, only the floor dimensions are needed. Acceptable single module widths for typical "wet" (those having water and using chemicals) laboratories for many scientific and engineering disciplines, vary from a minimum 10 ft 6 in. (3.2 m) to a generous 11 ft 6 in. (3.5 m). Modules are aligned in a row or other basically linear arrays. Module depths may vary from building to building, but within a laboratory building usually one depth is standard. Commonly, module depths vary from a minimum of 20 ft up to 35 ft (6.1–10.67 m). This combination of dimensions offers a range of module areas from a minimum of 220–402 NASF (20.4–37.3 NASM). Determination of the module dimensions has a direct impact on the building structural grid layout. During the design phase, slight adjustments in the module proportions may occur to accommodate structural requirements.

   Net area standards set in Step 4 can be used to test the most suitable module dimensions and area. The number of linear feet of bench and wall for locating freestanding equipment is one key

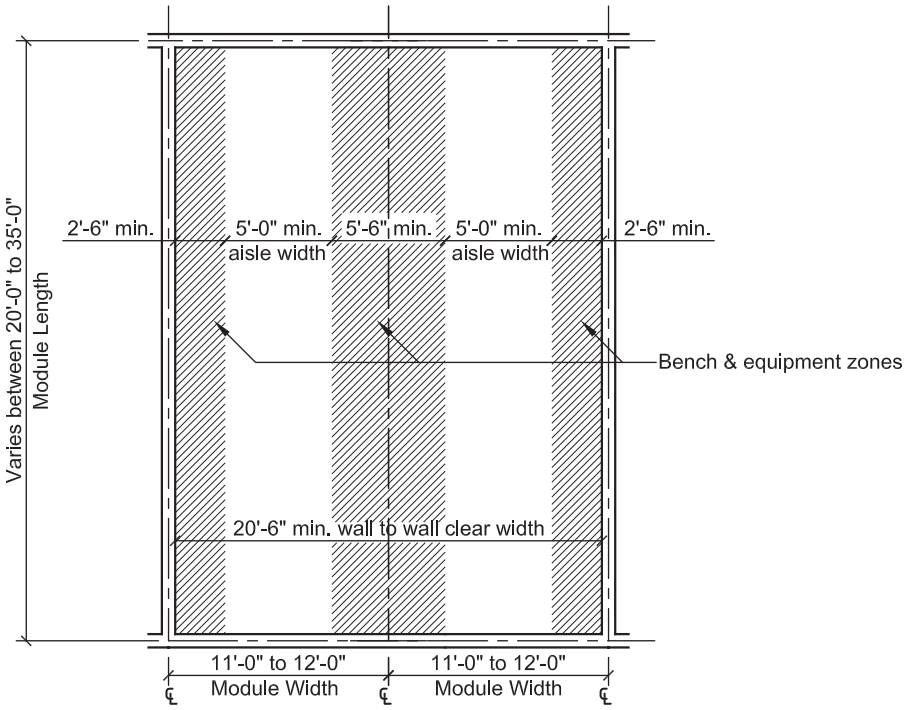


FIGURE 1-4. Plan of two module lab.

factor. For example, if area standards call for 15 linear feet (lft) (4.57 m) of bench, 5 lft (1.52 m) for equipment, and 4 lft (1.21 m) for a computer station at each bench, the programmer may select a module length of 32 lft (9.75 m) total. Thirty-two linear feet allows for the required bench, equipment, and computer station, but also a 5 lft (1.52 m) laboratory aisle and 3 lft (0.91 m) for another function in the area standards. The programmer may select 11 lft for the module width (see Section 1.2.4). These dimensions make a module of 352 NASF (32.7 NASM).

2. With a "draft" module, the programmer will diagram all the laboratory types to test area estimates and to test the size of the module. This is an iterative process to find a single module that provides the best fit for functions listed in the draft program. In another example, the program may call for a cell culture laboratory for one-person occupancy and one BSC with area for stacking incubators, one bench with a lab sink, a microscope table, and one refrigerator. The programmer will diagram these bench and equipment components on the module template. The area required for these functions requires less than a full module, but close to half a module. The programmer will graphically determine what simple fraction of module area is required to design a safe cell culture laboratory. This area will appear in the program area tabulation. Diagrams are a good test of optimal and efficient area, if all the equipment, functional, and safety information is available.

STEP 8: QUANTITIES OF ROOM TYPES. Three primary factors determine the quantities of room types: driven by headcount, influenced by building geometry, and balanced between shared and proprietary facilities.

The first factor is the count of functions stated by users and recorded in the project notes. For example, if there are 15 PIs in experimental sciences in a department, it is logical and very likely there will be 15 laboratories—minimum and of various sizes—and 15 PI offices. Functions and room types that are based on head count are relatively straightforward to estimate.

The second factor is based on the geometry of the proposed building or renovation, the number of levels, number of wings or other building layout conditions that influence access to shared and common functions. For example, if the proposed building has three occupied floors and PIs require a controlled environment room on the same floor as their laboratories, then it is reasonable that the program will provide at least one controlled environment room per floor, with a total of three or more in the building. Another example is if each laboratory floor is divided by a large atrium surrounded by PI offices, the program may provide two

controlled environment labs per floor. There is a safety consideration behind this decision. With one in each wing, scientists and staff, carrying potentially hazardous materials, do not have to cross the atrium and office suite to access a controlled environment room. These issues are relatively clear to determine once the building layout is designed. In the program phase, that information may not be known. The programmer may have to make a judgment call without it or make a note to allow a change in the number of those rooms later, during the design phase. However, the third factor is more complex to consider and requires sometimes difficult and potentially contentious discussions among the scientific personnel and laboratory managers.

Questions concerning the use of centralized versus proprietary facilities assigned to individual investigators or research teams is the third factor that must be answered before it is possible to complete quantification of each type of support room and laboratories that will appear on the room-type list. Outline and detailed functional building program processes address the major issue of which facilities will be repeated on each laboratory floor: those shared by occupants of a department, those common to all occupants of the building, and those provided outside the building.

For example, controlled environment rooms may be provided on each floor of a multilevel laboratory building, but only one radiation laboratory may be provided for all members of a department that requires it. A shipping and receiving dock is an example of a single facility for use by an entire building. An example of a support facility that may be located exterior to a laboratory building in a separate structure is a flammable chemical storage facility. Although it is often more economical to build centralized laboratory support facilities rather than to duplicate them for each department or laboratory group, costs for operating and administering centralized services must be taken into account in owners' operations budgets.

In the programming phase, the program project team resolves all issues of centralized and shared versus proprietary facilities with PIs, users, laboratory managers, and the owner's representatives. After that, the number of each type of room can be estimated. This task should not be deferred until the design phase because changes can have a serious impact on building area after the building construction budget is set. However, some minor adjustments to the specific number and distribution of some support rooms may be made during the design phase without serious consequences.

Step 9: Building net and gross area calculation. Net assignable area is the unit of measure discussed in Steps 1–8. This area is easy to explain and visualize; programmers often bring bright-colored masking tape to user group meetings and simply put the tape on the floor to demonstrate the measure in full scale. Users can look at it and walk around the perimeter to gain another, kinesthetic understanding of the area numbers. The other measures of area used by architects, engineers, and particularly the construction industry, are more difficult to illustrate directly.

Planners and architects use a number of terms to characterize area data, as shown above in Step 4, for "net assignable area." Terms adopted by the Building Owners and Managers Association (BOMA Z65.1, 1996) are frequently referenced. Here are definitions of a few useful terms.

Net assignable area is the floor area, excluding interior partitions, columns, and building projections, that lies within the walls of a room. It refers to the program total area for rooms and spaces on the room-type list assigned to or available for assignment to a specific occupant, group, or function. Net assignable area may also refer to the total assigned floor area within all rooms and spaces on the room-type list under all categories except for personnel and building support.

Net usable area is floor area that is assigned or available for assignment to a specific occupant, department, or function, and includes area occupied by interior walls, columns, and building projections, but it excludes public circulation areas such as exit corridors, stairs, elevators, and vertical utility shafts. Net usable area may also define the total floor area within the building's exterior wall enclosure that includes floor area taken up by the structure and partitions, but excludes public circulation areas and vertical shafts.

Departmental gross area is the floor area within the exterior wall enclosure assigned to a specific group or department. It includes secondary, private circulation hallways within the department's boundaries, interior walls, columns, and building projections. Departmental gross area is usually synonymous with rentable area.

Gross area is the total building area (BOMA Z65.3, 2009). This is the only measure that the construction industry uses for building cost estimating and benchmarking. Gross area includes the area occupied by the structure, exterior walls, partitions, and vertical shafts plus all usable public areas and vertical circulation such as atriums, stairs, and elevators. Interstitial space is the volume above the ceiling to the underside of the floor above, constructed between any two occupied floors of a building that is dedicated to mechanical, electrical, and plumbing distribution systems. Interstitial space is not included in building gross area. However, areas of interstitial floors are calculated at 50% for building code purposes. Interstitial floors are structures to hold persons and MEP equipment and utility distribution systems.

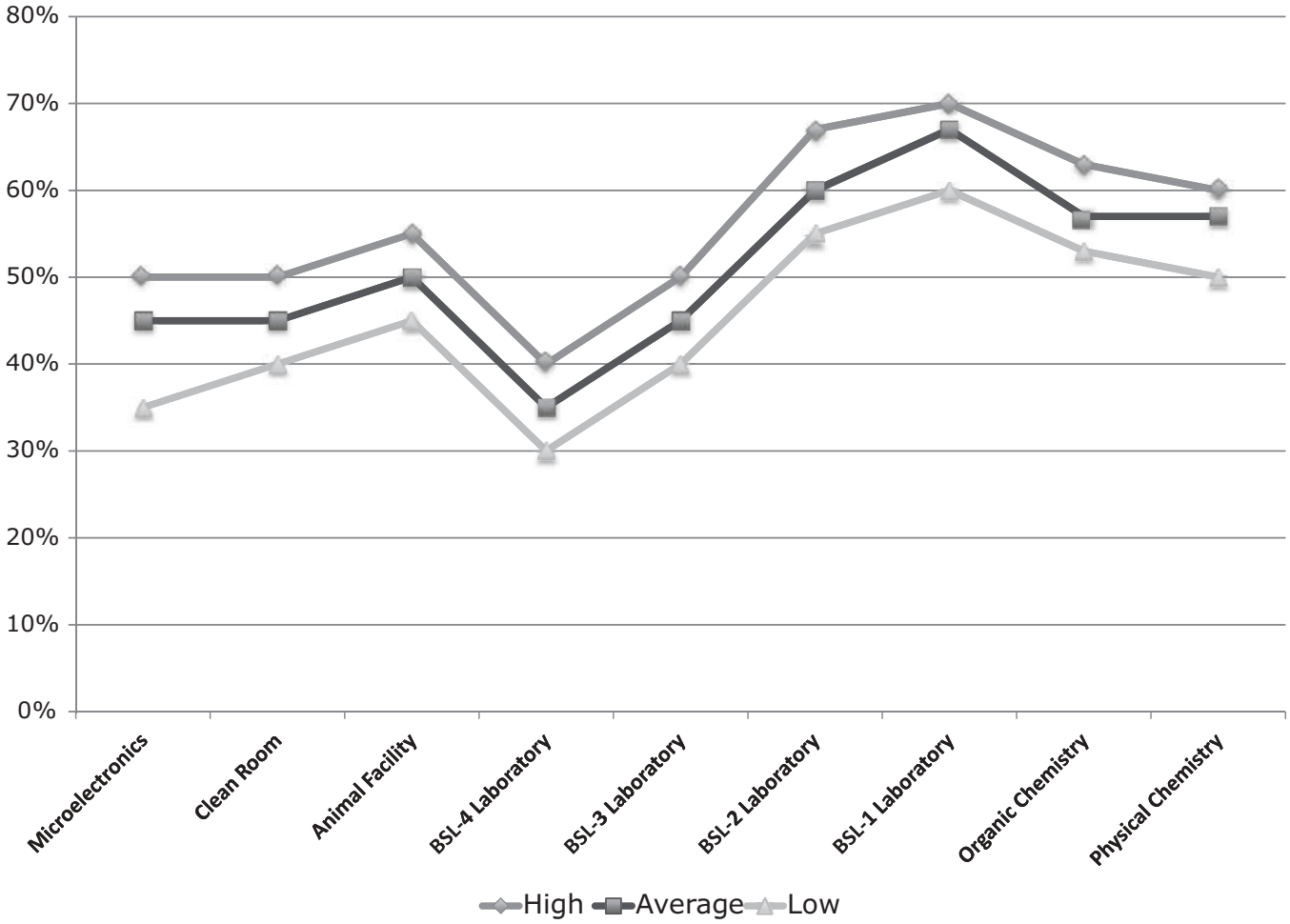


FIGURE 1-5. Range of net-to-gross ratios by laboratory type.

Total area calculations are determined as follows. Laboratory building configurations show variations of 60–85% net assignable laboratory area on a typical floor. Total net area must be converted to gross area to estimate the amount of actual building area that will be constructed to accommodate all the programmed functions on all floor levels. The conversion factor used to make this calculation is called the net-to-gross ratio. Net-to-gross ratios vary from 45% for animal facilities and intensive chemistry laboratory buildings with a high proportion of laboratory area—up to 70%—for efficient research laboratory buildings. Laboratories constructed in temperate and cold climates that have mechanical penthouses and often basements to accommodate all MEP/FP/IT equipment in a layout that allows ease of maintenance for complex systems. This area counts in gross area calculations. Microelectronics, biosafety laboratories at Levels 3 and 4, and other highly specialized and mechanically intensive buildings commonly have 30–45% net-to-gross ratios. These are efficient buildings too, but the nature of their functions requires a higher percentage of total area for special mechanical, HVAC, plumbing, and electrical systems (see Figure 1-5).

Buildings containing a low proportion of laboratories to nonlaboratory areas may achieve higher net-to-gross ratios. Some laboratory buildings do not have mechanical penthouses or expansive mechanical equipment rooms. When utilities such as steam, hot water, and process chilled-water are supplied from an external source, such as a central utility plant, these buildings experience higher net-to-gross ratios than laboratory buildings that are mechanically freestanding. Net-to-gross factors should be very carefully considered and conservatively estimated during the programming phase because they have a great impact on construction estimating and the design process following program completion.

STEP 10: SPATIAL RELATIONSHIPS OF FUNCTIONS. The next task in developing outline and detailed functional programs is to inform the design architects and engineers of the important relationships between the parts of the building that are identified in the room list. Conceptual and **o**utline building programs do not need to specify what is on every floor; that information is developed and organized later during the planning process. However, after the building site has been selected, conceptual floor plans may be shown in detailed functional programs. There are five sets of questions that have proven helpful to programmers and user groups for establishing important relationships between spaces and functions:

1. What is the organizational structure of the institution, corporation, or agency for which the building is being designed? Should room assignments and groupings reflect a hierarchy, or is some other pattern or principle preferred?
2. Do materials, processes, or waste products contained or produced in one area affect the function of, or pose a hazard for, any other area or function? If the answer is affirmative, what arrangements can be made to reduce or eliminate conflicts? Are appropriate rooms assigned to specialized waste handling and storage? Where should they be located with regard to the areas of waste generation, pathways used for waste removal, and supply air intakes? What are spatial considerations for stockrooms?
3. How close should laboratory support facilities be to the laboratories they serve? Are there critical relationships that affect health, safety, the environment, or efficiency?
4. Do certain laboratories, or the mechanical services to them, need to be isolated from other building functions or services for reasons of health and safety, or as a necessary part of their procedures and equipment operation?
5. How close should researchers' offices be to laboratories? Should offices be within laboratories, contiguous with laboratories, across the hall, in a separate wing or zone of the building? What are the health, safety, and efficiency implications of each location?

The last question generally brings up one of the more contentious issues in laboratory building planning. Some researchers insist that their offices be located in or immediately adjacent to their laboratories, whereas other researchers prefer to have their offices outside the laboratory zone. The caution is that offices in laboratory zones may be readily used by enterprising researchers for certain laboratory functions whether or not these offices are designed and equipped to safely support any laboratory function. Especially in academic settings, there is pressure on researchers to acquire new equipment or projects, even when appropriate laboratory space and funding for renovations are not available. Proximity of offices to laboratories usually dominates other criteria, such as adequate power, piped utilities, and appropriate ventilation. In the worst cases, offices adapted by researchers have additional power supplied by electric extension cords and piped utilities for gas and water by rubber tubing, strung across corridor ceilings from nearby laboratories. Offices have their doors propped open to improve ventilation by exhausting fumes into corridors and capturing more cool air for equipment that would otherwise overheat. Extremely serious health and safety hazards are generated by these kinds of unofficial and unsupervised construction adaptations made by researchers.

When offices are located in laboratory zones, whether across the hall from, adjacent to, or within laboratories, ventilation requirements for these offices should meet laboratory standards, in which general exhaust and 100% outside supply air are provided. In addition, electric panels should be sized to accommodate future increased power demands when offices are converted to laboratory use. There are higher initial construction costs to provide piped utilities and laboratory waste drains to offices, but if future flexibility and safety are priorities, it is a reasonable investment. These criteria should be included in the building program list of performance requirements.

Answers to these five questions provide additional information to assist the program project team to prepare a description of critical adjacencies that may be documented in text, charts, and diagrammatic floor plans. Figure 1-6 illustrates a matrix format, similar to that of a road mileage map, and Figure 1-7 shows a bubble diagram format that conveys adjacency information in a graphic fashion, representing, for this example, a clinical laboratory (discussed in Chapter 15).

STEP 11: BASIS OF DESIGN. Basis of Design (BOD) in a laboratory facility program document is a "set of conditions, needs, and requirements taken into account in design of a facility" (*Business Dictionary*, www.businessdictionary.com). The BOD lists and describes the major components and systems of a building or renovation project. One major purpose of a BOD is to offer the owner a concise, but comprehensive narrative description of the proposed project. A second purpose is to provide the cost estimator with a summary of major scope components and systems for the building

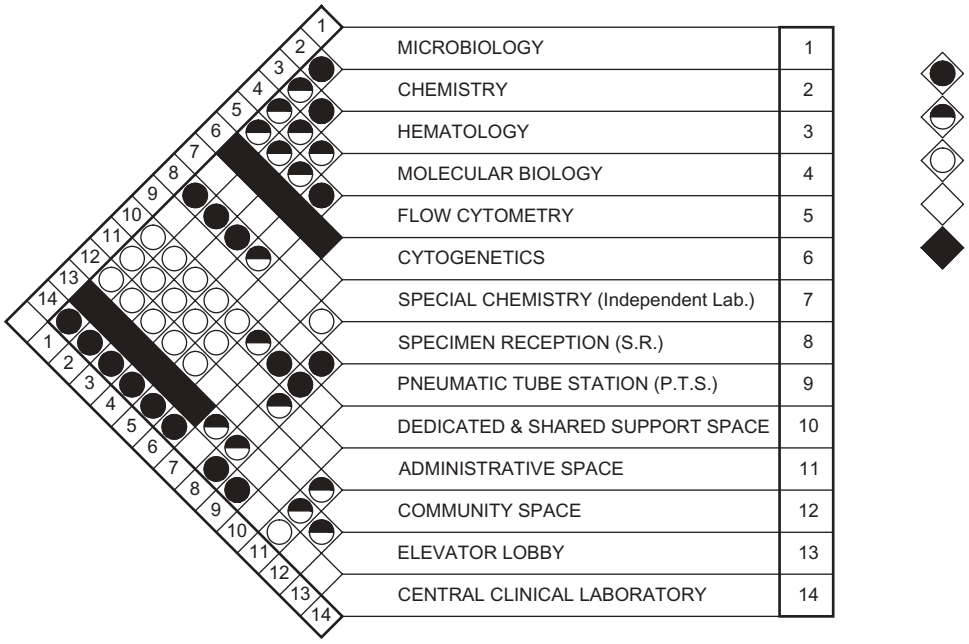


FIGURE 1-6. Adjacency matrix diagram.

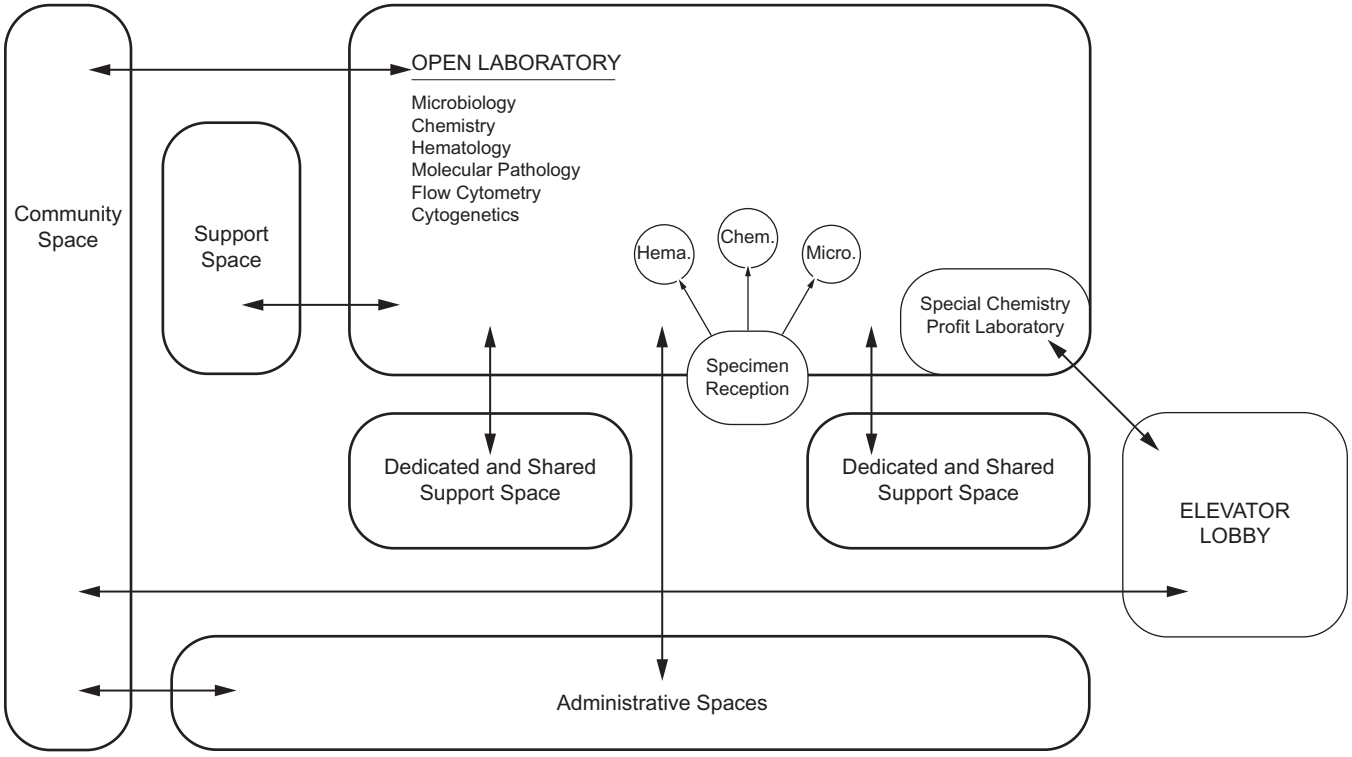


FIGURE 1-7. Adjacency bubble diagram.

TABLE 1-7. Some Components Included in the Design of Laboratory Buildings

Architectural	HVAC	Electrical
Exterior Enclosure	Heating System	Primary/ Secondary Feeds
Roofing System	Cooling System	Distribution Systems
Windows/ Glazing	Laboratory Ventilation	Emergency Power Equip
Interior Partitions	Control Systems	Standby Power Equipment
Interior Finishes	Filters	Control Systems
Special Features	Lab Chemical Hoods	Transformers
Safety Equip & Features	Energy Conservation	UPS & Line Conditioning
Structural	**Plumbing**	**Security & Alarms**
Foundation System	Hot Water System	Work Space Systems
Floor Framing System	Chilled Water System	Public Space Systems
Roof Framing System	Purified Water Sysem	Entry Control System
Seismic Force Strategy	Lab Piped Utilities	Control & Alarm Station
Stairs	Drainage Systems	Special Systems
Special Conditions	pH Neutralization	Audiovisual Equipment
Lighting	**Fire Protection**	**Safety Equipment**
Work Space Fixtures	Sprinkler System	Emergency Eye Wash
Public Space Fixtures	Fire Alarm System	Emergency Safety Shower
Control Systems	Fire Pump/ Standpipe	Chemical Storage Cabinets
Lamp Selections	Special Conditions	Fire Extinguishers

to facilitate generating the estimate. Table 1-7 is a sample list of some components included in a BOD for laboratory buildings.

Step 12: Cost model or estimate of construction and project costs. The final task that may be considered for all program types is estimating the probable cost of construction, perhaps the most critical information the owner needs in a program document. Should an owner or administrative leaders set a construction budget without regard for the documented requirements and for the size and complexity of the project, success of the building's occupants, functions, safety, and its appropriateness will be put at risk. Unless the program project team—professional architects and engineers or an in-house team—has available to them extensive, up-to-date cost data on laboratory buildings, we recommend that well-qualified professional cost estimators should be hired to do this task. Professional cost estimators, with current, in-depth experience in laboratory building construction, can review the program description, whether conceptual, in an outline, or a BOD, in a detailed functional program, and develop a construction cost estimate. The estimator should be asked to provide design assumptions and the percent range of accuracy. A range of ±20 to 25% accuracy is not unusual during the programming phase because of construction market volatility and general economic factors. Figure 1-8 is a graph that shows relative construction costs for typical laboratory types. Software development laboratory construction cost is the base value of 1.0. Obviously, accuracy improves as the design phase proceeds, with development of plans, building engineering, and specifications. The owner's cost of the building includes many more categories of cost above construction cost, shown in Table 1-8. Construction cost alone comprises 50–75% of project costs in new construction and 30–80% of renovation projects.

1.2.1.3 Conclusion. For the design team, building programs contain comprehensive list of functions, performance specifications, and state the owners' goals. For building owners, building programs are documents against which building designs can be evaluated for adherence to the stated goals, functions, and specifications. To further assist the architects and engineers, the laboratory standard operating procedures and safety manuals used by the building occupants should accompany the building program to alert the design team to particular health and safety concerns of the owners and users. When such documents have not yet been prepared, borrowed manuals for similarly engaged facilities or appropriate sections of the present manual may be used for preliminary and basic guidance.

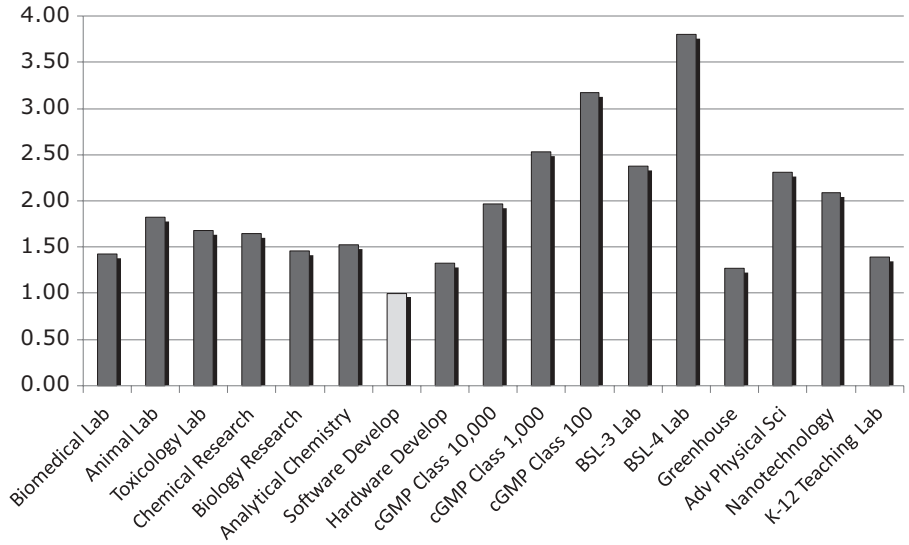


FIGURE 1-8. Cost index by laboratory facility type.

TABLE 1-8. Examples of Owner's Project Cost Components

Construction Cost	Legal Fees
Contingencies: Owner's, Design Changes, etc.	Owner's Management Services
Surveys: Site, EIS, Subsurface, Hydrology, etc.	Predesign Services Fees: Programming, Feasibility Study, Site Selection, etc.
Land Acquisition	Design Services Fees:
Permits: Utility Connection, Construction, Occupancy, etc.	Construction Management Fees
Site Development: Roads, Drainage, Utilities, Cut & Fill, Grading, etc.	Communications: IT Systems, Computer & Server Equipment, Wireless Network
Relocation & Reconnection of Utilities	Reimbursable Expenses
Landscaping (beyond 5 ft of building perimeter)	Interim Financing and Fees
Special Foundations & Subsurface Work	Cost Escalation
Hazardous Materials Remediation	Movable Equipment & Furnishings
Parking	NIC Fixed Equipment
Facilities for Temporary Relocation	Moving Expenses
Construction Cost	Legal Fees
Contingencies: Owner's, Design Changes, etc.	Owner's Management Services
Surveys: Site, EIS, Subsurface, Hydrology, etc.	Predesign Services Fees: Programming, Feasibility Study, Site Selection, etc.
Land Acquisition	Design Services Fees:
Permits: Utility Connection, Construction, Occupancy, etc.	Construction Management Fees
Site Development: Roads, Drainage, Utilities, Cut & Fill, Grading, etc.	Communications: IT Systems, Computer & Server Equipment, Wireless Network
Relocation & Reconnection of Utilities	Reimbursable Expenses
Landscaping (beyond 5 ft of building perimeter)	Interim Financing and Fees
Special Foundations & Subsurface Work	Cost Escalation
Hazardous Materials Remediation	Movable Equipment & Furnishings
Parking	NIC Fixed Equipment
Facilities for Temporary Relocation	Moving Expenses

Note. EIS = Environmental Impact Study; NIC = not in contract.

1.2.1.4 Transition to Design Phase – Traditional Process and Integrated Design Process. Traditional project design teams consist of architects and engineers, either in-house employees or contracted individuals or firms, and key owner's representatives, including environmental health and safety professionals (EH&S). To begin the planning process, project design teams use program documents and predesign studies that describe the scope of the project and project requirements to develop a schematic design. Throughout the planning and design process, the project design team engages laboratory users and occupants to obtain additional information, learn their preferences, and to make decisions. To obtain final decisions, the team meets with and makes periodic presentations to owner's representatives and user groups throughout the design development phase. After the team produces construction documents, interaction with users diminishes or ceases. Planning and design processes for new construction may take one year or more. The process duration is more variable for renovations, based on the area and complexity of the renovation, and the number of phases. See Chapter 3, Section 3.1.3 for more information on renovation project planning.

Over the past decade, a new integrated project design process (IPD) has evolved in the A/E/C industry (architecture/engineering/construction). The National Institute of Building Sciences in its *Whole Building Design Guide* (NIBS, 2012) offers strong recommendations and guidance for use of this new method. One major difference between a traditional design process and IPD is addition of a building construction or construction management team at the very beginning of the design process; they work with the traditional design team composed of architects, engineers, and their consultants. "The design of buildings requires the integration of many kinds of information into an elegant, useful, and durable whole. An integrated design process includes the active and continuing participation of users and community members, code officials, building technologists, contractors, cost consultants, civil engineers, mechanical and electrical engineers, structural engineers, specifications specialists, and consultants from many specialized fields. The best buildings result from continual, organized collaboration among all players. . . . The integrated design process enables project team members to work together from the project outset to develop solutions that have multiple benefits." (NIBS, 2012, p. 1) The phases of design (schematic design, design development, and contract documents) remain similar between traditional and IPD process, both start with programming described above in Section 1.2.1.2. "Regardless of a project's scope, research and programming is a crucial first step in developing a successful design. No later than the completion of these tasks should the client engage the architect or other prime consultant who will oversee the design process and its final implementation. . . Gradually a design emerges that embodies the interests and requirements of all participants, while also meeting overall area requirements and budgetary parameters. At this stage, schematic designs are produced" (NIBS, 2012, p. 1).

1.2.2 Planning

The end product of planning, the first phase of the design process, is a set of schematic design drawings, engineering systems descriptions, and outline specifications for materials to be used in construction. In a schematic design, architects customarily show the layout of each floor level and indicate circulation including egress pathways; they also present their initial concepts of what the building will look like, including the height, shape, volume, and primary materials of the enclosure. Schematic design drawings show locations on the site and site development for vehicular, service, and pedestrian entry points. From these drawings, engineers will prepare their estimated load calculations and make preliminary equipment selections. They will also develop concepts for all mechanical, electrical, and plumbing systems distribution, including fire protection, laboratory water, purified water, waste treatment, safety control systems, normal electrical service and IT systems, energy conservation, and emergency power. They will identify possible locations for primary equipment and mechanical rooms, as well as for utility distribution risers, air intakes and exhaust outlets, utility entry points, and sewage connection. The structural engineer will propose a structural system and grid of column and beam locations in the schematic design.

Schematic design drawings will show the size and location of every room listed in the building program by type and by floor level. This is a good time to develop a detailed layout of the generic modular laboratory (the basic spatial organizing unit of laboratory buildings) if it was not already proposed in the program document. Preliminary room and area assignments for the proposed occupants of the building may be shown on the schematic design drawings when the owner identifies the occupants.

The project design team should communicate intensively and frequently during the planning process to exchange information, to discuss issues brought forward by the generation of design ideas, to resolve problems that were not foreseen during the building program phase, and to make decisions. To establish effective lines of communication within the owner's entire group, a small committee should be designated to act as the

owner's representative. The committee may include a few future laboratory users, PIs, supervisors and managers (along with other occupants if it is a mixed-use building), and facility management. It should also include EH&S professionals and key administrators. The leader of the building committee is an employee of the organization; to perform leadership responsibilities, this person should have the time officially authorized and the workload in his or her normal job commensurately reduced for the entire design phase. On a day-to-day basis, the leader receives informal oral and official written communications from the project design team then distributes this information to the building committee and directly to specific users, to elicit their opinions on issues or design decisions under consideration. This is an iterative process and requires participation of the stakeholders, not surrogates, to make it work well. Construction is disruptive, even disturbing, to technical people with previously well-established locations and routines. There is a "churn cost" involved in moving or relocating people, even to superior facilities. Regular and specific communications during design and through construction can go far to reducing the tensions of change.

In the schematic design phase, options in planning, laboratory layouts, building mechanical systems, and architectural design should be explored because the project design team is still creating it. Things tend to lock up increasingly after this point. In the phase that follows, called *design development*, the project design team will develop greater detail and clearer definition of the agreed-upon concept. This process leads to the final design, so opportunities for major design changes diminish dramatically as the design development phase ends.

Cost estimators usually provide estimates at the conclusion of each design phase, including schematic design and design development. Adjustments in building area, quality of materials, or methods of construction are generated during these phases to keep the project within budget. Late changes and afterthoughts brought to the design team during the construction document phase are expensive to execute and time-consuming; they put the project schedule at risk with increased costs.

1.2.2.1 Building Spatial Organization. While the architect designs the optimal building enclosure configuration, site location, and image, the project design team will also generate concepts for the internal organization of the building spaces and infrastructure. The internal organization of a laboratory building is comprised of six major patterns of spatial definition:

1. Circulation of people and materials (Section 1.2.3)
2. Generic laboratory modules (Section 1.2.4)
3. Distribution of mechanical equipment and services (Section 1.2.5)
4. Structural system (Section 1.2.6)
5. Site regulations (Section 1.2.7)
6. Building enclosure configuration (Section 1.2.8)

The project design team must consider these patterns of spatial definition together during the planning phase and thoroughly coordinate them during all later design phases. Although structural and mechanical engineers can design many solutions to fit building enclosures, a comprehensive engineering concept is needed in the schematic phase to fulfill building performance requirements and provide optimal solutions for function, safety, and flexibility. All systems should complement one another to provide a safe and healthful work environment efficiently and at reasonable cost. Drawing techniques, such as those available in computer-aided design and drafting (CADD) and three-dimensional representation methods, allow superimposition of the design layouts prepared by mechanical and electrical engineers upon those prepared by the architects and structural engineer to detect physical conflicts. Some building information management (BIM) computer programs do this process in dimensions and also create a comprehensive building database. This helps create well-coordinated construction documents. Ultimately, the compatibility of all of the systems that will define the facility depends on the expert knowledge and creativity of the project design team.

1.2.3 Circulation of People and Materials

For legal and safety reasons, how people and materials circulate within and around the laboratory building are vital concerns. The designer must consider building code requirements, accessibility needs, and transport of hazardous materials.

1.2.3.1 Building Code Considerations. Health and safety issues of circulation are primarily concerned with (1) emergency egress of building occupants, and (2) access to the building and its internal parts by emergency personnel, such as hazardous materials response officers, fire fighters, and police officers. Building codes regulate these issues (Baum, 2005, provides good background on this topic). The major reference sources used in this book are the International Building Code (IBC, 2012), the International Fire Code (IFC, 2012), the National Fire Protection Association's Life Safety Code 101 (NFPA, 2012), the Occupational Safety and Health Administration's (OSHA) Laboratory Standard 1910.1450 (2013), and Standard 29CFR 1910.1200 App E (OSHA, 2013), and the Americans with Disabilities

Act (ADA, 1990). The latest editions of these laws, codes, and standards define and specify all the components for building egress and access that pertain to occupant safety. Specific sections of note are the following:

- International Building Code (2012): Chapter 3, "Use and Occupancy Classification," and Chapter 10, "Means of Egress."
- NFPA Bulletin 101 (2012): Life Safety Code, Section 1.12, "Danger to Life from Fire," and Section 1.1.3, "Egress Facilities."
- OSHA Health and Safety Standards (2011): 29 CFR 1910.35, Chapter XVII, Subpart E, "Means of Egress."
- Americans with Disabilities Act of 1990, amended in 2008: 28 CFR, Title III, Part 36, "Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities, Final Rule"; Subpart D, "New Construction and Alterations"; Paragraph 4.3, "Accessible Route"; and Paragraph 4.3.1.0, "Egress."

Historically recognized building codes in the United States include the Building Code Officials' Association (BOCA) Code, the Uniform Building Code (UBC), and the Southern Building Code Congress International (SBC). Although these older codes are no longer published, many existing buildings were designed to their specifications. For renovations and building additions, project designers must go back to these codes to judge the conditions that are newly relevant. Past editions of these codes are available online. The International Building Code (IBC, 2012) is the most current code referenced in this edition. State and city codes also address building circulation conditions, occupant egress, and emergency responder access. Requirements in other current codes may differ somewhat from the specific IBC citations referred to in this book, but they take precedence when they are more restrictive or are adopted by the jurisdiction having authority.

1.2.3.1.1 International Building Code Requirements. Chapter 10, Section 1003, "Means of Egress" (IBC, 2012) shows the general requirements, such as minimum ceiling and door heights, vertical and horizontal projections into the egress pathway, and means of egress continuity. People usually flee a building by corridors and stairs. Section 1004 discusses occupant load. It is important that egress pathways are wide enough to allow building occupants to exit safely under normal and emergency conditions. According to the occupancy use selected for laboratory buildings discussed in IBC (2012) Chapter 3, " Use and Occupancy Classifications," laboratory building occupant load can be calculated at 50 net ft^2 (4.65 m^2) per occupant in buildings classified as Educational Group to 100 gross ft^2 (9.3 m^2) per occupant classified as a Business Group. See Table 1004.1.1, "Maximum Floor Area Allowances per Occupant" and Table 1005.1, "Egress Width per Occupant Served" (IBC, 2012) for all occupancy groups. Per the IBC, Educational Group pertains to educational facilities only up to grade 12 (IBC, 2012). Laboratory is not a classified building use in the IBC (2012). The great majority of higher education, corporate, and government agency laboratories are classified in Business Group 'B' (IBC, 2012). Other special-risk laboratory buildings may be classified in High Hazard Group 'H' (IBC, 2012). Section 1.2.4.2 contains details of use and occupancy classification and an adaptation of Table 1004.1.1 in the IBC (2012).

The IBC sets requirements for exit door and egress pathway widths based on the occupancy load and upon whether the laboratory building is protected by an automatic sprinkler system. We recommend installation of automatic sprinkler systems in laboratory buildings; Section 1007 of the IBC (2012) explains the requirements for accessible means of egress.

1.2.3.1.2 Accessibility Guidelines. Ease of access and emergency evacuation for disabled persons merit special attention. The Americans with Disability Act of 1990, 28 CFR, Title III, Part 36 (ADA, 2008) describes and discusses specific issues of accessibility and safety for disabled persons in commercial facilities, which may include laboratories. The act contains extensive guidelines on design standards that are based, in part, on ANSI Standard A117.1-2003, "Usability for Physically Handicapped People" (ANSI, 2003). As with building codes, state and local jurisdictions may require more stringent standards for accessibility; the project team must check to make sure that new construction, additions, or renovations comply if the laboratory building is in the category of "public accommodation." Private commercial and industrial laboratories in certain aspects may have fewer accessibility requirements if no disabled persons are employed there currently. However, in the future they may need to comply with the ADA. Buildings that are accessible facilitate employment of disabled persons and their integration into the science and engineering workforce. No architectural barriers should be designed and constructed at main entrances, doorways, public toilet rooms, elevators, drinking fountains, public telephones, or other public accommodations within laboratory buildings.

Standards for accessible design are upgraded regularly. In general however, the clear floor area required for persons in wheelchairs to turn around is a circle with

minimum 5 ft (1.5 m) diameter. The maximum slope on ramps in public corridors or for access to special laboratories with raised floors is 1:12. Ramps must be structured to safely carry the live load of persons and materials using them. Door minimum clear width opening is 32 in. (81 cm). The preferred minimum door width in good laboratory design is 36 in. (91 cm). There also must be adequate clearances on both sides of swinging doors on the latch side with 1.5 ft (46 cm) minimum, 2.0 ft (61 cm) preferred on the in-swinging side and 1 ft (30 cm) on the out-swinging side. Laboratory building design should incorporate all basic access accommodations for all public pathways, doorways, and public facilities to avoid high costs of future retrofits.

Surrogates for visible signs, highly legible signs, and acceptable door and elevator hardware should be provided for those who are visually impaired. Alarms, warnings, and controls detectable by both disabled and unimpaired people are required by code, as well as by ADA. See Chapter 2, Section 2.2.2.4 for details of accessibility in laboratory design.

1.2.3.1.3 Transport of Hazardous Materials. Laboratory buildings may contain a wide variety of hazardous materials, as listed and described in Chapter 2, Sections 2.4.5 and 2.4.6, as well as in Chapter 27, Section 27.1. Laboratory occupants, trained EH&S staff persons, and external vendors transport these materials to and from laboratories, laboratory support rooms, and support spaces such as mechanical equipment and pump rooms. People must be able to safely deliver hazardous materials and then remove hazardous waste from locations ranging from penthouses down to subbasements, where mechanical equipment is located that must be maintained. Materials movement is safer using clear, unobstructed horizontal pathways of sufficient width to negotiate turns easily. People pushing lab carts, handtrucks, and dollies, which move well on smooth, level, horizontal pathways, have difficulty with ramps, narrow corridors and doorways, raised thresholds, and hard-to-open doors. Keep these impediments out of the design and detailing of floors and doors. Clearance requirements may be more specific for motorized material-handling equipment than for manual equipment.

Vertical pathways, including stairs and elevators, increase risk of breakage and spills of transported hazardous materials. We highly recommend service elevators in multilevel laboratory buildings for transport of hazardous materials. Passenger elevators should not be used for transport of hazardous materials. Service elevators that access penthouses and subbasements are critical for maintenance personnel and operations. Service elevators with restricted, keycard access can be used to safely transport vessels containing cryogenic liquids and gas cylinders. Many jurisdictions prohibit the use of passenger elevators for transporting these materials. When this type of hazardous material is in a service elevator cab, people should not ride in the cab. One person loads the elevator on one level, and another person receives and removes the hazardous material at the destination level. This method avoids the risk of asphyxiation of persons in the elevator cab. See Section 2 of Chapters 17, Gross Anatomy Laboratory; Chapter 19, Autopsy Laboratory; Chapter 20, Morgue Facility; and Chapter 22, Animal Research Laboratory for other service elevator considerations for these laboratory.

Laboratory workers may choose to use stairways if they are hand-carrying small, lightweight trays or boxes containing hazardous materials, and if service elevators are in inconvenient locations. Workers should use secondary containment trays to capture spills and sealed containers if the carried vessels break or tip over.

1.2.3.2 Common Circulation Configurations. Laboratory buildings commonly have four personnel and materials' handling configurations: (1) single corridor, double-loaded; (2) internal loop corridor; (3) perimeter loop corridor; and (4) corridor grid. Supplementary approaches include service corridors and finger corridors. Figures 1-10 to 1-14 show examples of these common circulation configurations and variations with supplementary circulation.

Table 1.9 presents pros and cons of common corridor configurations. We do not recommend one over the other; there is not a right or wrong pattern. Evaluating facility safety circumstances and access requirements will help the design team to determine the best choice.

1.2.3.2.1 Single Corridor. Buildings with single corridors are simple and efficient. Both ends of single corridors generally have emergency egress doors and/or fire stairs to evacuate the building according to code. Elevator cores may be any location along the corridor. Centered single corridors, shown in Figure 1-9A, generally provide space for laboratories along both sides of buildings. Single corridors offset from center can provide layouts with laboratories on one side and offices or other functions on the other, as shown in Figure 1-9B. Single-corridor building layouts such as Figures 1-9B and 1-9C can fit on narrow sites.

1.2.3.2.2 Internal Loop Corridor. Internal loop corridor options are shown in Figures 1-10A and 1-10B. As the name implies, these corridors wrap around building center core spaces and provide access to laboratories and offices on two to four sides of the building. When supplementary corridors cross the center core, shown in Figure 1-10B, providing convenient shortcuts for occupants, positive interaction between occupants on both sides of the building increases. Some shared laboratory

TABLE 1-9. Comparison of Circulation Patterns in Laboratory Buildings

	Circulation Patterns			
	Single	Racetrack	Perimeter	Grid
PROS				
1	Highest efficiency			
2	Double-loaded, high efficiency	Double-loaded, high efficiency		Double-loaded, high efficiency
3	Occupant interaction increases			
4			Separate service corridor possible	Separate service corridor possible
5			Lots of exterior windows in corridor	
6	Exterior windows in labs/ ofcs	Exterior windows in labs/ ofcs	No exterior windows in labs/ ofcs	Exterior windows in labs/ ofcs
7		Wide floorplate possible	Wide floorplate possible	Extra-wide floorplate possible
CONS				
1		Lower efficiency	Lower efficiency	Lowest efficiency
2			Single-loaded, low efficiency	
3		Occupant interaction lower	Occupant interaction lower	Occupant interaction lower
4	No service corridor possible	No service corridor possible		
5	Very few exterior windows in corridor	Very few exterior windows in corridor		Very few exterior windows in corridor
6			No exterior windows in labs/ ofcs	Few exterior windows in labs/ ofcs
7	Difficult to get wide floorplate			

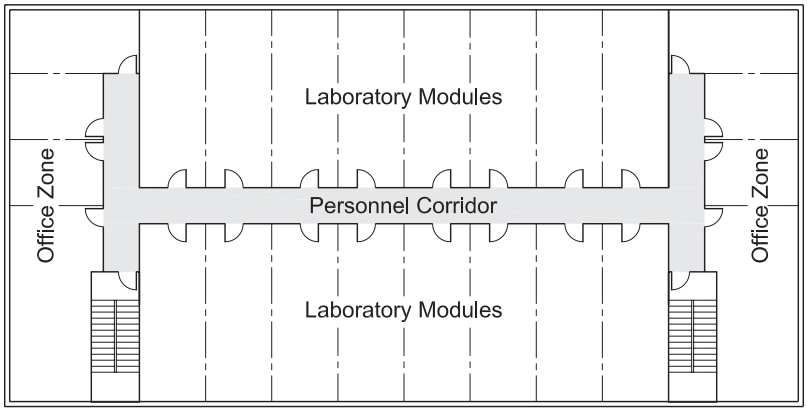


FIGURE 1-9A. Single center corridor, building layout.

support functions may have entry doors on both ends, again allowing easy access for occupants on both sides of the building.

1.2.3.2.3 Perimeter Loop Corridor. Figure 1-11A shows a perimeter loop corridor wrapping around the building at the exterior wall on at least two sides. At the ends of some buildings, perimeter corridors may move inward from the exterior wall, as shown in Figures 1-11A and B. Because perimeter loop corridors can have lots of window area, Figure 1-11C shows the corridor on one side is widened to accommodate an open office layout. The perimeter corridor on the opposite side can be used for public access or for service functions. This design

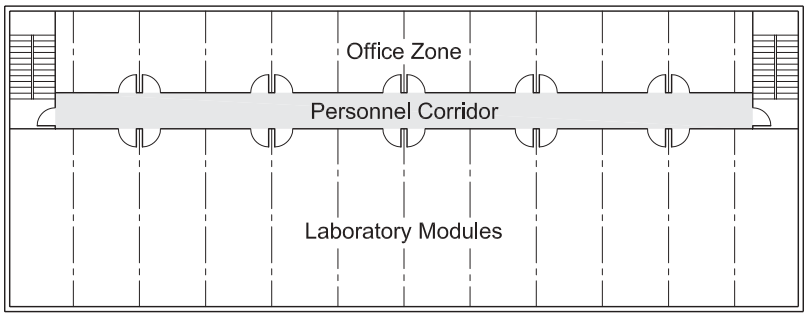


FIGURE 1-9B. Single offset corridor, building layout.

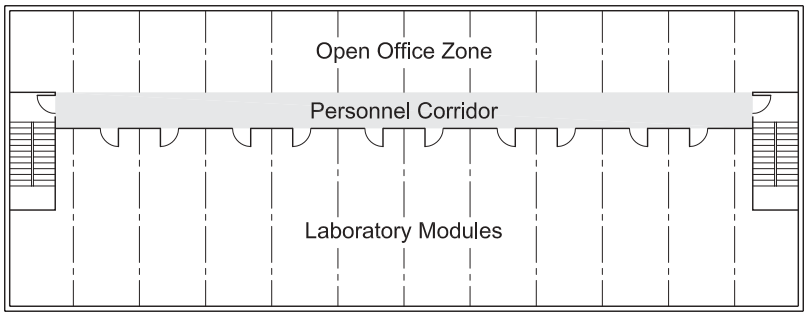


FIGURE 1-9C. No-corridor building layout.

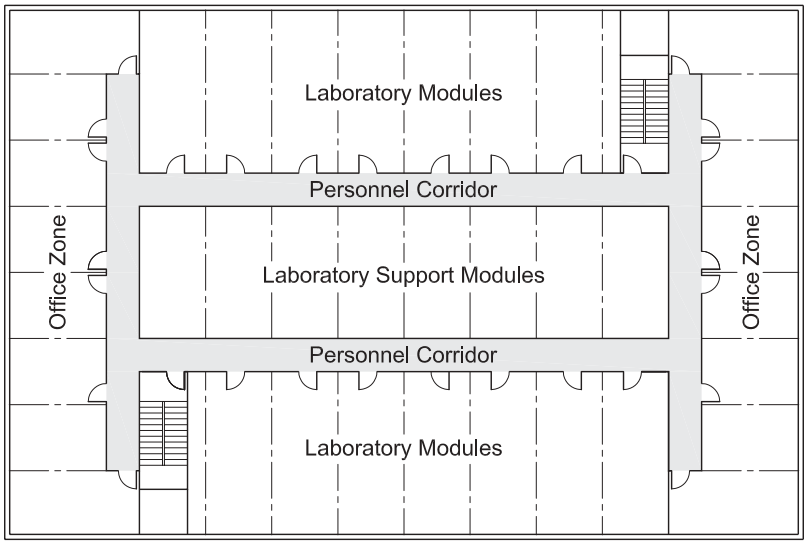


FIGURE 1-10A. Internal loop corridor with core, building Layout.

allows laboratory occupants' desk space to be proximate to, but still outside of the laboratories. Supply air is provided to corridors, and that air passes into the laboratory zone due to laboratories' slight negative pressurization. Figure 1-11D shows a perimeter loop corridor layout that includes a central service corridor to improve flexibility for laboratory changes.

1.2.3.2.4 Grid Corridor System. Grid corridors allow easy access to all parts of buildings with large, wide floor plates. Grids are used when a large percentage of laboratory and building functions do not require windows for access to natural light and views, such as shown in Figure 1-12. Good signage is important in buildings with grid corridor systems because a network of corridors

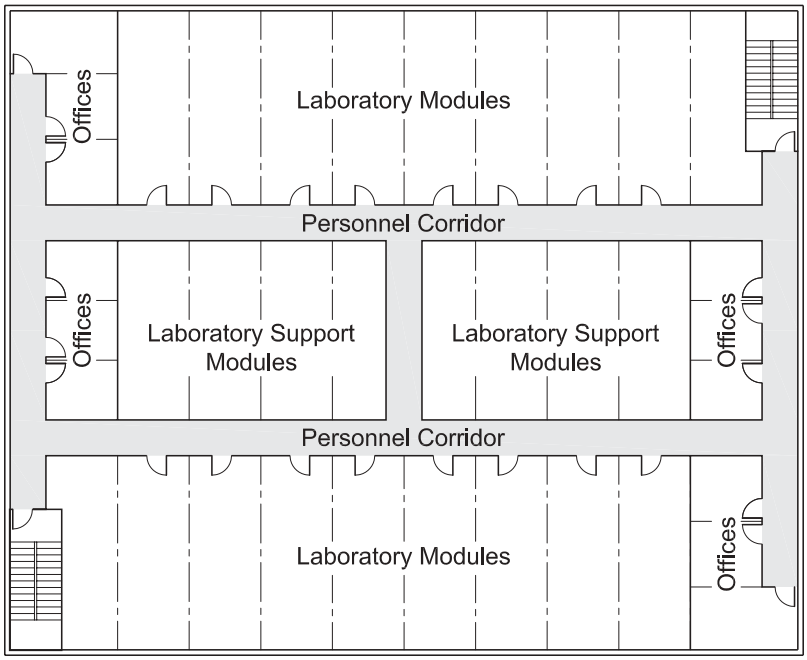


FIGURE 1-10B. Internal and perimeter loop corridors, building layout.

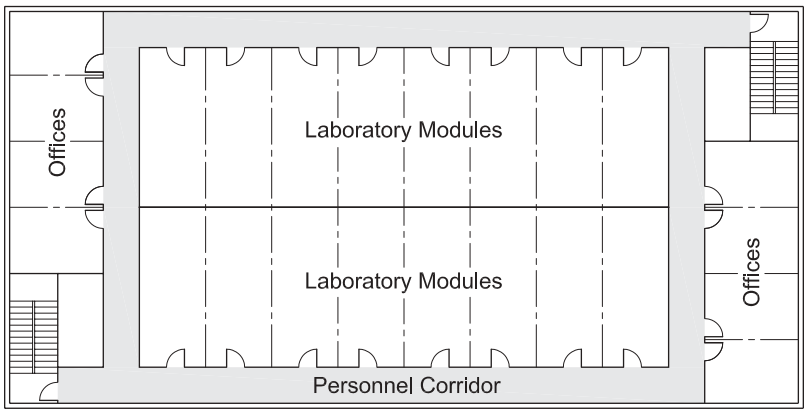


FIGURE 1-11A. Combination loop corridors, building layout.

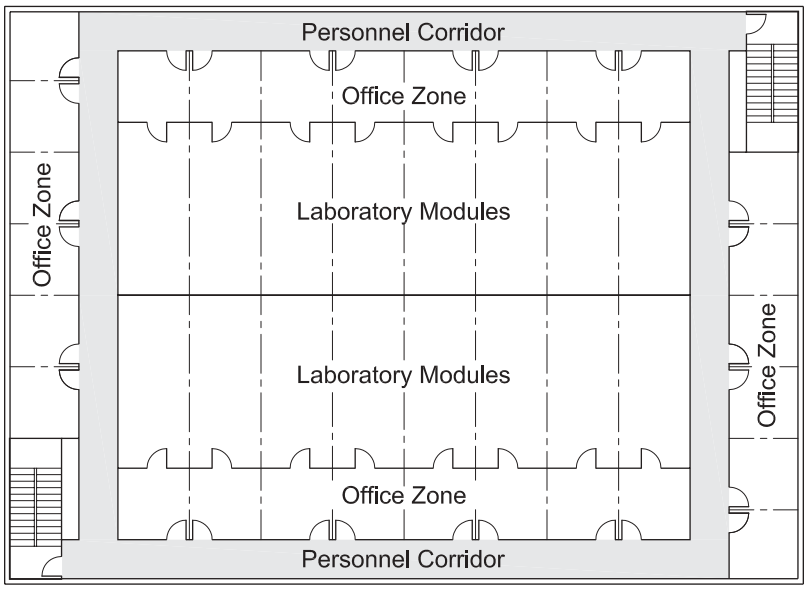


FIGURE 1-11B. Combination loop corridors, building layout.

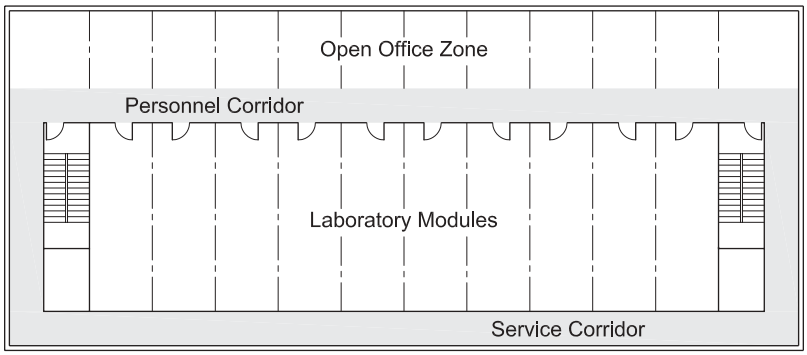


FIGURE 1-11C. Combination loop corridors with open office zone, building layout.

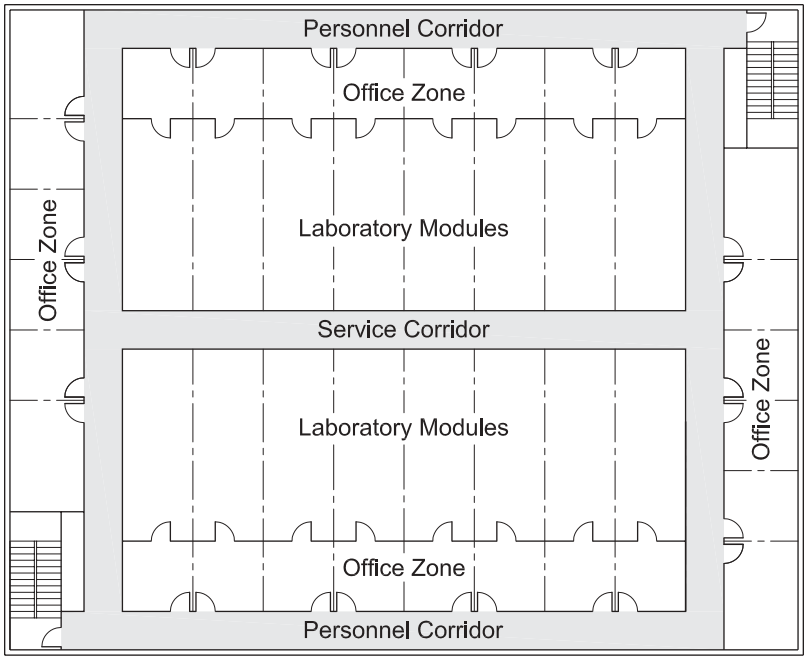


FIGURE 1-11D. Combination loop with center service corridors, building layout.

can be very disorienting to new building occupants and visitors.

1.2.3.2.5 Service Corridor. Service corridors are restricted access pathways, used by scientists, technicians, EH&S, transport, and maintenance personnel. Service corridors are normally designed for building plans that use perimeter and grid corridors. Laboratory exhaust air ducts are supported from the structure above and enter laboratories through walls enclosing service corridors. Figure 1-11D shows a layout that permits servicing of pipes and ducts inside vertical shafts or mounted directly upon service corridor walls outside laboratories, greatly reducing the frequency of and risks to maintenance personnel having to enter laboratories. If service corridors' walls are constructed with fire-resistive assemblies and according to building code, they can also provide secondary egress pathways from each laboratory and among separate fire zones.

1.2.3.2.6 Finger Corridors. Finger corridors, as illustrated in Figure 1-13, can be designed for building plans that use primary single corridors that are double-loaded, or internal loop corridors. All building codes restrict the lengths of finger corridors because code officials regard them as dead-end corridors, even if technically, finger corridors have second exits. Under normal conditions, the maximum length is 20 ft (6 m). For laboratory buildings wider than 75 ft (23 m), adding finger corridors, entered from the single central corridor, can offer public

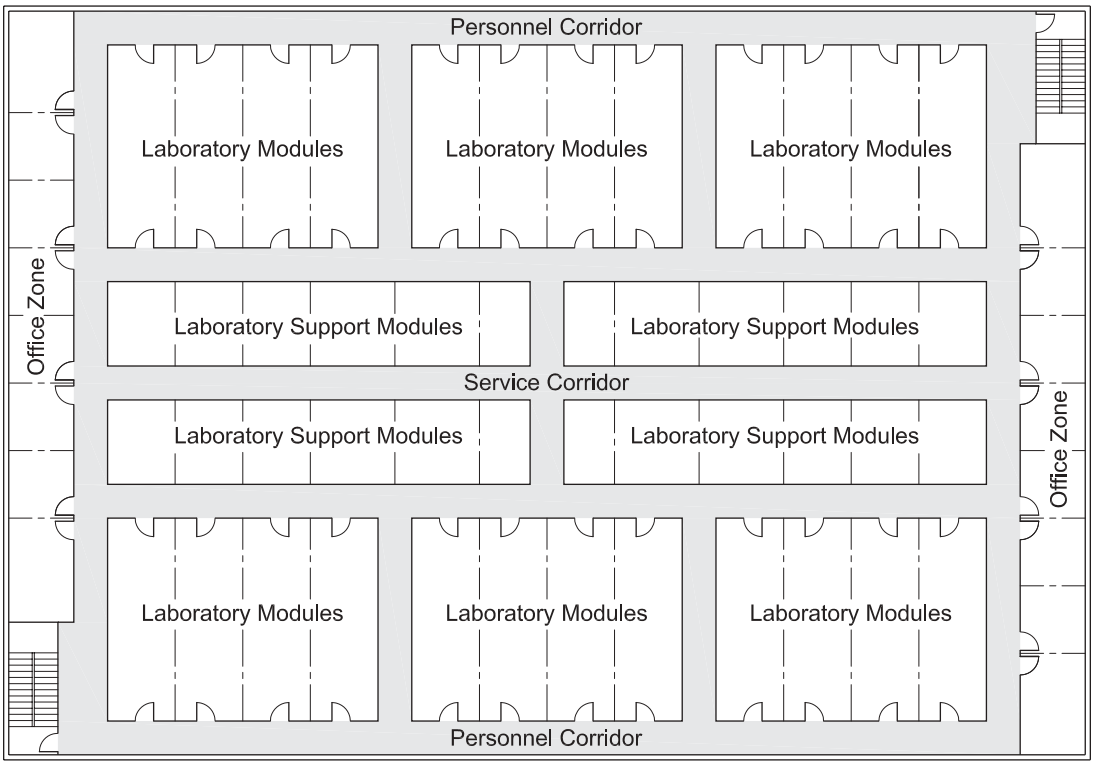


FIGURE 1-12. Grid corridor system, building layout.

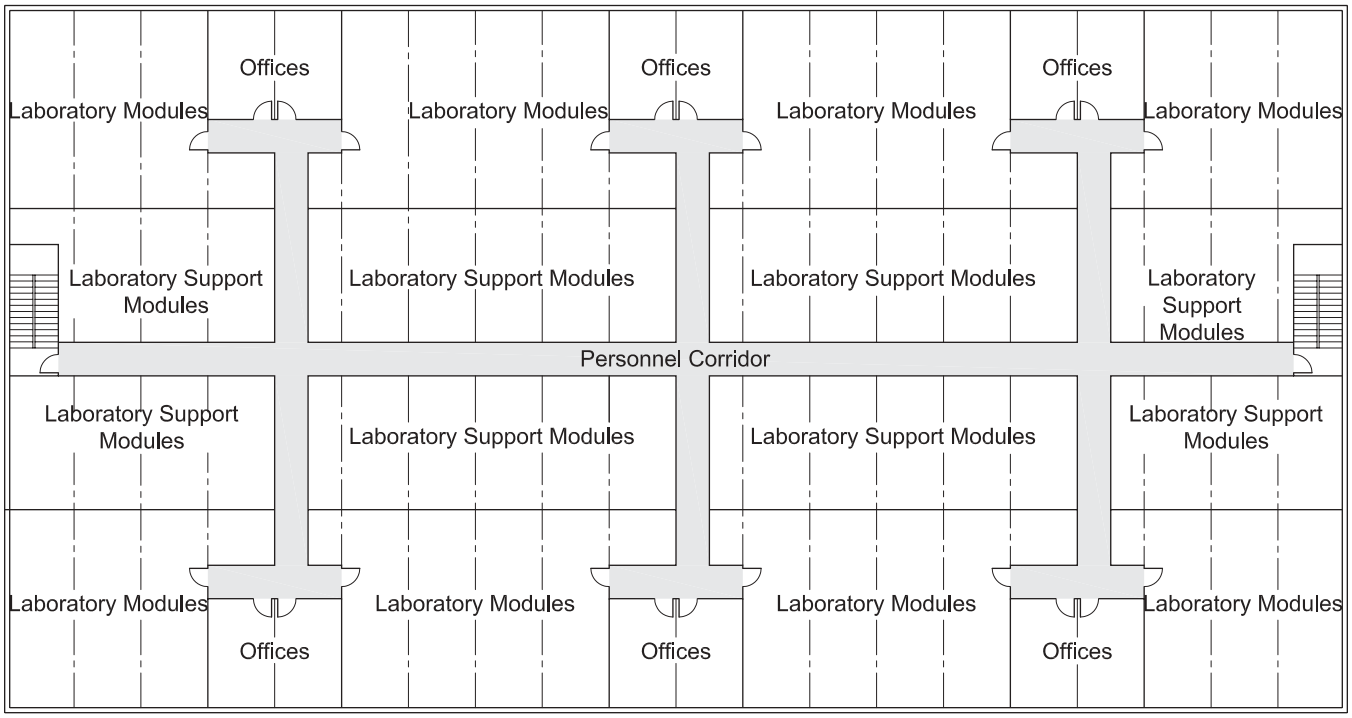


FIGURE 1-13A. Wide floor plate with finger corridors, building layout.

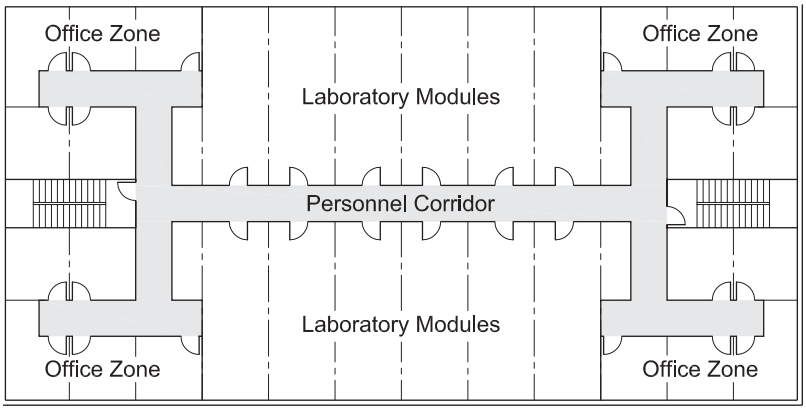


FIGURE 1-13B. Narrow floor plate with finger corridors, building layout.

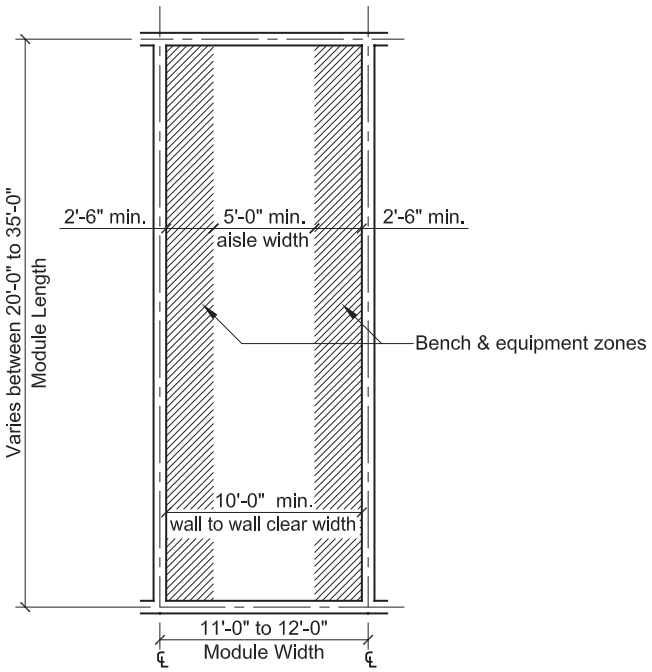


FIGURE 1-14. Single laboratory module diagram.

access to support functions and offices that otherwise would force primary access through laboratories, an access that is not recommended.

1.2.4 Laboratory Module

In Section 1.2.1.2.1, Step 7 shows how to use module areas for generating a laboratory program. The plans above show that using a modular approach to planning laboratories is efficient, and the resulting laboratories are more flexible because they have common dimensions. A single laboratory module is defined as a basic unit of space of a size commonly referred to as a *two-person laboratory* (Figure 1-14). Formulation of the internal organization of the laboratory building begins with a decision on the dimensions of the standard or generic laboratory module and the occupancy density. This task redirects the planning focus from the large scale of the total facility down to the small scale of a single laboratory module, the basic working area generally for one to three laboratory occupants. Chapter 2, Section 2.2.1 has information on laboratory module size and proportions.

1.2.4.1 Laboratory Unit. The National Fire Protection Association, Standard 45, Fire Protection for Laboratories Using Chemicals (NFPA, 2011), defines a laboratory unit as "an enclosed space used for experiments or tests." It may be an assembly of a number of laboratory modules, corridors, contiguous accessory spaces, and offices into this larger space category—the laboratory unit. See the definition of departmental gross area in Section 1.2.1.2.1. Step 9, which has some similarity to the definition of laboratory unit. Under NFPA 45 (2011), entire buildings may be defined as a single laboratory unit. This standard offers criteria for planning laboratory units (Standard 45, NFPA, 2011). The IBC (2012) does not use the term laboratory unit to categorize laboratory space.

1.2.4.2 Building Code Allowable Chemical Limits. In strong contrast to NFPA standards 45 and 101, the IBC (2012) has lower limits for volumes and weights of chemicals in laboratory buildings under Business (B), Educational (E), or Institutional (I) use and occupancy groups. Allowable limits are given in Table 307.1 (1), "Maximum Allowable Quantity per Control Area of Hazardous Materials Posing a Physical Hazard" (IBC, 2012). Table 1-10 has been adapted from IBC Table 307.1(1) (IBC, 2012). The IBC (2012) limits total allowable volumes of hazardous materials on each floor or in specific fire control areas on each floor, and in the entire

TABLE 1-10. Adapted from IBC (2012) Table 307.1(1) Maximum Allowable Quantity per Control Area of Hazardous Materials Posing Physical Hazard

MATERIAL	CLASS	Group when the Maximum Allowable Quantity is Exceeded	STORAGE						USE CLOSED SYSTEMS						USE OPEN SYSTEMS			
			Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes	Gas at Cu Ft at NTP	Notes	Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes	Gas at Cu Ft at NTP	Notes	Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes
Combustible Liquid[c, j]	**II**	**H-2 or H-3**	NA		**120**	a, b	NA		NA		**120**	a	NA		NA		**30**	a
	IIIA	**H-2 or H-3**			**330**	a, b					**330**	a					**80**	a
	IIIB	**NA**			**13,200**	b, c					**13,200**	c					**3,300**	c
Combustible Fiber	**Loose**	**H-3**	**(100)**		NA		NA		**(100)**		NA		NA		**(20)**		NA	
	Baled		**(1000)**						**(1000)**						**(200)**			
Cryogenics, Flammable	**NA**	**H-2**	NA		**45**	a	NA		NA		**45**	a	NA		NA		**10**	a
Cryogenics, Oxidizing	**NA**	**H-3**	NA		**45**	a	NA		NA		**45**	a	NA		NA		**10**	a
Flammable Gas	**Gas**	**H-2**	NA		NA		**1,000**	a, b	NA		NA		NA		NA		NA	
	Liquid				**30**	a, b	NA				**30**	a, b						
Flammable Liquid[c]	**1A**	**H-2**	NA		**30**	a, b	NA		NA		**30**	a	NA		NA		**10**	a
	1B, 1C	**or H-3**			**120**	a, b					**120**	a					**30**	a
Combined Flammable Liquid (1A 1B 1C)	**NA**	**H-2 or H-3**	NA		**30**	a, b	NA		NA		**30**	a	NA		NA		**10**	a
					120	a, b					**120**	a					**30**	a
Flammable Solid	**NA**	**H-3**	**125**	a, b	NA		NA		**125**	a	NA		NA		**25**	a	NA	
Pyrophoric Material	**NA**	**H-2**	**4**	b, d	**(4)**	b, d	**50**	b, d	**1**	d	**(1)**	d	**10**	b, d	**0**		**0**	**0**
Organic Peroxide	**UD**	**H-1**	**1**	b, d	**(1)**	b, d	NA		**0.25**	d	**(0.25)**	d	NA		**0.25**	d	**(0.25)**	d
	I	**H-2**	**5**	a, b	**(5)**	a, b	NA		**1**	a	**(1)**		NA		**1**	a	**(1)**	a
	II	**H-3**	**50**	a, b	**(50)**	a, b	NA		**50**	a	**(50)**	a	NA		**10**	a	**(10)**	a
	III	**H-3**	**125**	a, b	**(125)**	a, b	NA		**125**	a	**(125)**	a	NA		**25**	a	**(25)**	a
	IV	**NA**	NL		NL		NA		NL		NL		NA		NL		NL	
	V	**NA**	NL		NL		NA		NL		NL		NA		NL		NL	
Oxidizer	**4**	**H-1**	**1**	b, d	**(1)**	b, d	NA		**0.25**	d	**(0.25)**	d	NA		**0.25**	d	**(0.25)**	d
	3	**H-2 or H-3**	**10**	a, b	**(10)**	a, b	NA		**2**	a	**(2)**	a	NA		**2**	a	**(2)**	a
	2	**H-3**	**250**	a, b	**(250)**	a, b	NA		**250**	a	**(250)**	a	NA		**50**	a	**(50)**	a
	1	**NA**	**4,000**	b, c	**(4,000)**	b, c	NA		**4,000**	c	**(4,000)**	c	NA		**1,000**	c	**(1,000)**	c
Oxidizing Gas	**Gas**	**H-3**	NA		NA		**1,500**	a, b	NA		NA		**1,500**	a, b	NA		NA	
	Liquid		NA		**15**	a, b	NA		NA		**15**	a, b	NA		NA		NA	

(*Continued*)

TABLE 1-10. (*Continued*)

MATERIAL	CLASS	Group when the Maximum Allowable Quantity is Exceeded	STORAGE						USE CLOSED SYSTEMS						USE OPEN SYSTEMS			
			Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes	Gas at Cu Ft at NTP	Notes	Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes	Gas at Cu Ft at NTP	Notes	Solid Pounds (Cu Ft)	Notes	Liquid Gallons (lbs)	Notes
Unstable	**4**	**H-1**	**1**		**(1)**		**10**		**0.25**		**(0.25)**		**2**		**0.25**		**(0.25)**	
Reactive	**3**	**H-2 or H-3**	**5**		**(5)**		**50**		**1**		**(1)**		**10**		**1**		**(1)**	
	2	**H-3**	**50**		**(50)**		**250**		**50**		**(50)**		**250**		**10**		**(10)**	
	1	**NA**	NL		NL		NL		NL		NL		NL		NL		NL	
Water	**3**	**H-2**	**5**		**(5)**		NA		**5**		**(5)**		NA		**1**		**(1)**	
Reactive	**2**	**H-3**	**50**		**(50)**		NA		**50**		**(50)**		NA		**10**		**(10)**	
	1	**NA**	NL		NL		NA		NL		NL		NA		NL		NL	

Notes: 1 Cu Ft = 0.023 m^3; 1 lb = 0.454 kg; 1 Gallon = 3.785 L; NL = not limited; NA = not applicable; UD = unclassified detonable.

[a]Maximum allowable quantities shall be increased 100% in buildings equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 of IBC (2012). Where not "e" applies, the increase for both notes shall be applied accumulatively.

[b]Maximum allowable quantities shall be increased 100% when stored in approved storage cabinets, day boxes, gas cabinets, exhausted enclosures, or safety cans. Where Note "d" also applies, the increase for both notes shall be applied accumulatively.

[c]The permitted quantities shall not be limited in a building equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 of IBC (2012).

[d]Permitted only in buildings equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 of IBC (2012).

building—no matter the size of the floor or building. IBC Section 414, paragraph 414.2 (IBC, 2012) defines a control area as "a building or portion of a building within which the exempted amounts of hazardous materials may be stored, dispensed, handled or used." Fire control area requirements for fire-rated assemblies are described in IBC, Section 414.2 (2012) as well. IBC Table 307.1(2), Maximum Allowable Quantity per Control Area of Hazardous Materials Posing a Health Hazard (IBC, 2012), applies to other categories of hazardous chemicals. See Table 1-11 which has been adapted from IBC Table 307.1(2).

The IBC (2012) Table 414.2.2 shows the number of fire control areas allowed per floor level and the percentage of hazardous materials allowed on each level. Figure 1-15 shows a graphic representation of the control area concept for laboratory buildings. IBC does not depend on fire-hazard classifications for laboratories, just allowable chemical volumes to guide laboratory planners. This is another reason why collecting chemical inventories for each laboratory, as well as for the entire building, is important to complete in the programming phase, as noted in Section 1.2.1.2.1, Step 6.

Laboratory buildings that will exceed the maximum allowable quantities per control area of hazardous materials, as shown in Tables 1-10 and 1-11, fall into the High Hazard Group (H) use and occupancy classification as defined in IBC, Section 307 (IBC, 2012) and IFC, Section 415 (IFC, 2012). Group H is handled as a separate classification because it represents an unusually high degree of hazard that is not found in the other occupancies. It is important to isolate industrial or storage operations that pose the greatest dangers to life and property and to reduce their hazards by incorporating protective measures described in the regulatory provisions of building codes. The classification of a material as high hazard is based on information derived from the U.S. Code of Federal Regulations (DOL 29 CFR; IBC, 2012, Section 307) and NFPA standards.

There are five categories of Group H occupancies. Group H-5 was generated by the semiconductor industry to address acute hazards from hazardous production material (HPM) facilities, as discussed later in Chapter 23, Microelectronics and Cleanroom Laboratories. Group H-4 addresses acute health hazards from corrosive, toxic, and highly toxic materials. Groups H-1, H-2, and H-3 are listed in order of diminishing hazard from materials posing a physical hazard, such as fire and explosion. IBC offers five exceptions to H-Group use and occupancy based on a "list of conditions that are exempt from a high-hazard classification because of the building's construction or use; the packaging of materials, the quantity of materials, or the precautions taken to prevent fire" (IBC, 2012, Section 307).

An important table in NFPA 45 is Table 10.1.1 "Maximum Quantities of Flammable and Combustible Liquids and Liquefied Flammable Gases in Sprinklered Laboratory Units Outside of Inside Liquid Storage Areas" (NFPA 45, 2011). NFPA's Table 10.1.5 shows allowable chemical quantities for unsprinklered buildings (NFPA 45, 2011). NFPA's Table 5.1.1 provides fire separation requirements for sprinklered laboratory units (NFPA 45, 2011). NFPA recommendations are based on the number of gallons of flammable liquids stored within the laboratory unit per 100 ft^2 (28 L/m^2). The concept is that the amount of flammable liquids allowed within a laboratory unit is directly proportional to its size, up to a defined maximum area of 10,000 NASF (929 NASM). If the jurisdiction having authority adopts an edition of NFPA 5000, Building Construction and Safety Code (NFPA, 2012), and NFPA 45 as its legal building code, the project design team will use the tables referenced here to understand the allowable limits of chemical quantities in each laboratory unit. The NFPA 45 (2011) standard relies upon definitions of hazard classes for each laboratory to determine fire enclosure requirements. Laboratory units may be classified by fire hazard and by explosion hazard (NFPA 45, 2011). Class A is high, Class B is moderate, Class C is low, and Class D poses minimal fire hazard. In practice, hazard classifications of laboratory units are often made after occupancy, rather than in the planning or programming phases. This can become a serious impediment in designing flexible laboratory buildings, unless the most conservative classification is used. It can also delay obtaining an official Certificate of Occupancy from the authority having jurisdiction. Some NFPA documents are not adopted as legal code or specific sections are not referenced by the official code; project design teams must seek out the correct references to understand allowable limits for chemical storage and use. This is another example of how the design of laboratory buildings affects their operations and can potentially limit the research conducted there.

After determining the quantities and types of hazardous chemicals and materials, the project planner will investigate the distribution of these materials. Obviously, the planning process of laboratory buildings must establish a reasonable subdivision of space and use of fire protective construction assemblies to limit the spread of fire, fumes, and hazardous materials, such as highly toxic or radiation-producing chemicals, gases under high pressure, and highly pathogenic materials. The U.S. Environmental Protection Agency (EPA) establishes hazardous material classifications for chemical hazards; the Department of Transportation (DOT) determines classifications for high-pressure gases. The National Institutes of Health (NIH) in cooperation with

TABLE 1-11. Adapted from IBC (2012) Table 307.1(2), Maximum Allowable Quantity per Control Area of Hazardous Materials Posing Health Hazard

	Storage						Use Closed Systems						Use Open Systems			
MATERIAL	Solid Pounds[a,b] (Cu Ft)	Notes	Liquid Gallons (Pounds)[a,b]	Notes	Gas at Cu Ft at NTP[a]	Notes	Solid Pounds[a] (Cu Ft)	Notes	Liquid Gallons (Pounds)[a]	Notes	Gas at Cu Ft at NTP[a]	Notes	Solid Pounds[a] (Cu Ft)	Notes	Liquid Gallons (Pounds)[a]	Notes
Corrosive	**5,000**	a, b	**500**	a, c	**810**	b, d	**5,000**		**500**	c	**810**	b, d	**1,000**		**100**	c
Highly Toxic	**10**		**(10)**	c	**20**	e	**10**		**(10)**	f	**20**	e	**3**		**(3)**	f
Toxic	**500**		**(500)**	c	**810**	b	**500**		**(500)**	f	**810**	b	**125**		**(125)**	f

Note: 1 Cubic Foot = 0.023 Meters^3, 1 Pound = 0.454 Kilograms, 1 Gallon = 3.785 Liters.

NL = Not Limited, NA = Not Applicable, UD = Unclassified Detonable.

[a]Quantities shall be increased 100% in buildings equipped throughout with an approved automatic sprinkler system in accordance with Section 903.3.1.1. Where Note "f" also applies, the increase for both notes shall be applied accumulatively.

[b]Quantities shall be increased 100% in buildings equipped throughout with an approved automatic sprinkler system in accordance with Section 903.3.1.1. Where Note "e" also applies, the increase for both notes shall be applied accumulatively.

[c]The aggregate quantity in use and storage shall not exceed the quantity listed for storage.

[d]A single cylinder containing 150 pounds or less of anhydrous ammonia in a single control area in a nonsprinklered building shall be considered a maximum allowable quantity. Two cylinders, each containing 150 pounds or less in a single control area, shall be considered a maximum allowable quantity provided the building is equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1.

[e]Allowed only when stored in approved exhausted gas cabinets or exhausted enclosures as specified in the International Fire Code.

[f]Quantities in parentheses ( ) indicate quantity units at the head of each column.

the Centers for Disease Control and Prevention (CDC) rules on pathogenic agent classifications, among others. The current IBC (2012) lists these categories adapted in Table 1-11. The control area principle for health hazards is the same as that for physical hazards defined above. In addition, the NIH /CDC (42CFR Part 73, 2012) and the U.S. Department of Agriculture (USDA; 9CFR Part 121, 22012) generate lists of Select Agents (SA). The Department of Homeland Security (DHS) publishes the list of Chemicals of Interest (COI) (6CFR Part 27, Appendix A, 2012) and enforces regulations on both SAs and COIs, that may affect the design with respect to allowable quantities and classifications. However, the greatest impact of SA and COI designations are operational and regulatory considerations. Ideally, these health-hazard categories of materials are identified during the programming or planning phases to ensure that suitable layout, construction materials, ventilation, safety ventilation devices, and safety equipment are provided in the budget, as well as in the design of these laboratories.

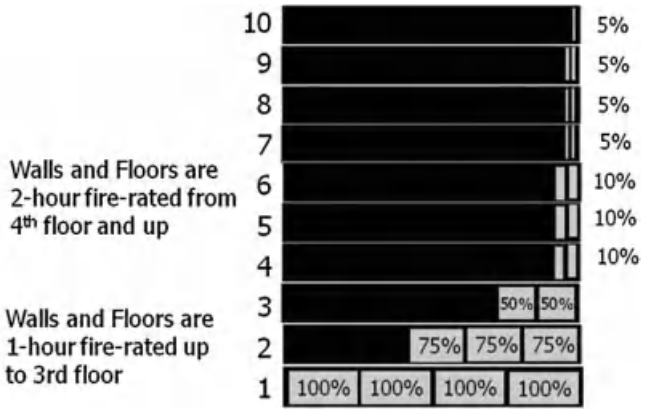


FIGURE 1-15. Section diagram of a 10-story laboratory building by floor—showing the number of fire control areas and percentage limits on chemical inventory.

1.2.5 Distribution of Mechanical Equipment and Services

Mechanical engineers, in consultation with the architects and project engineer, design the distribution of ventilation air, mechanical equipment, piped utilities, and electrical power. Plans for recommended laboratory layout options and distribution of services are presented in Figures 1-16 to 1-22. These layouts are categorized by the location at each module of the vertical shafts that contain risers of electric conduit, piped utilities, and ventilation ducts.

Vertical shafts of adequate dimensions, when located centrally or at each module, allow ducts from additional chemical fume hoods and other special exhaust systems to be installed there in the future. The same flexibility is available for piped utilities to each module through horizontal distribution on each floor and from risers located in central vertical shafts. Area needs for vertical shafts range between 1% and 10% of the net usable

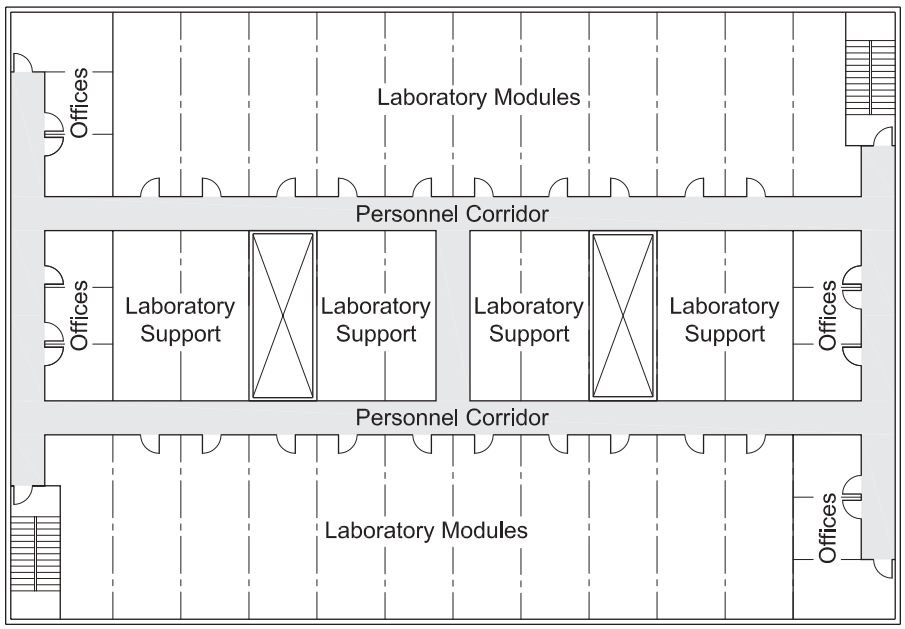


FIGURE 1-16. Mechanical, electrical, and plumbing shafts located in central core zone, building layout.

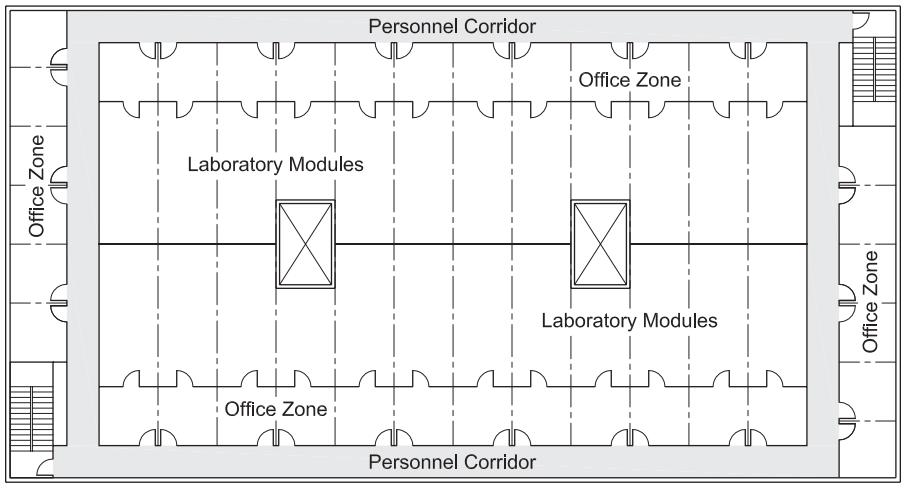


FIGURE 1-17A. Mechanical, electrical, and plumbing shafts located in center, building layout.

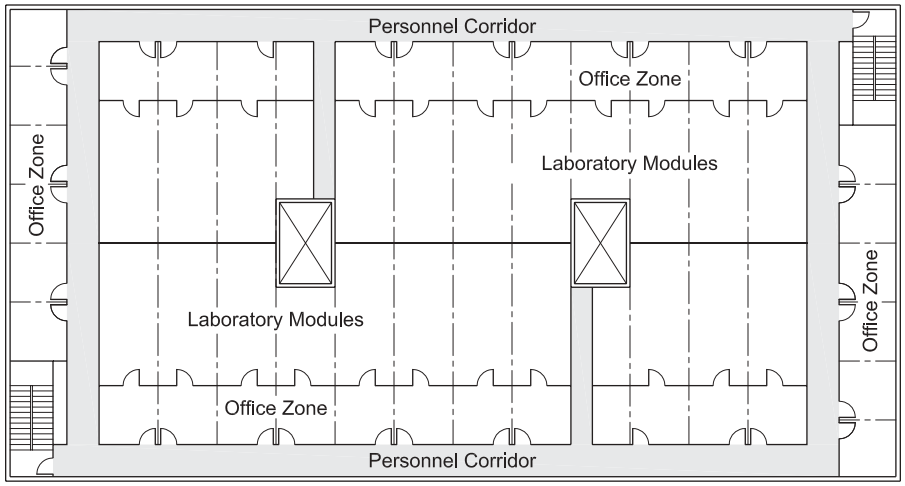


FIGURE 1-17B. Mechanical, electrical, and plumbing shafts located in center with access corridor, building layout.

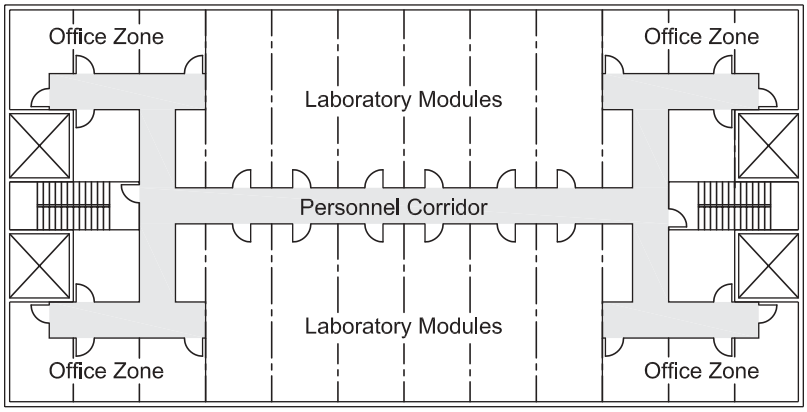


FIGURE 1-18. Mechanical, electrical, and plumbing shafts located at ends, building layout.

FIGURE 1-19A. View of interstitial floor at Fredrick Hutchinson Cancer Center Research Laboratory.

FIGURE 1-20A. View of interstitial space at Bausch and Lomb research building.

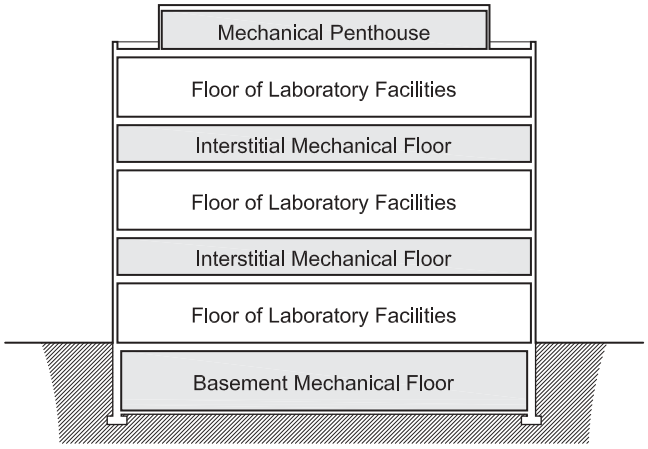


FIGURE 1-19B. Section diagram of laboratory building with interstitial floors.

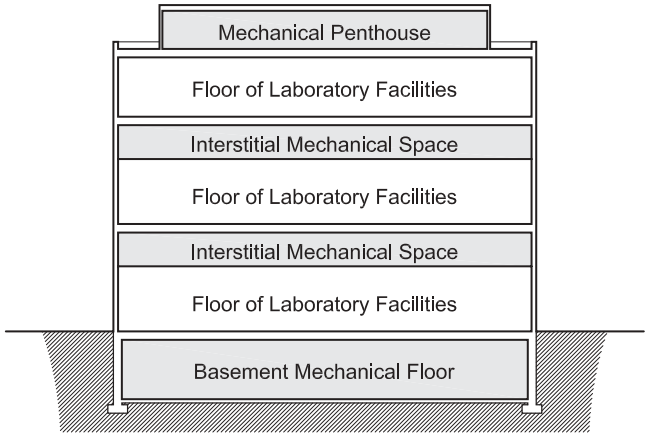


FIGURE 1-20B. Section diagram of a lab building with interstitial spaces between floors.

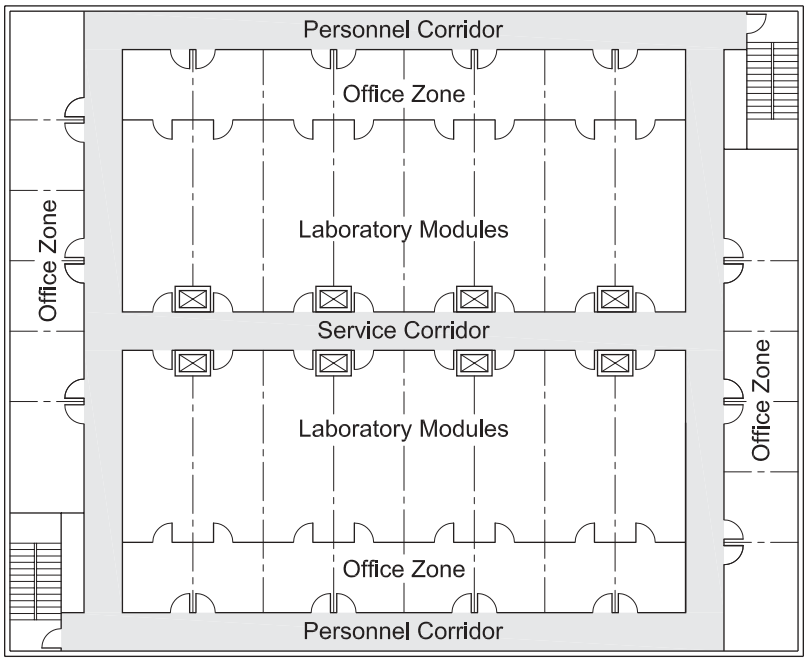


FIGURE 1-21A. Mechanical, electrical, and plumbing shafts located on service corridor, building layout.

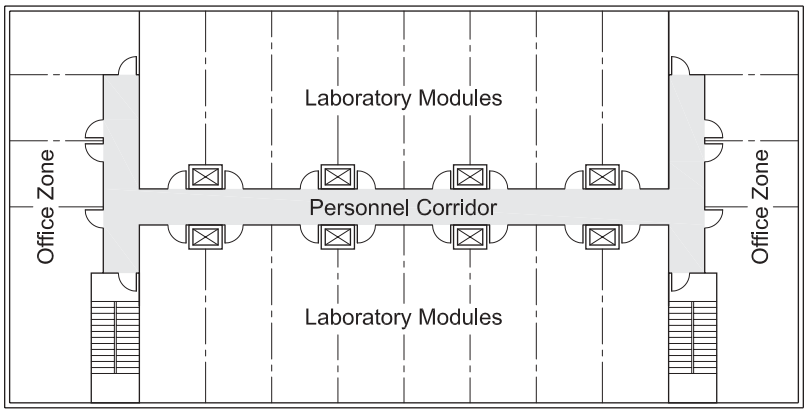


FIGURE 1-21B. Mechanical, electrical, and plumbing shafts located on personnel corridor, building layout.

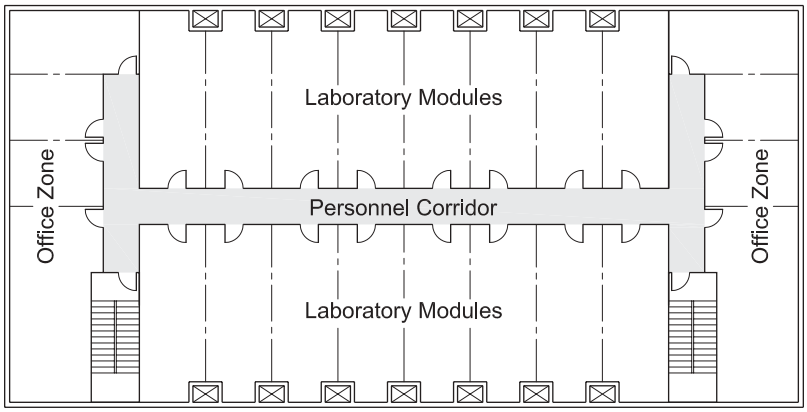


FIGURE 1-22. Mechanical, electrical, and plumbing shafts located on exterior walls of lab modules, building layout.

area on a typical laboratory floor. Engineers can locate large central riser shafts in zones that do not interfere with laboratory layouts, as illustrated in several figures here.

Adequate floor-to-floor height is needed to accommodate horizontal ducts that emerge from central shafts. Horizontal distribution on each floor still requires main exhaust duct risers to extend to the roof to discharge contaminated exhaust air in a zone well above the roof surface. Large central shafts are likely to occupy less total net area than systems designing vertical riser shafts at each module. Older laboratory buildings often do not have adequate floor-to-floor heights to allow horizontal distribution of both ventilation air and piped utilities above major corridor ceilings; Chapter 3, Sections 3.2.2.4 and 3.2.2.5 have additional information.

Laboratory buildings constructed in the 1950s to 1990s were often designed with modular vertical shafts because exhaust manifold systems for chemical fume hoods, and variable air volume (VAV) exhaust valves were not available or regarded as too risky in the laboratory design field. Chapters 33 and 34 provide descriptions of these systems. Vertical continuity from floor to floor and through the entire building to exhaust fans and other energy recovery equipment on the roof is important for both options, central vertical shafts and individual riser shafts. Otherwise, static pressure in ducts increases considerably. Chapter 33 discusses exhaust duct static pressure concepts and practice.

On the other hand, supply air systems for multistory buildings are usually provided from a combination of vertical riser and horizontal duct systems. Supply air is filtered and conditioned at air-handling units that may be located anywhere between the basement and penthouse on the roof. Primary air supply risers are also distributed in central or individual vertical shafts. From there, air is distributed to each space by horizontal ducts. Horizontal supply and exhaust air duct runs require vertical space above ceilings that is unobstructed by structural frame members to maintain comfortable and

functionally adequate ceiling heights. In general, greater ceiling height beneath structural members is required for utilities and systems that require horizontal distribution. Use of interstitial floors, constructed solely for maintenance of utility and air distribution, is the ultimate example of horizontal distribution systems. The building layouts depicted in Figures 1-16 through 1-22 are discussed below.

1.2.5.1 Central Utility Shafts in Laboratory Service Core. Central utility shaft layout locates shafts within a core area on the laboratory floor (Figure 1-16) in buildings that have internal loop corridor configurations. The center core zone is for special laboratory support, building services, and vertical circulation. An advantage to laboratory building layouts with utility shafts located in a center core is improved building flexibility. These shafts can be made large enough to walk into to install new risers and make repairs, and they are accessible from corridors. Maintenance workers do not need to enter through laboratories. They are suitable for mid- and high-rise laboratory buildings. "High-rise buildings are defined as buildings with occupied floors located more than 75' (22.86 m) above the lowest level of fire department vehicle access" (IBC, 2012). Layout of the core zone can economically allow for specialized support room layouts and mechanical services because rooms in the core are closest to the utility shafts. Utility shafts located in support core areas are effective when chemical fume hoods are in a manifold system, as well as installed with dedicated risers to fans on the roof. With VAV and a fume hood, exhaust manifold systems can achieve some load diversity for supply and exhaust air volumes. Load diversity can permit reductions in duct sizes and commensurate reduction in floor area for central utility shafts. These economies are discussed in Chapters 35 and 38, Energy Conservation and Sustainable Laboratory Design, respectively.

A disadvantage in the layout shown in Figure 1-16 is that long horizontal ducts are required from chemical fume hood locations within labs around the building perimeter. These exhaust ducts then pass into central core shafts above public access corridors. Static pressure gains from length of ducts and bends lead to larger duct sizes.

1.2.5.2 Centralized Utility Shafts. Central utility shafts (Figure 1-17A) have the advantage of producing a relatively low ratio of utility shaft area to net laboratory area, improving overall building efficiency. Chemical fume hoods can be placed adjacent to shafts, or in a linear array at the rear of the laboratories. The layout of all pipes and ducts for a cluster of up to four laboratories accessible from any one of the central utility shafts permits some variation in module length than in other plans. A serious disadvantage is that access to service these shafts occurs within at least one laboratory on every floor, which is undesirable. Finger corridors to shafts, shown in Figure 1-17B, can be planned for access that does not require maintenance workers entering laboratories.

1.2.5.3 Utility Shafts at Ends of Building. End shaft arrangements work very well when supply air and exhaust air are distributed in continuous horizontal runs along both sides of the building illustrated in Figure 1-18. Air volume diminishes as the distance from end shafts increases. Reduction in air volume permits the very efficient layout of ducts. However, if cross-sectional area in ducts remains constant, these ducts provide flexibility for future additions or changes in exhaust devices and supply air volume requirements. Another advantage of end location shafts is that the laboratory floor is continuous, without major shafts interfering with laboratory layouts, adjacencies, or cores. The disadvantage is aesthetic: solid tall volumes of shafts on both building ends reduce the area available for exterior windows. Also, for very long buildings, shafts located at the ends are not as effective as centralized shafts, again due to pressure loss from the distance the ducts have to go.

1.2.5.4 Interstitial Floors. Interstitial floors are structural floors located between occupied laboratory floors: They are used by construction workers and maintenance staff to access mechanical ductwork, plumbing and fire protection pipes, electrical and IT distribution conduit and cables, and controls for all these utility systems. Interstitial floors are the best solution for maximum flexibility in laboratory buildings, which will undergo frequent renovations or modifications. Services can be maintained, modified, removed, and reconfigured without disturbing laboratories above, below, or beside the construction area. According to building codes, interstitial floors require a minimum clear ceiling height of 80 in. (2 m) for safe passage. Figure 1-19A is a photo of an interstitial floor; Figure 1-19B shows a section through an interstitial laboratory building.

All engineering disciplines should design for distribution of services in horizontal zones. For safety in the event of water infiltration or a leak, the lowest zones should be reserved for wet utilities and the highest zones reserved for electrical utilities and information technology (IT) cables.

Disadvantages are noted in Section 1.2.1.2.1, Step 9. Interstitial floors increase the building total gross area by 50% of the actual interstitial floor area. Interstitial floors require the same number of exits and exit pathways as occupied floors. There can be construction cost

premiums associated with interstitial floor laboratory buildings.

Another approach to long-term flexibility in laboratory buildings is designing only interstitial space between laboratory floors. There is no structural floor, but metal frame platforms, sometimes called "catwalks," may be designed and installed for maintenance workers to gain access to limited areas, control systems, and equipment. Interstitial spaces need minimum clear ceiling heights of 80 in. (2 m) for safety, but this dimension may not be required by code. Stairs are required to provide safe egress from catwalks and access platforms. Ladders are only acceptable under certain limited circumstances to access specific equipment. The authority having jurisdiction may require two paths of egress from interstitial space platforms. Figure 1-20A is a photo of an interstitial space with a catwalk. Figure 1-20B is a section showing interstitial spaces between laboratory floors.

1.2.5.5 Individual Utility Shafts Adjacent to Service or Public Corridors. There are advantages and disadvantages to placing individual utility shafts adjacent to service corridors. Section 1.2.3.2 provides a description of service corridors; Figure 1-21A shows possible shaft locations. An important advantage is that chemical fume hoods will be located away from the door and adjacent to vertical utility shafts, favoring short, energy-efficient connections to exhaust risers. Data entry stations, which generally represent the area of lowest potential hazard in the laboratory, can then be placed at the personnel or public access corridor wall, near primary exits.

A major disadvantage of a building layout with perimeter loop corridor and a center service corridor is that laboratories are strictly interior spaces, even if light into laboratories is borrowed from public corridors on exterior walls with large windows. If laboratories are normally operated in darkened conditions, these fully interior laboratories work very well. If not, the quality of the work environment for occupants may be diminished without adequate natural light and views to the outside.

For buildings with central or internal loop corridors, where utility shafts are placed adjacent to public access corridors (Figure 1-21B), maintenance and repairs can be done from the corridor rather than from within laboratories. The second exit from the laboratory is either further along the same corridor, or through another room. In this situation, the second exit can be located away from the primary corridor exit to establish two separate paths to egress. The width of the shaft itself forms an alcove against which the laboratory door can swing outward and yet not project too far into the corridor. An expansive window area on the exterior wall is possible because it can be kept free of most utilities and mechanical services.

The primary disadvantage of locating utility shafts at interior public access corridor walls is that chemical fume hoods, which should be away from the primary egress, will also be distant from risers. Therefore, a run of horizontal duct must be used to connect chemical fume hoods, or other special exhaust devices, to the riser in the shaft. Horizontal ducts from individual chemical fume hoods are more vulnerable to corrosion from acid condensation than vertical ducts. The second disadvantage is the alternative egress route may open into another laboratory or office rather than into a corridor in a separate fire zone, as is possible in the service corridor example as shown in Figure 1-21A. A third disadvantage is that laboratory entries can occupy only the spaces between shafts. This arrangement is common in old laboratory buildings before the Americans with Disabilities Act was passed in 1991. Now, required clearances on both sides of the door latch are wider for wheelchair access. The project design team should configure spaces between individual vertical shafts with sufficient clearances, at a minimum of 5 ft (1.5 m) to meet ADA requirements.

1.2.5.6 Individual Utility Shafts at an Exterior Wall. When vertical utility shafts are located at exterior walls, chemical fume hoods can be located adjacent to shafts at the rear of the laboratory, as shown in Figure 1-22. This arrangement provides a threefold advantage: (1) There are very short horizontal runs for the duct connections to individual exhaust risers in the shaft; (2) chemical fume hoods are away from primary exits; and (3) data entry stations can be arranged at the corridor wall away from potential hazards.

Maintenance inside utility shafts must be done inside laboratories, which presents a distinct safety disadvantage for maintenance workers, as well as a major disruption to laboratory workers. Welding, as well as other repair activities that pose increased fire risks in a laboratory environment, should be scheduled when the laboratories are not occupied. A fire watch should always be maintained during welding activities in occupied laboratory buildings. Another disadvantage is that the second exit from such laboratories is likely to be near the primary exit, and open into the same public corridor. When shafts occupy most of the area of the exterior wall, window area is restricted, allowing in less natural light and views. Sustainable design principles discourage severe limitations on natural light into workplaces.

1.2.6 Structural System

The organization and dimensions of laboratory modules on a typical floor guide structural engineers on spacing

of columns and sheer walls. Module gridlines may predict where dead loads from walls, benches, and equipment occur. Some structural engineers prefer to offset structural grids from module grids to avoid conflicts of major floor beams with drainpipes that can cause structural complications. There are several advantages to shifting the module grid off the structural grid by a short distance, in the range of 8 in. to 16 in. (20–41 cm), according to the structural system selected. Because sink drainpipes drop down through the floor directly beneath sinks, if the sinks are located directly above beams or a column cap, sleeves may have to be installed through these structural members. Vertical shafts for distribution of utilities and mechanical services show where major penetrations in the floor slabs will likely occur. Frequent consultations between the design structural and plumbing engineers for coordination are highly recommended so typical conflicts such as these can be resolved early in the design process. Architects must be advised of these considerations so they locate sinks and equipment drains away from structural members, where possible.

1.2.6.1 Depth of Structural Members Supporting Laboratory Floors. It is desirable to have as much space as possible above finished laboratory building ceilings (or equivalent free space when there is no finished ceiling) to use for installing the ducts, pipes, and electrical services characteristic of current laboratory facilities. Deep, solid beams reduce this unobstructed clearance, and truss-type structural members (such as bar joists) do not improve conditions significantly. During design, there is always competition between structural requirements and the needs of the mechanical trades for the ceiling space above the occupied laboratory work zones. Members of the project design team need to negotiate and strike a reasonable balance between the requirements of efficiency and economy for all construction components. In these decisions, however, project design teams must keep in mind that mechanical and electrical systems consume 30–60% of the total laboratory construction cost. Structural systems account for 10–13% of total construction cost. Ample floor-to-floor heights simplify mechanical system installation, reduce costs, and allow greater opportunities for the economies of horizontal utility distribution and future flexibility. These are compelling reasons.

1.2.6.2 Heavy Live Loads. In Section 1.2.1.2.1, Step 6, data was collected on equipment identified through an equipment inventory or the building programming process, and the spaces that pose structural or construction difficulties from heavy live loads can be determined from that data. For instance, special design and construction will be required in areas that contain equipment that is unusually heavy, or that is either sensitive to vibration or produces significant vibrations. Scientific areas or specific equipment that must be isolated from the building structure and the heavily loaded structure will have to be designed differently from areas with typical laboratory floor loads. Consideration must be given to how heavy equipment will get into the building, how it will be moved to its final location, and installed. What building areas will the extremely heavy equipment move through? Structural damage, or even failure, may occur in areas not designed for such heavy loads, even if the loading is of short duration. Heavy loads are commonly posed by radiation source equipment shielded with lead, and by large filtration tanks for central water purification systems.

1.2.6.3 Vibration Isolation Considerations. Some laboratories, such as those used for microelectronics, optical physics, surgery, neuroscience research, and electron and other high resolution microscopy suites, have very stringent requirements for structural stability and isolation from sources of building vibration. Greater than usual structural mass and stiffness, combined with building foundation stability, can contribute to reductions in structure-borne vibrations that are generated within and outside laboratory buildings by traffic, trains, and equipment. On the other hand, reduction of effects from vibration-generating factors such as airborne noise produced by high-velocity air currents within a room and within ducts, turbulent fluid flow in piping, and vibrations caused by people walking and carts moving along building corridors adjacent to sensitive areas can be handled by active vibration suppression measures and special vibration dampening and/or mounting devices.

Good site location and thoughtful building layout, particularly regarding mechanical rooms, elevators, and utility distribution pathways, can help to reduce vibration in laboratories highly sensitive to vibration. Attention to construction details of machine, duct, and pipe mountings, as well as use of local vibration-isolating devices and structurally independent platforms at sensitive equipment locations, are able to reduce effects of building vibration. Acoustical and structural engineers who are specialists in structural dynamics can analyze potential trouble spots on the site and in the laboratory building; they can establish design criteria for vibration control appropriate for the instruments and processes proposed for the building. The unit of measure commonly used for laboratory buildings by acoustical engineers is velocity in micro-inches per second (μin./s). Instruments that measure noise in decibel units (dB)

and only in the audible range of humans do not provide adequate data to design structural systems. Acoustical experts can assist building designers develop strategies to reduce internally generated noise and vibration. In some laboratories and laboratory support areas, such as machine shops or glass-washing rooms, where excessive noise levels may generate a concern for health and safety, acoustical engineers should be consulted during the design phase to devise building construction methods that will isolate or reduce noise at the source.

1.2.7 Site Regulations

A new laboratory facility will be within the boundaries of one or more municipal, regional, and national jurisdictions. Each of these governing units enacts regulations governing land use and construction methods within its boundaries that will affect construction and site location of the proposed facility. Local zoning ordinances, for example, often contain criteria for the following planning concerns: fire district regulations, building use classification, building height restrictions, allowable floor area-to-site area ratio (site coverage), clearance and easements within and around site boundaries, number of parking spaces required on the site, and guidelines on the connection and use of utilities such as sewer and water. Some state regulatory and municipal agencies require permits to exhaust contaminated air from laboratory exhaust ventilation systems. Other jurisdictions having authority inspect, regulate, and issue permits for sewer discharge from laboratory buildings. When buildings are equipped with automatic sprinklers, most local zoning and building codes are less restrictive on allowable building height and total floor area. We recommend that laboratory buildings be equipped with sprinklers throughout, as discussed in Section 1.4.

Approvals by local governing boards and regulatory agencies having jurisdiction are generally required before construction can begin. Therefore, a thorough search of all applicable codes, regulations, and ordinances early in the planning phase is prudent. Early preliminary plan reviews with agencies that issue critical permits are advised because these discussions allow the owner and the project design team to anticipate problems and make adjustments to comply with local building officials' interpretation of the codes, or to appeal the building official's ruling. In addition to site requirements by jurisdictions having authority, there are many sustainable design considerations to be evaluated in developing sites for future laboratory buildings. Information on and discussion of sustainability issues and guidelines are provided in Chapter 38, Sustainable Laboratory Design.

1.2.8 Building Enclosure

The final factor that influences laboratory building layout is the building enclosure. The enclosure should provide the total building area required, comply with the building program, and meet zoning requirements. The volumetric and geometric characteristics of the structure include perimeter shape, number of floors, total building height, site coverage, and orientation to sun and prevailing winds. The concepts for sustainable design (Chapter 38) have great impact on the design of exterior building enclosures.

For renovations, building enclosure, total building area, and the structural system are known and portions of these existing systems typically are relatively fixed. Therefore, the assignment of functions to various existing spaces and proposed modifications to those spaces are conducted in a manner that will fulfill the building program goals in the most effective way. In renovation and building conversion to laboratory use, there is generally less design flexibility than in new construction. This subject is reviewed in Chapters 3 and 4 on laboratory building renovation.

1.3 GUIDING PRINCIPLES FOR BUILDING HEATING, VENTILATING, AND AIR-CONDITIONING SYSTEMS

Laboratory building ventilation is needed to provide an environment that is safe and comfortable. It is accomplished by providing controlled amounts of supply and exhaust air plus provisions for temperature, humidity, and air velocity control. Good laboratory local exhaust ventilation captures toxic contaminants at the source and transports them out of the building by means of ductwork, a fan, and sometimes an air cleaner, in a manner that will not contaminate other areas of the building by recirculation from discharge points to clean air inlets or by creating sufficient negative pressure inside the building to subject inactive hoods to downdrafts. The building supply ventilation system may provide all of the replacement air needed for local exhaust air systems in addition to taking care of all comfort requirements, or there may be a separate supply system for each function. Chapter 29, HVAC Systems, contains information on HVAC system design.

1.3.1 Laboratory and Building Pressure Relationships

Laboratory safety requires a careful balance between exhaust and supply air volumes as well as concern for the quantity of each. Even within the same laboratory type, requirements can vary depending on the hazard

rating of the materials being used, the quantity of hazardous materials that will be handled, and the nature of the laboratory operations. Communication with laboratory users at an early stage in planning will help to identify and locate sites of known and potential hazards, making it possible to provide adequate facilities to meet additional needs.

Ventilation systems for laboratories can be divided into three main categories based on function.

1. *Comfort ventilation* is provided to the laboratory by a combination of supply and return airflows through ceiling and wall grilles and diffusers. The main purpose is to provide a work environment within specified temperature, air exchange, and humidity ranges. Part or all of the comfort ventilation may be provided by special systems such as fume hoods, installed for health and safety purposes.
2. *Supply air systems* provide the required replacement or makeup air removed by the health and safety local exhaust ventilation systems. Comfort ventilation air may be supplied by one system and replacement air for health and safety exhaust systems by another, or the two supply systems may be combined.
3. *Health and safety exhaust ventilation systems* remove contaminants (that cause adverse health effects, fire, or explosion or are merely a nuisance) from the work environment through specially designed hoods and duct openings.

Components of a ventilation system include fans, ducts, air cleaners, inlet and outlet grilles, sensors, and controllers. Automatic fire dampers are usually required in supply air ducts when the ducts pass through fire barriers and are advisable in any case when work with large quantities of flammables is contemplated.

1.3.2 Dedicated and Branched Air Systems

Building supply air may be provided through a central system that serves all areas, for example, offices, storage areas, and public areas as well as all laboratories. Alternatively, there may be separate systems dedicated exclusively to laboratory use. Comfort air exhaust systems (more commonly known as general exhaust systems) that serve both laboratory and nonlaboratory spaces may be, and commonly are, combined. The potential for recirculating contaminated air, particularly after a spill or accidental release, may make recirculating comfort exhaust air from laboratory spaces less attractive. However, recirculation is permissible and commonly done as long as certain conditions are met. See Chapter 2, Section 2.3 and ANSI Z9.5 (2012) and Z9.7 (2007) for more details.

Although individual dedicated exhaust ducts and fans were previously recommended for each major local exhaust hood, manifold systems that combine exhaust ducts from several hoods are more commonly used to reduce the number of small stacks on the roof or to reduce shaft space for mechanical services. Manifold systems can be considered for a renovation project where individual dedicated exhaust ducts and fans are already used only if a sound duct system of adequate capacity is already in place. The advantages and disadvantages of using manifolded exhaust duct systems versus single hood exhaust systems depend on numerous factors.

The advantages of a manifold system are

1. Lower initial cost because the number of ducts, fans, and stacks will be fewer.
2. Better atmospheric dispersion of the exhaust plume because of the enhanced momentum effect of a larger air mass exiting from the stack.
3. Less maintenance required for fewer installations.
4. Reduced duct shaft space needs within the building
5. Dilution of toxic or flammable air contaminants in exhaust streams
6. Ability to apply diversity factor. Diversity is described in more detail in Chapter 2, Section 2.3.4.6.
7. Potential for installing a redundant fan is increased.
8. Potential for installing emergency power to the fan is increased.
9. Potential for installing additional fan capacity is increased.
10. Potential for efficiently installing and utilizing VAV controls is increased.
11. Number of roof penetrations is reduced.
12. Operating costs will likely be lower.
13. Potential for locating the stack to blend in architecturally with the building is increased.
14. General exhaust can also be connected to the manifold system to allow for dilution and energy recovery.

The disadvantages of a manifold system are

1. Different exhaust streams may not be compatible. Generally, this is not a problem for common laboratory operations when the quantity of contaminants

is low and the dilution volumes in the system are high.
2. The need to add a booster fan for each individual branch that requires addition of an air-cleaning device (e.g., hoods used for radioactive isotopes) when the manifold system as a whole does not.
3. Branch ducts require careful air balancing and a control mechanism to maintain design air flow distribution (see Chapters 29, 34, and 35).
4. Inability to shut off individual components without the addition of sophisticated control systems that automatically rebalance supply and exhaust volumes for each laboratory connected to a single multihood exhaust system.
5. Fan failure affects all hoods in the system unless there is a back-up fan.
6. System controls (static pressure, capacity) are more complex.
7. Difficult to apply in renovation projects in existing buildings. See Chapter 3, Section 3.3.
8. Some hoods, such as perchloric acid and radiation hoods, are not recommended in manifold systems because of their specific requirements.

Before selecting a manifold system, the above advantages and disadvantages should be carefully considered for the specific applications. If a manifold system is to be used, the following requirements should be included in the design.

1. Easy access to a straight duct run in each branch to allow for air flow measurements
2. A monitor at each exhaust point to indicate correct flow
3. Easy access to all control valves for inspection and repair
4. Adequate exhaust capacity for each space served
5. Maintenance of desired directional airflow requirements for each type laboratory at all times required by laboratory type (see Part II, Chapters 5–28)
6. Negative pressure throughout manifold plenums should be reasonably uniform to maintain design airflow from branch ducts
7. A standby or cross-connected exhaust fan that can be put into service rapidly in the event of a fan failure. Alternative methods to maintain manifold suction may satisfy this requirement.
8. Emergency power to the exhaust fans
9. Training for maintenance personnel and laboratory users in the proper use, inspection, and care of manifold systems. This criterion is often overlooked and is very critical.

1.3.3 Constant Volume and Variable Air Systems

It is advisable, in all cases, to maintain constant pressure relationships between laboratory rooms (greatest negative pressure), anterooms, corridors, and offices (least negative pressure) to avoid intrusion of laboratory air into other areas of the building. The pressure cascade (step down of pressure from one level to another) will provide airflow in the desired directions. This becomes particularly important in the event of an accidental release of a volatile chemical in a laboratory. For laboratories in which hazardous chemicals and biological agents are used, pressure gradients that decrease (lower negative pressure) from areas of high hazard to areas open to public access are an essential part of the building's health and safety protective system. Even in laboratories where hazardous materials are not usually employed, animal holding rooms, animal laboratories, autopsy rooms, media preparation rooms, pathology laboratories, and similar facilities are likely to generate unpleasant odors. Graded air-pressure relationships are usually relied on to prevent release of foul-smelling air from these rooms. The reverse-pressure relationship is required for germ-free and dust-free facilities such as operating room and white room (cleanroom) laboratories. Pressure relationships are created by controlling the relative quantities of supply and exhaust air to each space. See ANSI standard Z9.5 (2012) for a more detailed discussion.

As a rule, in rooms and spaces requiring only comfort ventilation, the pressure relationships relative to the laboratory spaces are intended to be maintained constantly; this calls for invariant airflows. This does not apply to the relatively short period when opening doors to enter or exit unless required by the specific laboratory type. Health and safety ventilation systems may also be designed for continuous, invariant service. Such an arrangement is advantageous when the number of exhaust-ventilated health and safety facilities is small and when the health and safety air-supply systems have been combined with the comfort system. However, when health and safety exhaust ventilation represents the major proportion of the total air circulation requirements for the entire building, energy conservation measures call for an ability to shut down these services when they are not needed. To be effective, there must be two separate supply and exhaust air systems: (1) a comfort ventilation system that provides constant and invariant design temperature, humidity, air exchange, and room pressure conditions; and (2) one or more tempered replacement modulating air-supply ventilation system that is individually coupled to specific exhaust air devices so that both may be turned on and off simultaneously to avoid disturbing the room pressure relation-

ships established by the comfort ventilation system. For a more thorough discussion on variable air-volume systems design, controls, and components, refer to Chapter 35. It is sometimes advantageous to provide a constant-volume system to some parts of a laboratory building and variable systems to others. The nature of the installed facilities and the intensity of laboratory usage will determine the advisability of hybrid ventilation systems.

1.3.4 Supply Ventilation for Building Heating, Ventilation, and Air-Conditioning Systems

1.3.4.1 Supply Air Volume. All air exhausted from laboratories must be replaced with supply or infiltration air. An equivalent volume of replacement or makeup air is essential to provide the necessary number of air changes needed to facilitate comfortable and safe working conditions and to maintain design pressure relationships between rooms and other spaces for health and safety protection. Overall building air pressure must be maintained positive to atmospheric pressure to reduce the rate of outside air filtration. Low internal building pressure can cause excess outside air filtration. This imbalance draws water and contaminants into the building and hastens deterioration of joint seals in the building envelope.

When laboratory health and safety exhaust ventilation requirements are not dominant, total building air-conditioning needs for maintaining heating, cooling, and ventilation loads may dictate the supply air volume to each room. Total supply air volume cannot be calculated until the amount of air to be exhausted has been determined.

A variable air-volume supply system will meet the needs of the space by reducing or increasing air quantities caused by changing space conditions and orientation. Interior spaces and those facing north will require reduced air flow, whereas those facing south, east and west will require increased air flow to meet the requirements for air-conditioning.

1.3.4.2 Supply Air Velocity, Temperature, and Discharge Location. The location and construction of room air outlets and the temperature of the air supplied are critical. High-velocity air outlets create excessive turbulence that can disrupt exhaust system performance at a hood face. In addition, comfort considerations make it necessary to reduce drafts. Therefore, the supply air grilles should be designed and located so that the air velocity at the occupant's level does not exceed 50 fpm (0.25 m/s). There is no single preferred method for the delivery of replacement air; each building or laboratory must be analyzed separately. For a more detailed discussion of location of supply air grilles, see Chapter 2.3.2.1.1, Memarzedah (1996), and the NIH design guidelines (NIH, 2011).

1.3.4.3 Air Intakes. Outside air intakes must be located so as to avoid bringing contaminated air into the building air-supply systems. Examination of likely contaminant sources, such as air exhaust stacks, should be conducted before outside air intakes are selected. The ANSI Z9.5 (2012) standard on laboratory ventilation recommends that a risk assessment of exhaust discharge location in relation to the air intake be conducted. For details, see Section 1.3.5. Experience indicates a minimum distance of 30 ft (9 m) from air-discharge openings to air intakes is recommended to reduce vapor, gas, or fume reentry problems, but it is good practice to design for the maximum feasible separation. Outside air intakes located at ground level are subject to contamination from automobile and truck fumes, whereas air intakes at roof level are subject to contamination from laboratory exhaust stacks or high stacks serving off-site facilities in the vicinity. When a building contains more than 10 stories, it is advisable to locate the air intakes at the midpoint of the building. Difficult sites such as those surrounded by elevated topography or higher buildings may require wind tunnel tests to investigate the vapor, gas, or fume reentry problem under simulated conditions. Computer-modeling programs are also available to assist in stack-discharge design and air-intake location. It is recommended that this type of study be done for all new buildings constructed as well as those undergoing major renovations.

1.3.5 Air Discharges

For all laboratory hoods, the stack on the positive side of the exhaust fan should extend at least 10 ft above the roof parapet and other prominent roof structures to minimize exposure of a worker on the roof. A minimum height of 10 ft does not guarantee that harmful contaminants will not reenter the building via the air intake.

To further assist the exhaust air to escape the roof boundary layer, the exhaust velocity should be at least 2000 fpm; there should be no weather cap or other obstructions to prevent the exhaust discharge from rising straight upward, see Figure 2-18). When selecting a laboratory stack design, consult Chapter 41 of the *2011 ASHRAE Application Handbook* (the American Society of Heating, Refrigeration, and Air-Conditioning Engineers [ASHRAE], 2011. It provides an excellent resource. Another excellent resource is Appendix 3 of ANSI standard Z9.5 (2012), which outlines a quick method for selecting laboratory exhaust system design and is reproduced in Appendix F.

1.3.5.1 Exhaust Fans. All exhaust fans should be installed on the building roof to maintain the exhaust ducts inside the building under negative pressure as a health protection measure. This arrangement makes certain that should duct leakage occur, it will be inward. In rare cases where exhaust air ductwork operates at positive pressure relative to the building interior, special care must be exercised by frequent pressure testing with the use of a tracer gas to ensure that the ductwork is airtight. Many types of exhaust fans are manufactured, but only a few meet all the requirements of a good exhaust ventilation system. Double-belted centrifugal utility-type exhaust fans are generally preferred because they are very reliable, have desirable pressure-volume characteristics, are widely available, and are easily adaptable to roof mounting and the attachment of a stack of suitable cross section and height for proper discharge of exhaust air. For critical exhaust air systems, a direct-connected fan and motor avoid failure from slackening or loss of fan drive belts. Such an installation can be further simplified by selecting a weatherproof motor and eliminating the motor and drive housing. The materials of construction for the fan, including protective coatings, should be selected to withstand corrosive and erosive conditions characteristic of the exhaust gases and aerosols that will be handled. Considerations of life expectancy and maintenance availability will influence the final selection. It is important to specify fans manufactured and rated in accordance with standards established by the Air Movement and Control Association (AMCA).

A variable air-volume exhaust fan is a necessary adjunct to a VAV supply system. It will conceptually be the catalyst that produces the signal to the supply fan that more or less air is required to maintain space-pressure relations or when a chemical fume hood is turned on or off, producing a signal of a change of status. The fan control is commonly maintained by using a static pressure controller to maintain a constant static pressure in the duct system(s). Variable air-volume systems and controls are discussed in Chapter 32, Laboratory Hoods and Other Exhaust Air Contaminant-Capture Facilities and Equipment.

Fans with backwardly inclined impellors with self-limiting horsepower characteristics have been used widely for general building ventilation purposes. Fan housings are usually constructed of steel and bonderized. When used for exhaust air contaminated with low concentrations of corrosive elements, the impellor and the interior of the fan and connecting ducts are often coated with baked primers and finishes especially formulated to meet corrosion resistance standards. For severe corrosive service, especially when high humidity is also present, rigid polyvinyl chloride (PVC) or fiberglass-reinforced polyester (FRP) construction is essential. FRP is preferred because of its superior resistance to breakage and vibration cracking. It is necessary to add fire-retardant chemicals to the polyester resin. When exhaust fans are located on the roof and discharges straight upward without a rain cap, a drain connection should be placed at the bottom of the fan housing. (See Section 2.3.5.3 for additional design information.)

1.3.6 Supply Air Cleaning

All building supply air, including all portions of recirculated comfort air, should be cleaned according to the requirements of the space. The correct degree of filtration is important because excessive filtration results in a greater pressure drop through the system, thereby increasing operating costs, whereas insufficient filtration results in contamination of critical work areas or excessive maintenance costs from rapid soiling.

Many filter media are available, each providing a specified degree of air cleanliness. The choice depends on the need. Filters are classified in the *HVAC Systems and Equipment Handbook* from ASHRAE (2012, Chapter 28) as throwaway or renewable. Throwaway filters are used once and discarded. They are rated as low efficiency (35% dust removal), medium efficiency (85% dust removal), or high efficiency (95% dust removal). The performance characteristics of a number of throwaway dry media filters used for air cleaning are shown in Chapter 30, Fans. Renewable filters are seldom used for building air cleaning. Electrostatic precipitators are also used for cleaning building supply air. They are designed for 85% or 95% atmospheric dust collection efficiency. Electrostatic precipitators are always made as cleanable units, the interval between cleaning being more or less than 3 months depending on the dirtiness of the outside air. Cleaning involves washing the dust-collecting plates with detergent and water. Units may be purchased for manual or mechanical cleaning. Electrostatic precipitators generate small amounts of ozone during normal operation, and their use is counter-indicated where this gaseous compound would be considered an interference with the work to be undertaken in the new laboratories. Should this be the case, it would also be necessary to remove the same compound from the air introduced into the building because ozone regularly occurs in outdoor air in most parts of the United States. Ozone, sulfur dioxide, and most hydrocarbons that are normally present in urban air can be removed from ventilation air by passing it through gas-adsorption activated carbon beds after particle filtration or after treatment by electrostatic precipitators.

Cleaning of recycled comfort ventilation air before discharge to the atmosphere is seldom, if ever attempted, nor is it necessary. This is not always true for health and safety system exhaust air. Filtration, liquid scrubbing, and gas adsorption may be needed to prevent the emission of toxic, infectious, and malodorous gases and aerosols to the atmosphere. Exhaust air cleaning is discussed in Section 2.3.5.3 and Chapter 31, Air Cleaning.

1.3.7 Supply and Exhaust Ducts

All ductwork should be fabricated and installed in accordance with Sheet Metal and Air-Conditioning Contractors' National Association's standards (SMACNA, 2010). Ducts should be straight, be smooth inside, and have neatly finished joints. All ducts must be securely anchored to the building structure. The usual material for supply and exhaust ducts in comfort ventilation systems is galvanized steel. More corrosion-resistant materials, such as stainless steel, FRP, and PVC, are frequently used for health and safety system exhaust ducts. See Chapter 33, Table 33-1 for information on the chemical resistance of materials used for exhaust ducts and plenums. It should be noted that the NFPA standard requires a building to have sprinklers where PVC duct is used for exhaust ducting (NFPA 45, 2011).

It is essential that all ducts be constructed and installed in a leak-tight manner if the system is to function as the designer intended it to. This is especially important for exhaust ventilation ducts, which usually operated under far higher negative pressures than do comfort ventilation systems; hence, the leakage through even small gaps in longitudinal seams and joints leads to a significant drop in system efficiency. The seams and joints of stainless steel ducts are usually welded airtight. Plastic pipes are constructed without longitudinal seams, and the joints are sealed with plastic cements of appropriate composition. Inorganic sealants should be used for some hoods such as perchloric acid hoods. It is easier to construct airtight systems with round ducts than rectangular ducts. Rectangular ducts should be avoided at any cost in the health and safety exhaust air systems because they cannot be made airtight by any practical method. For noncorrosive material-containing systems, seams and joints may be sealed with long-lasting ventilation duct tape. Whatever method is selected, it is essential that ducts be made leak-tight if they are to give satisfactory service.

Ideally in a constant-volume ventilation system engineering and installation can be accomplished to ensure appropriate air supply and exhaust from laboratories without use of any "trimming dampers" in all duct runs. In reality, these dampers are frequently used. The designers routinely provide capacity for growth or changes in use and the air quality is adjusted to meet design requirements. The "trimming dampers" also known as balancing dampers are sometimes a necessity but should be avoided whenever possible. In a variable volume system where per design requirements the volume needs to modulate, special terminal boxes are provided. More details are provided in Chapter 29, HVAC Systems.

Ducts are excellent conductors of sound. Care must be expended to secure them so as to avoid vibration and the propagation of noise. In addition, they should be isolated from fans and other noise-generating equipment with the use of vibration-reducing connections and the installation of acoustical traps in the ducts between noise and vibration sources and the point of discharge to occupied areas.

1.3.8 HVAC Control Systems

Controllers are essential to ensure that all HVAC systems in a laboratory building will operate in a safe and economical manner. Control systems are needed for temperature, humidity, air exchange, and pressure regulation.

Control systems can be electric, computer-based, or pneumatic. Pneumatic systems are operated by high pressure. The source of the air should be different from that of the laboratory air because the loss of control air can have a significant effect on building systems. Variable air volume systems require unique control systems such as static pressure controllers, inlet vane dampers on centrifugal fans, feather blades on vane axial fans, variable speed drives, and solid-state rectifiers. Variable air-volume systems and controls are discussed in Chapter 34.

1.3.8.1 Temperature Control. The temperature in most laboratory buildings does not require close regulation—that is, no better than ±3°F (±1.75°C). Worker efficiency and productivity may be affected adversely when ambient temperature control permits temperatures to exceed 85°F (30°C) in summer or to fall below 60° F (16°C) in winter.

The comfort range is determined by combining dry bulb temperature, relative humidity (RH), and air velocity to derive a value called *effective temperature* (ASHRAE, 2009). An effective temperature of 77°F (25°C) is considered to be a very desirable condition. This is achieved in winter by 68°F (20°C) with 35% RH (65%), and in summer by 78°F (26°C) with 50% RH (65%). More information on comfort indexes and comfort standards is given in Chapter 29.

1.3.8.2 Humidity Control. Although close humidity control is not required in most laboratory buildings,

some degree of humidity control should be included to provide comfort and avoid extremes. Some laboratories such as animal facilities and microelectronic laboratories have specific, tight humidity requirements. Refer to the type of laboratory in Part II. Chapter 29 should be consulted for additional details on humidification systems.

1.3.9 Air Exchange Rates

Recommended air exchange rates for comfort ventilation for public areas and for commercial and industrial workplaces are contained in the ANSI/ASHRAE ventilation Standard 62 (ANSI/ASHRAE, 2010). In most organized communities, the applicable building code will prescribe minimum ventilation rates for indoor air quality for a variety of building users. They are the lowest air exhaust rates that must be maintained in each occupied room, even when the health and safety exhaust ventilation systems are turned off. See Chapter 2, Section 2.3.4.1 for a discussion of air exchange rates required in laboratories.

In crowded areas where smoking is permitted, the minimum air exchange rates required by the building codes will be inadequate to please a high percentage of nonsmokers; in addition, outside air rates of 30–60 CFM per active smoker will be needed to keep tobacco smoke concentrations close to background levels (ANSI/ASHRAE 62-1, Ventilation for Acceptable Air Quality; ASHRAE, (2010).

1.3.10 Fan Rooms (Equipment Rooms, Mechanical Rooms)

Because of the nature of the work that is required to maintain the equipment within the fan room, the design of the room is important from the standpoint of ensuring the owner of delivering a complete system that performs as designed and that will continue to perform during the life of the building. All too often, the space provided for a fan room is too small to accommodate the equipment that is required to provide the services to the building. Nevertheless, the mechanical contractor viewing the mechanical drawings installs the equipment that is required to provide the building services. The equipment is usually installed double-tiered or in a fashion that makes it easiest for the sheet metal contractor because ducts are in locations that dictate the fan location. The piping contractor, not having the necessary room, installs the piping in the easiest manner. The control contractor, being the last in, and of course having the smallest pipe, can install equipment and piping with ease. Often these contractors are not concerned with the need to maintain the equipment, to make it accessible for changing a motor, bearings, filters, and all other maintenance that may be required over its useful life. It is extremely difficult when you open the door and find the following situation: There is no space; it is difficult to stand up in many locations, or identify the equipment because it is not visible. Sometimes, it is almost impossible to get to it.

The layout of the fan room should be considered as important as the rest of the building, with input from those responsible for maintaining the building. Easy access to all equipment and controls are required.

1.3.11 Glass-Washing Rooms

Glass-washing rooms are a part of a laboratory facility for a department or several departments all using the same facility in a laboratory building to perform the necessary washing and sanitizing of glassware used in research.

The glass-washing facility requires large amounts of hot water, which is usually generated in the facility or remotely located close to the facility because of intermittent use. Most laboratories require that the glassware be washed, sterilized, and ready for use the following morning, or the washing and sterilization is done early in the morning so that the glassware is ready for use in experiments that day.

The normal procedure is to wash the glassware in hot water and provide either distilled or purified water for the final rinse to provide exceptionally clean glassware and remove all traces of residue from previous experiments. This requires exceptionally large amounts of thermostat-controlled hot water, and the method of heating is usually steam. It also requires an adequate source of pure water that is used as the final rinse.

Adequately sized drain piping should be provided to remove the volume of water that is discharged to drain, usually by a butterfly valve that is normally a part of the glassware washer.

Because of the high heat load in the glass-washing area, the need for cool air is required year round so that those involved in this practice can perform their work in relative comfort. Autoclave rooms are also in this category, and the comfort of the operators should be considered.

Cage-washing areas also require large amounts of hot water delivered over short periods; therefore, equipment sizing is critical to ensure capacity is available when needed. Linear trench drains are often installed at exit doors of rack washers to capture drips from clean cage racks as they are removed from washers. Other very large floor drains are needed in all areas of cage-wash facilities.

1.3.12 Commissioning

Commissioning is a term used for final acceptance of mechanical/electrical systems in the building. The process is fully described in Chapter 36, Project Execution and Bidding Procedures, and Chapter 37, Commissioning.

1.4 GUIDING CONCEPTS FOR LABORATORY BUILDING LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

It is the purpose of this book to help design laboratory buildings that provide work space and buildings that are free from the risk of accidental injury or loss to its users and visitors, the building or equipment and materials contained therein, and to preserve and protect the environment. This section provides important information, sometimes overlooked, regarding 10 building and material safety systems that are not discussed elsewhere in the book, but relate to the accomplishment of the book's purpose. Each of these issues will need to be reviewed when planning or designing each laboratory building or any areas within the building in conjunction with any necessary risk analysis. Where the risk is deemed higher than acceptable, implementation of the concept will become mandatory to eliminate the risk. The use of health and safety professionals to provide help in such decisions is advised.

1.4.1 Emergency Electrical Considerations

The primary electric feed to laboratory buildings should be as reliable as possible. For example, separate and distinct feeds connected to a common bus and then to two separate transformers with network protectors should be installed, and each transformer should be large enough to carry the building load so that the loss of any one line will not interrupt building power. When such practice is not possible, some other fail-safe electrical connection designs should be used. Even with this type of reliable service, it is often necessary to provide emergency electrical power because any of the primary electrical service components (transformers, main feeders, etc.) may fail and then emergency power will be required. Each building should have its own emergency power source that is adequate for all egress lighting and other life-safety requirements, as defined in the National Electrical Code (NFPA 70, 2011), and if adopted by the jurisdiction having authority, Safety to Life from Fire in Buildings and Structures (NFPA 101, 2012). Several critical systems in laboratories may have to be connected to emergency electrical power for continuity of operation as well as for safety concerns. Items that should be connected to emergency electrical power are the following:

1. Fire alarm systems
2. Emergency communication systems
3. Fire pump, when it is electrically driven and not backed up by another driver
4. Emergency smoke evacuation systems
5. One elevator for buildings over 70 ft in height
6. Egress pathway lighting
7. Emergency lighting in rooms
8. Egress signs that require lighting
9. Exhaust fans connected to critical health and safety exhaust ventilation systems
10. Makeup air systems serving critical exhaust systems
11. Heating systems and controls to prevent the building from freezing during temperature extremes
12. All other systems whose continuing function is necessary for safe operation of the building or facilities during an emergency period

Certain experimental procedures may need to be protected against power failure due to the critical nature of the experimentation, research, or process. Loss of power may result in costly loss of data, experimental animals, materials, and research time. Determination of which procedures qualify for connection to the emergency power is usually an administrative issue. The design team should try to determine through communications with building owners and users what the most likely maximum emergency power electrical load may be.

In general, diesel-driven generators are preferred because they are readily available, easily maintainable, and easy to start (in less than the 10 s mandated by NFPA 70, 2011). Gas turbines are available in smaller sizes and may be satisfactory. However, turbine starting is sometimes difficult for large-size generators.

The emergency generator should be connected to the selected load with a series of transfer switches. The transfer switches should automatically turn over to emergency power when normal power fails. Annunciation through a local or remote panel should be provided to let operators of the building know which transfer switch has changed modes. The generator control board should have an ammeter installed so that operators can see the load on the generator and manually select other loads when necessary.

If emergency electrical power distribution is run throughout the facility, it must be run on a distribution

system that is separate and distinct from the primary electrical distribution system. This is to prevent concurrent cable failure of both primary and emergency power in case of a fire or other emergency condition. Some building codes require construction of separate electrical closets because emergency power distribution panels cannot be in the same closet.

1.4.1.1 Uninterruptible Power Supplies. Many laboratories use uninterruptible power supplies (UPSs) for computers and other critical electronic equipment. These devices produce normal line voltage (120 vac, 60 Hz) when the normal power for the area has failed, and they represent a serious electrical shock hazard to unsuspecting emergency responders. When these devices are applied and managed individually, central control becomes very difficult. Therefore, consideration should be given to installing a central UPS with adequate current capacity to handle all the equipment in the laboratories and associated offices. It would then be easy to have the UPS current switched off for safety when necessary. Central UPS systems frequently employ battery systems that require no hydrogen gas ventilation considerations. In situations where older type lead acid batteries are banked together to provide high-capacity electrical energy, the storage rooms or facilities containing them must have passive ventilation and explosion-proof electrical fixtures.

1.4.2 Construction Materials

According to the International Building Code (IBC, 2012), laboratory buildings engaged in education, research, clinical medicine, and other forms of experimentation are included in the category of Class A building construction and Use Group B. Therefore, all pertinent sections of the IBC code should be followed in the design and construction of all laboratory facilities, with special emphasis on fire safety for unusual as well as all ordinary hazardous conditions. Specifically, the provisions of Article IX (Fire-Resistive Construction Requirements) that govern the design and use of materials and methods of construction necessary to provide fire resistance and flame resistance must be followed. Flame resistance is defined in the code as "the property of materials, or combinations of component materials, which restricts the spread of flame as determined by the flame-resistance tests specified in the code." Some of the specific subjects covered in Article IX of the IBC are enclosure walls, firewalls and firewall openings, vertical shafts and hoist ways, beams and girders, columns, trusses, fire doors, fire windows and shutters, wired glass, fire-resistance requirements for plaster, interior finish and trim, and roof structures. The purpose of the requirements of the IBC code is to provide a building that will allow its occupants to safely exit from the building in case of fire and unusual smoke conditions.

The general philosophy of all interior building design with respect to the combustible properties of construction materials should embrace the idea of eliminating those materials responsible for rapid flame spread and heavy smoke generation. Materials used in research buildings provide more than ordinary cause for concern because the sources of fire initiation in laboratories are many times more numerous than for most other building uses.

1.4.3 Safety Control Systems for Laboratory Experiments

Provisions should be made for automatic or remote shutdown of well-defined portions of a building's services that provide energy to experimental operations having the capability to threaten parts of the building or personnel within the building or to produce undesired effects should the experiment get out of control while attended or unattended. This type of control should be used for the most sensitive types of operations where uncontrolled failure could result in a major loss of equipment or damage to the building, the release of highly toxic substances into the environment, or personal injury. A study committee composed of designers, users, and health and safety professions should determine areas of risk that will benefit by application of laboratory experiment safety control systems (see Section 1.4.5.2). In addition to the safety control aspects of remote data processing, there may be a need for the laboratory user to transfer data electronically to remote locations such as an office or central computer facility. Data transfer cables with RS 232 and other standard connections are routinely installed in modern laboratory facilities.

1.4.4 Fire Detection, Alarm, and Suppression Systems

Costs of retrofitting fire alarm, detection, and suppression systems after the construction of any type of laboratory building are very high. Therefore, consideration should be given to these systems during the design stage of new and renovated laboratories. Automatic water sprinklers are considered the best fire control for laboratory buildings.

1.4.4.1 Fire and Smoke Detection. Laboratory buildings should be equipped throughout with a heat-sensitive fire detection system as a minimum. A standard sprinkler system will qualify, even with its inherently

slower detection ability. Another way of providing good building detection coverage is with the use of linear temperature sensing (LTS), also known as line-type systems. These are basically temperature sensing wires and they detect completely along their run, but have the capacity of providing specific information about the location of any detected spot. They are faster to respond to an elevated temperature area and provide a much earlier warning of the existence of a fire than the water sprinkler system can. These LTS systems can also be used in laboratory units and therefore integrate the complete building detection system.

There are other types of detection systems that can be deployed in the laboratory building and its' rooms. They include but are not limited to

- Optical flame detection (OFD)
- Aspirating smoke detection (ASD)
- Rate of rise thermal detection (ROR)
- Ionization products of combustion detection (ID)
- Optical smoke detection (OSD)
- New developments such as video image flame detection (see NFPA 72, 2013)

There continues to be advancement in the technology of flame, heat, smoke, and products of combustion detectors. For example, for several years ID detectors were the fastest devices used to detect insipient fires. That distinction now goes to OSD and ASD detectors. This becomes important when the risk to the building and its' contents demands rapid detection. The employ of a qualified fire protection engineer to assist in the up-to-date selection of detection and suppression systems is recommended.

- Optical flame detectors work by sensing infrared radiation at specific flicker rates. They are good in situations where flames break out quickly, as with flammable liquids and gases.
- Aspirating smoke detection systems work by drawing room air through a tube into a central analyzing box where lasers or other devices look for the small particles of smoke. The ASD systems are presently the fastest responding type, but are rather expensive.
- Rate of rise thermal detectors work by having air, trapped in a small chamber, which when heated, expands against a diaphragm, and triggers a switch. They are inexpensive, but not well suited for early detection; however, they are reliable.
- Ionization detectors work by having room atmosphere pass through a chamber in which an ionized beam becomes attenuated by collisions with smoke or other particles of specific size, triggering an electrical signal.
- Optical smoke detectors work by scattering light from light-emitting diodes (LED) off the smoke particles passing through the system chamber. The scattered light triggers the signal. These detectors have become fast, reliable, and relatively inexpensive.

The use of LTS and OSD systems for general building detection is recommended. Where different detection systems are more appropriate for specific laboratory and other building room applications, they are discussed in the respective chapters in this book. Fire and smoke detectors must meet Underwriters Laboratory (UL) standards and be installed and spaced in accordance with National Fire Alarm Code (NFPA 72, 2013).

1.4.4.2 Fire Suppression.

1.4.4.2.1 Fixed Automatic Systems. All laboratory buildings should be designed with a complete water sprinkler system in accordance with "Installation of Sprinkler Systems" (NFPA 13, 2013). Wherever unusual hazards exist, special design of the system will be necessary. When water is contraindicated for fire suppression because large amounts of water-reactive materials such as elemental sodium are present, or large amounts of flammable or combustible liquids are used or stored, other complete fire suppression systems must be used. The specific application of these nonsprinkler systems are discussed in the appropriate chapters on laboratory type.

There are several fire suppression systems available today and more are constantly being developed. Freon, also known as Halon is no longer available due to its negative environmental impact. At the present time, a mixed gas system composed of nitrogen, argon, and carbon dioxide is recommended. This system extinguishes fires by reducing the oxygen content below that which will support a flame, yet this atmosphere has been determined to be safe for humans. It was developed by Tyco Fire Products (www.tyco-fire.com) and carries their registered trademark name of INERGEN®.

Another important fixed automatic extinguishing agent is aqueous film-forming foam (AFFF). AFFF extinguishes fire by smothering it from getting combustion air. This system can be used in some locations where water sprinklers would not be advised due to the problems created by water run-off. One of those locations is within the laboratory building and is the fuel containment room for a liquid-fueled, such as a diesel fueled, emergency electrical generator. Most building codes require that this fuel containment room

be separate from the generator room. A fire involving the diesel fuel would be floated on top of sprinkler water run-off and possibly carried to other rooms or areas. Another appropriate system for this fuel location is one of the dry chemicals such as sodium or potassium bicarbonate or mono-ammonium phosphate. They extinguish flammable and combustible liquid fires through chemical reaction with the flame along with some smothering. The AFFF system is recommended due to its effectiveness. In some instances, a water-spray, also known as a water-mist system may be effective.

Due to the complexities of design, application and installation requirements of these engineered or preengineered off-the-shelf systems, a licensed or certified fire protection or safety engineer should participate in decisions regarding the best suppression system to use in any given application. All automatic fire suppression systems should be connected to the building central alarm system.

The vertical standpipes used for the water sprinkler system should also serve fire-hose cabinets on each floor of the laboratory building. Hoses should have a 1.5-in. (3.8 cm) diameter, and vertical risers should be so spaced that the maximum length of hose to reach a fire will not exceed 50 ft (15 m). Longer hose runs may lead to loss of fire control because a hose length exceeding 50 ft (15 m) is difficult for persons lacking adequate hands-on fire training to turn on and use.

1.4.4.2.2 Hand-Portable Extinguishers. In the last several years, several new extinguishing agents have been developed for hand portable use along with the more familiar water, carbon dioxide, and several types of dry chemicals. Some of these were developed to replace ozone-depleting chlorofluorocarbons (CFC) such as Halon 1211, but many still contain some ozone-depleting chemicals. It is believed that these agents will eventually become obsolete as better materials are developed. There are basically four types of hand-portable fire extinguishers for general use. They are

- Gas, such as carbon dioxide compressed in heavy steel cylinders
- Water in pressurized fiberglass and metal containers
- Dry chemicals in pressurized metal containers
- Vaporizing liquids (new) using hexafluoropropane in pressurized metal containers

Gas and vaporizing liquid extinguishers are considered "clean" agents in that they leave no messy residue (an important criteria when convincing a lab person to use one). Dry chemicals and water, as expected, leave a mess behind after use. From an effectiveness standpoint, the hexafluoropropane (FE 36, developed by E.I. DuPont Inc., Wilmington, DE) is the best and is recommended for use within laboratory rooms and other specific areas discussed later. Dry chemical is the next best extinguishing agent; the most diverse agent is mono-ammonium phosphate in that it will extinguish all three classes of fires—normal combustibles, flammable and combustible liquids, and electrical fires. Gas and vaporizing liquid extinguishers are recommended for general use throughout the building, in halls, corridors, and egress ways. In most instances, hand-portable fire extinguishers are used to assist with exiting from the room or building. There are instances where personnel will return to a laboratory room that is on fire, for the purpose of extracting notes and materials or to fight the fire itself. This activity is not advised, but because it does take place, it is recommended that fire extinguishers installed in halls and exit ways be sized large whereas units in laboratory rooms may be smaller. 6A 60BC is the minimum size recommended for halls and corridors. All fire extinguishers must be sized and installed in accordance with NFPA 10 (2010), "Portable Fire Extinguishers."

Special portable fire extinguishers should be considered for unique situations, e.g., areas where quantities of reactive and pyrophoric metals are in use or storage. Special portable fire extinguishers use suppression agents other than those listed above.

1.4.5 Alarm Systems

1.4.5.1 Fire Alarms. A Class A supervised fire alarm or signaling system should be installed throughout the laboratory building in accordance with "Installation, Maintenance and Use of Protective Signaling Systems" (NFPA 72, 2013). All manual pull stations, sprinkler alarms, and heat-sensing detectors should be connected to it. Pull station placement should be in accordance with NFPA 101 (2012) and should not be placed more than 200 ft (60 m) apart. All other detection systems should alarm locally, and connection to the Class A system should be considered only after reviewing the false alarm potential. Alarms should be detectable by in both sight and sound.

1.4.5.2 Laboratory Experiment Alarms. Provisions should be made for a three-tier alarm system in all laboratories in which experiments or operations need to be monitored for failure. The system should be designed to provide a communications link between the laboratory and a central station in the building that is monitored at all times, or at the very least, when there are unat-

tended operations in laboratory units. In general, a three-tier alarm system consists of the following parts:

1. A local alarm for room occupants that is audible and visual.
2. An audible and visual alarm outside the laboratory door to pinpoint the location of the problem.
3. Remote annunciation to a constantly attended location.

The use of remote annunciation is critical in a large facility because it may be the only means of alerting service personnel to the problem. Remote annunciation is most critical during weekends and normally unoccupied periods. It is strongly recommended that alarms to all electromechanical equipment connected to laboratory safety systems be annunciated to a central location.

Microchip technology is in use in many highly hazardous laboratories and may be advantageous when more than one kind of alarm condition must be monitored, for example, fire, hazardous gas, and HVAC system alarms. The single monitor for observing all three of the examples is advantageous to having three different systems to observe.

1.4.5.3 Other Service Alarms. Alarms may be needed to indicate failure of exhaust fans and makeup air systems as well as for fire, loss of pressure, loss of temperature, presence of toxic gases, low air oxygen content, and other conditions that often require monitoring. In addition, whenever building services that are not normally monitored could cause loss through flood, fire, explosion, or release of hazardous materials in the event of their failure, a separate monitoring system with three-tier alarms should be installed.

1.4.6 Hazardous Waste

A designated area must be provided to collect, consolidate, and store hazardous chemical, biological, and radioactive wastes in preparation for disposal. Hazardous chemical waste can be stored for short periods in the laboratory unit before being collected and sent to a central holding room or being shipped off site for disposal. For the laboratory unit, space for this temporary storage needs to be added to the floor plan and for the laboratory building, a more sophisticated facility may be necessary. General waste collections, such as those from janitors' operations, should consist solely of paper, glass, and other nonhazardous and recyclable refuse; waste chemicals should never be included. General waste and recyclable materials should be collected and stored in an area of the building not associated with the chemical, biological, and radioactive waste storage areas. The waste storage facility should be within the main laboratory building or in an external facility. (See also Chapter 27 for more information about hazardous laboratory waste management.)

1.4.7 Chemical Storage

In addition to provision for the storage of a few days' supply of chemicals in each laboratory unit, there should be a central chemical storage room for bulk supplies. This room should be sized to hold enough materials to ensure continued operations without interruption. The purchasing (procurement) department can assist in determining what this quantity should be. "Just-in-time" (JIT) purchasing agreements with suppliers, where advantageous, can reduce the necessary size of the central chemical storage room. Compressed gas cylinders should not be stored in the central storage room unless there is a separate room within it with high rates of ventilation. Good floor drainage should also be provided for compressed gas storage areas, where floor water may be present.

See Chapter 28 for more detailed information on chemical storage rooms.

1.4.8 Compressed Gas Storage and Piping

When the laboratory management elects to pipe gases from a central compressed gas-dispensing facility instead of placing cylinders in each laboratory unit, or where both methods are used jointly, the location of the central facility, and an outline of the design features must be included as an integral part of the building design.

A central gas cylinder farm should be located in a room with an outside wall for explosion venting in the ratio of 1 ft^2 (0.09 m^2) of venting surface for each 40–60 ft^3 (3.7–5.6 m^2) of room volume (see "Venting of Deflagrations," NFPA 68, 2007) or be housed in a room attached to the outside of the building. The room should be adequate in size to store in segregated locations full cylinders and empty cylinders awaiting removal for refilling as well as the manifolds necessary for piping the gases. Ventilation in this room should be adequate to vent heat from the sun load on the roof and walls and to remove gases leaking from a failed regulator or valve. Air changes should be a minimum of six per hour for flammable gases as required by OSHA 1910.106 (OSHA, 2013).

Rigid and secure supports for gas tanks should be provided; they should be designed to provide storage flexibility. Compressed gas cylinders for a high-pressure laboratory should be located within that laboratory, or

close to it, to avoid any loss of high discharge pressure in the piping system that occurs for the general laboratory gases when piped from a central location.

The gas piping system should be of stainless steel with low-pressure reducers and orifice restrictions wherever the pipe diameter exceeds 1/4 in. (6.4 mm) to limit accidental flow into any area. The piping system should be external to the building when this is feasible. Internal piping and exterior piping alike should be exposed to view wherever possible. Excess flow check valves may also be installed to control runaway flow conditions of toxic or flammable gases. Double-walled gas piping should be considered for highly toxic and flammable gases such as arsine and hydrogen, which are used in microelectronics. (See "Cleanrooms," NFPA 318, 2012; "Standard for the, Storage, Use and Handling of Compressed and Liquefied Gases in Portable Cylinders," NFPA 55, 2010; and Chapter 23, Microelectronics and Cleanroom Laboratories.)

1.4.9 Fuel Gas

A fuel gas shutoff must be provided for the entire building and should be located so that it is easy to reach and activate under emergency conditions. Shut-off valves should be provided for individual laboratories, groups of laboratories, or specific laboratory floors. For more information on this requirement, see Section 4 of Chapter 2.

1.4.10 Hazardous Materials, Equipment, and Procedure Signs

Personnel within a laboratory building or about to enter a laboratory building need information regarding the operations, materials, risks, or special situations within. This information is most important to emergency response personnel, such as firefighters and police or ambulance personnel, so they can carry out their functions safely and efficiently, usually in a time of stress. Many communities and cities have ordinances requiring certain signs such as those for flammable storage, which must be complied with. An acceptable system of signs is described in "Standard System for the Identification of the Hazards of Materials for Emergency Response" (NFPA 704, 2012). It was developed around nonlaboratory users of chemicals, but in some cities and communities there may be an ordinance that requires compliance with NFPA 704 for laboratories. When a specific code is not mandated, we recommend the adoption of a less complicated and less difficult to interpret sign system that can better protect emergency response personnel in laboratory situations, such as the system shown in Appendix C.

1.4.11 Fire Command Room

Many city fire departments require that laboratory buildings be equipped with a Fire Command Room that is directly accessible by the fire department via a locked outside door and within which are the fire detection and alarm electrical panels along with existing floor plans of the building, MSDSs, and a computerized building data system.

1.5 MISCELLANEOUS SERVICES

1.5.1 Lighting

Good lighting is essential in a laboratory due to the often long hours spent by researchers in performing highly detailed and concentrated work. The lighting energy intensity may also be significantly higher than other spaces, i.e., office space. Lighting energy impact on a building is not as large as other usage, for example, as compared to HVAC systems, but it is significant. Local energy codes and ASHRAE standard 90.1 impose limitations with the intent is to promote an energy conservation discipline to minimize overlighting and overuse of electrical power. "Energy Efficient Design of New Buildings" (ASHRAE Standard 90.1, 2010) and "Energy Conservation in Existing Buildings–Commercial" (ASHRAE Standard 100, 2006) should be consulted.

The Environmental Protection Agency's (EPA) Labs21® project has done significant research on laboratory lighting and recommend:

1. The use of lighting to supplement daylight
2. The use of direct–indirect ambient lighting parallel to benches
3. The use of task lighting wherever possible and reduce overall ambient lighting

Lighting is also affected by the brightness of walls, ceilings, floor, and work surfaces. To aid in the proper distribution of light a white or nearly white ceiling is recommended. Floors have more to do with contrast reduction in the visual field than with contributing to the overall lighting quality.

1.5.2 Lighting Level Guide

Suggested minimum lighting densities are presented in Tables 1-12 and 1-13. Two terms are defined: lighting power density (LPD) in watts/ft^2 and room cavity ratio (RCR).

The RCR is a shape factor (e.g., for a room) used in lighting calculations.

TABLE 1-12. Lighting Power Densities Using the Building Area Method. (Adapted from ASHRAE 90.1, 2010)

Building Area Type[15]	LPD (W/ft^2)
Automotive facility	0.82
Convention center	1.08
Dining: bar lounge/leisure	0.99
Dining: cafeteria/fast food	0.90
Dining: family	0.89
Exercise center	0.88
Fire station	0.71
Gymnasium	1.00
Health-care clinic	0.87
Hospital	1.21
Library	1.18
Manufacturing facility	1.11
Museum	1.06
Office	0.90
Retail	1.40
School/university	0.99
Transportation	0.77
Warehouse	0.66
Workshop	1.20

TABLE 1-13. Lighting Power Densities Using the Step-by-Step Space Method

Common Space Types[a]	LPD, W/ft^2	RCR Threshold
Atrium		
First 40 ft in height	0.03 per ft (height)	NA
Height above 40 ft	0.02 per ft (height)	NA
Audience/Seating Area—Permanent		
For auditorium	0.79	6
For Performing Arts Theater	2.43	8
For Motion Picture Theater	1.14	4
Classroom/Lecture/Training	1.24	4
Conference/Meeting/Multipurpose	1.23	6
Corridor/Transition	0.66	Width < 8 ft
Dining Area	0.65	4
For Bar Lounge/Leisure Dining	1.31	4
For Family Dining	0.89	4
Dressing/Fitting Room for Performing Arts Theater	0.40	6
Electrical/Mechanical	0.95	6
Food Preparation	0.99	6
Laboratory		6
For Classrooms	1.28	6
For Medical/Industrial Research	1.81	6
Lobby	0.90	4
For Elevator	0.64	6
For Performing Arts Theater	2.00	6
For Motion Picture Theater	0.52	4
Locker Room	0.75	6
Lounge/Recreation	0.73	4
Office		
Enclosed	1.11	8
Open Plan	0.98	4
Restrooms	0.98	8
Sales Area	1.68	6
Stairway	0.69	10
Storage	0.63	6
Workshop	1.59	6

(*Continued*)

TABLE 1-13. (*Continued*)

Building-Specific Space Types	LPD, W/ft^2	RCR Threshold
Automotive		
Service/Repair	0.67	4
Bank/Office		
Banking Activity Area	1.38	6
Convention Center		
Audience Seating	0.82	4
Exhibit Space	1.45	4
Courthouse/Police Station/Penitentiary		
Courtroom	1.72	6
Confinement Cells	1.10	6
Judges' Chambers	1.17	8
Penitentiary Audience Seating	0.43	4
Penitentiary Classroom	1.34	4
Penitentiary Dining	1.07	6
Dormitory		
Living Quarters	0.38	8
Fire Stations		
Engine Room	0.56	4
Sleeping Quarters	0.25	6
Gymnasium/Fitness Center		
Fitness Area	0.72	4
Gymnasium Audience Seating	0.43	6
Playing Area	1.20	4
Hospital		
Corridor/Transition	0.89	Width < 8 ft
Emergency	2.26	6
Exam/Treatment	1.66	8
Laundry/Washing	0.60	4
Lounge/Recreation	1.07	6
Medical Supply	1.27	6
Nursery	0.88	6
Nurse's Station	0.87	6
Operating Room	1.89	6
Patient Room	0.62	6
Pharmacy	1.14	6
Physical Therapy	0.91	6
Radiology/Imaging	1.32	6
Recovery	1.15	6
Hotel/Highway Lodging		
Hotel Dining	0.82	4
Hotel Guest Rooms	1.11	6
Hotel Lobby	1.06	4
Highway Loding Dining	0.88	4
Highway Lodging Guest Rooms	0.75	6
Library		
Card File and Cataloging	0.72	4
Reading Area	0.93	4
Stacks	1.71	4
Manufacturing		
Corridor/Transition	0.41	Width < 8 ft
Detailed Manufacturing	1.29	4
Equipment Room	0.95	6
Extra High Bay (>50 ft Floor to Ceiling Height)	1.05	4
High Bay (25-50 ft Floor to Ceiling Height)	1.23	4
Low Bay (<25 ft Floor to Ceiling Height)	1.19	4

TABLE 1-13. (*Continued*)

Building-Specific Space Types	LPD, W/ft^2	RCR Threshold
Museum		
General Exhibition	1.05	6
Restoration	1.02	6
Parking Garage		
Garage Area	0.19	4
Post Office		
Sorting Area	0.94	4
Religious Building		
Audience Seating	1.53	4
Fellowship Hall	0.64	4
Worship Pulpit, Choir	1.53	4
Retail		
Dressing/Fitting Room	0.87	8
Mall Concourse	1.10	4
Sales Area	1.68	6
Sports Arena		
Audience Seating	0.43	4
Court Sports Arena—Class 4	0.72	4
Court Sports Arena—Class 3	1.20	4
Court Sports Arena—Class 2	1.92	4
Court Sports Arena—Class 1	3.01	4
Ring Sports Arena	2.68	4
Transportation		
Air/Train/Bus—Baggage Area	0.76	4
Airport—Concourse	0.36	4
Audience Seating	0.54	4
Terminal—Ticket Counter	1.08	4
Warehouse		
Fine Material Storage	0.95	6
Medium/Bulky Material Storage	0.58	4

[a]In cases where both a common space type and a building-specific type are listed, the building specific space type shall apply.

$$RCR = 5H\,(L + W) / L \times W$$

or alternatively,

$$RCR = (2.5)\ \text{Total Wall Area} / \text{Floor Area}$$

where H = height, L = length, and W = width of the room. A cubical room will have an RCR of 10; the flatter the room the lower the RCR.

The illumination levels in the *IESNA Lighting Handbook* (Illuminating Engineering Society of North America [IESNA], 2000; http://www.iesna.org/) for laboratories that are very high. Therefore, designers have a challenge to understand from the users what their needs are.

1.5.2.1 Corridor and Egress Lighting

Researchers often work alone and late at night. Properly lit corridors and stairways give a feeling of security to users. It is important that lighting designers provide this feature. Many times egress lighting is connected to emergency power to ensure sufficient lighting in the case of a power outage.

1.5.3 Plumbing

1.5.3.1 Sinks. Sinks should be constructed of materials such as stainless steel or epoxy resins that are resistant to chemical and other spillage. The drain should have a removable, cleanable strainer to prevent solid materials from getting into the drainage system.

1.5.3.2 Liquid Wastes. Most local plumbing codes now require certain types of acid-resistant waste piping for many kinds of laboratory drains.

Many municipal wastewater authorities also impose strict controls on the nature and quantity of chemicals that may be discharged into the sewers. Local authorities having jurisdiction should be consulted. For example,

in the Boston area the local Massachusetts Water Regulatory Authority (MWRA) limits the mercury discharge level to 1 part per billion (ppb). In certain cases, on-site filtration and treatment may be both advisable and cost effective.

A comprehensive program of contaminant control that includes source reduction, infrastructure cleaning, and end-of-pipe treatment should be considered during the early design phases. Source reduction is a preferable strategy because it tends to eliminate the problem. Internal cleaning capability should be provided by installing accessible traps and sampling stations. The nature and size of end-of-pipe treatment will depend only on the presence of one or more contaminants that needs to be removed.

A central pH control system may not be present in many older facilities and should be installed where required by local codes. This consists of a collection tank where acids and caustic liquids can be introduced to maintain pH level before discharge.

Many municipal waste/sewer authorities require that laboratory waste volume be measured and continuously monitored for pH. When the wastewater is not clear, many conventional water measuring devices and systems are unsuitable. Weir-type meters have been used successfully for waste measurement.

Another alternative is collection and containment of only the most hazardous fraction of the liquid waste to lighten purification requirements for the bulk of the liquid waste stream. Collected wastes may need to be treated as regulated hazardous waste.

1.5.3.3 Water Pressure. Sufficient water pressure should be available for all building needs. Separate piping loops are necessary for the sprinkler system and for potable water; the latter category includes drinking fountains, emergency eyewash fountains, deluge showers, lavatory sinks, and water closet water. Anti-scalding temperature-regulating devices should be installed in service hot water supply lines. For deluge shower and eyewash specifications, see Appendixes A and B. For standpipes in locations where municipal water supply does not provide sufficient pressure, separate water pressure booster systems are necessary. In locations where municipal water supply is not present or where the quantity or quality is not adequate, separate water storage systems will be necessary. For example, a laboratory building being built in desert regions may require a complete self-contained water system.

1.5.3.4 Drinking Water Protection. Laboratory buildings need to protect their drinking water systems from contamination. This requires separation of the laboratory water system within the building from the water systems used for drinking, kitchens, toilet rooms, emergency showers, and eyewashes. For example, the need to conserve and protect entire municipal drinking water supplies from contamination due to back siphonage or backpressure is addressed by the Massachusetts Department of Environmental Protection (DEP) Regulation 310 CMR 22.22 (CMR, 1990), which describes the need and the approved method for protecting state, city, town, and local drinking water systems from any possible degradation caused by cross contamination. A double-check valve, reduced-pressure backflow preventer with a relief valve and open drain is the only method approved by the regulation. It offers the best available backflow protection and can be used on toxic and nontoxic systems.

Testing of backflow prevention equipment is required semiannually in Massachusetts. An additional reduced-pressure backflow preventer installed in a bypass arrangement is required to enable these tests to be done without loss of water service to the building.

The drinking water system inside the building should be protected in the same way as the municipal supply, by using reduced-pressure, backflow preventers, and a bypass line to avoid loss of service during semiannual testing. The hot water supply system requires similar treatment to provide the same kind of protection to building occupants.

1.5.3.5 Water Harvesting and Reuse. Sustainable design may require water harvesting on-site, which will need on-site storage. Contamination control measures must be taken in this situation as well.

The reuse of wastewater is an excellent strategy and must be carefully reviewed and adopted wherever possible. Two examples are as follows:

1. Reject water created in the production of "clean water" is high-quality water and can be used for a variety of purposes.
2. Gray water from washbasins in the bathrooms can be reused for toile t flushing. Design must be done carefully, and storage and a separate piping system for toilets need to be installed. However, the savings can be significant.

1.5.4 Support Services

When designing laboratory buildings it is important to consider the health and safety issues related to laboratory support service personnel, e.g., maintenance, housekeeping, and security. Adequate space must be provided for housing these people and their equipment. These areas should be provided with the same health and safety features as the other laboratory areas, including

adequate ventilation, fire protection, lighting, and emergency egress. In addition, there may be some special considerations. For example, nonslip floor surfaces should be provided in glass-washing rooms, janitor closets, and similar areas in which floors are frequently wet. Adequate general ventilation and work space must be provided in mechanical and fan rooms. Provision must also be made for routine maintenance of laboratory ventilation systems, and adequate access must be provided.

1.5.4.1 Security. Depending on the nature of the laboratory and the work being carried out, several issues of security may need special consideration. Granting agencies and organizations often have unique stipulations. Most of these issues require attention in the planning stage as they involve such considerations as cable installation during the construction phase and the allocation of space. A central or main security office may be necessary, which would include TV monitors providing real-time monitoring of the premises via remote cameras. Guard stations at entrances to the building may be required; unguarded entrances may have to be wired to prevent unauthorized opening. Special locked rooms and areas may need to be monitored because they contain materials ranging from chemicals and drugs to proprietary systems and records.

Some laboratories make extensive use of magnetic-stripe ID cards in place of guard stations. Many laboratories have guards located at stations during normal working hours and switch to card-operated entrances during off-hours. Some use has been made of card-operated turnstiles, which can produce serious bottlenecks during evacuation emergencies. Biometric-type systems that use fingerprint or retina scans are becoming more common.

1.5.5 Electrical Harmonic Currents

Engineers have long been aware of the potential problems in building electrical systems caused by harmonic currents, but these problems were less noticeable before the extensive use of computers and other electronic devices.

A systems report published by Atkinson, Koven, Feinberg Engineers (Atkinson, 1991) provides a good description of the problem. Electrical systems found in most buildings are designed for traditional linear loads. Linear loads (such as motors, electric heaters, incandescent lighting, and fluorescent lighting with standard wire-wound ballasts) consume current on a continuous (linear) sinusoidal basis. When this type of load is balanced across a typical three-phase, four-wire power source, the return currents of each phase cancel each other out in the neutral conductor and there is no risk of transformer overload or wires overheating.

Now, however, because of the proliferation of solid-state devices (e.g., data processing units, personal computers, variable-speed motor drives, and electronic ballasts), nonlinear electrical loads result in the creation of harmonic currents in the distribution system. This is because solid-state devices draw current in pulses. The frequency of the pulses and their waveshapes are classified in terms of the harmonics of the fundamental frequency (60 Hz). Generally, the pulses appear in the third, fifth, and seventh harmonics (180, 300, and 420 Hz). The third harmonic current is the predominant contributor to the overall system current waveform distortion. The fifth and seventh harmonics have a lesser impact. These third harmonic currents do not cancel in the neutral conductor. The neutral conductor can be subject to extremely high currents (even in excess of the phase lag currents), causing hazards such as transformer overload and overheating of neutral wires and bus bars. This situation can place an excessive amount of stress on the electrical power systems, causing equipment failure and/or reduction in the system's life expectancy.

To offset these problems,

1. Install special electronic filters or transformers
2. Oversize the common neutral in a three-phase, four-wire circuit
3. Add a separate neutral conductor from each branch circuit to the electric panel

In an upgrade of an existing electrical system, a qualified electrical engineer using a harmonic analyzer should be retained to evaluate the extent of the problem and recommend any solutions.

1.5.6 Steam Quality

Steam is often used in laboratory buildings for heating, humidification, sterilization, and glass- and cage-washing activities.

The steam quality and its content could become a concern and should be evaluated. Steam quality is defined thermodynamically. A 100% steam quality is saturated steam. Steam of lesser quality contains moisture droplets.

Steam additives are mostly boiler treatment compounds and are added in the steam system to prolong the life of the boiler tubes, piping, and other auxiliary systems. These chemicals raise pH. They may possess some toxic properties. The most common compounds used in boiler treatment are amines, namely, morpholine, cyclohexylamine, and diethylaminethanol (DEAE). These amines minimize the effect of dissolved gases

such as carbon dioxide and sulfur dioxide on metals in boilers, feed water heater, and piping.

Poor steam quality sometimes leaves residue condensate on items being sterilized. This condensate could consist of a concentration of steam additives that may cause operational problems. For example, if animal feeds are being sterilized with poor-quality steam, such steam condensation would contaminate the feeds.

For humidification, direct steam injection remains a very popular method. However, when steam contains components that could cause health problems, a case can be made that such steam additives should not be used in direct-steam injection-type humidification systems. Several steam-to-steam generator systems are available in which building steam can be used as a heat source to evaporate city water (or in some cases, deionized [DI] water) to make "clean" steam. Other cold-mist humidification systems are also available that do not depend on steam at all.

Careful study of the steam additives proposed and of building steam should be done. A study done by Battelle Institute on their own steam ("Determination of Amines in Indoor Air from Steam Humidification"; Edgerton, 1989) provides a good discussion.

The Battelle study concluded that concentration of amines measured in indoor room air during normal operation of the boiler and humidifier can be very low compared with any established health standards. On the other hand, a NIOSH case study by Hills, Lushniak, and Sinks (1990) showed that overtreatment of boilers with such water treatment compounds can cause a health hazard for the occupants. Studies by Fannick, Lipscomb, and McManus for NIOSH (1983) show the effects of such compounds in a museum and report associated problems. Other NIOSH reports (McManus and Baker, 1981) provide a good background. The workplace amine concentration will depend on the boiler treatment compound control systems. If excessive chemicals can be introduced, this could result in problems.

At this time, the use of control steam for humidification should not be prohibited. Careful review of the current literature on boiler systems is needed before a final decision can be made. This work was validated by Memarzadeh (2009) of the National Institutes of Health in a White Paper called "Use of Clean Steam vs Utility Steam." He summarized the issues as follows (p. 7):

> "The way in which corrosion inhibitors are added to boiler systems may affect the risk of toxic exposure. Volatizing amines should only be used in systems with well-maintained automatic dosing devices. Manual dosing should not be allowed when automatic dosing equipment is inoperable. Individuals who design and maintain corrosion inhibitor feed mechanisms should be aware of the consequences of chemical overfeed.
>
> Time averaged estimates can be derived from historical weather data, boiler plant records, and simple titration measurements of steam condensate concentration from the holding tank. Care must be taken to avoid loss of the amine additive through volatilization when using titration methods to determine condensate concentration. The material balance may be used for real time modeling if the appropriate variables are constantly monitored and the effect of internal removal is known.
>
> With careful monitoring of water chemistry, along with periodic direct testing for amine levels in the humidified air space, operators of steam humidification systems can be assured that room air amine levels will be well below the permissible levels that may cause adverse effects in humans. Facility engineers and managers should consult a qualified water treatment professional to arrange for an evaluation of their steam humidification system, including possible airborne amine testing."

1.5.7 Pure Water System

Pure water is required in various research activities. The purity measurement is specific resistance in ohm/centimeters (Ω/cm) and is expressed in conductivity (μΩ at 77°F/25°C). Purity of water used for pharmaceutical laboratories, for example, is defined by United States Pharmacopoeia USP NF (2012).

The *Handbook of Facilities Planning* (Ruys, 1990) provides a good description of various other types of pure water standards. Standards have been established by the National Committee for Clinical Laboratory Standards (NCCLS), the College of American Pathologists (CAP), the United States Pharmacopoeia (USP), the American Society for Testing and Materials (ASTM), and the American Chemical Society (ACS). (See Table 1-14)

1.5.7.1 Production Methods. There are several methods for producing pure water. The most common are

- *Deionization.* Impurities are removed by passing water through synthetic resin beds with affinity for dissolved ionized salts and gases. The process will

TABLE 1-14. Pure Water Classification

Classification	Resistivity (MΩ/cm)
Absolute purity	18.3
Ultrapure	1.0
High purity	1.0
Low purity	1.0
Biopure	Pathogen free, sterile .1 ppm total dissolved solids

not remove bacteria, pathogens, particulates, or dissolved organic compounds. This process can provide water of 15–18 MΩ/cm purity. Resin beds require regeneration with sulfuric acid and caustic.

- *Distillation.* Impurities are removed from water by converting the liquid to vapor phase and then recondensing it as distilled water. Distilled water is free of all pathogens except dissolved ionized gases. Distillation can provide water of 0.8–1.0 MΩ/cm purity if the feedwater has been pretreated.
- *Reverse osmosis.* Impurities are removed by utilizing hydraulic pressure to force pure water through a membrane. This process removes some pathogens. It will not remove dissolved ionized gases. It is good for water with high total dissolved solids (TDS).
- *Filtration.* Solid particulate impurities are removed by passing the water through a porous membrane or medium. Types include sand filters, diatomaceous earth, cartridge filters, etc.
- *Other systems.* Combinations of the four systems described above may be used; in certain cases, special processes may be employed.

1.5.7.2 Pure Water Piping. Pure water is very aggressive and corrosive. The impurities in the pipe material in contact with the water can leach out into the pure water. The end-product water then may be unacceptable to the user. Common pure water piping materials are aluminum (type 3003), glass, polyethylene, polypropylene, stainless steel, and tin-lined copper. The cost of the material, joining methodology, pipe hanging detail, and most important, the possible water contamination described above must be considered before making the final selection.

A recirculated system provides the best assurance of an ongoing clean system. Dead legs in piping systems should be avoided because they could be a source of bacterial growth.

1.5.7.3 Central Pure Water Supply versus Onsite System. In a small project, an onsite system will be most cost effective. In a large building, it is sometimes not cost effective to produce and pipe the highest grade of pure water throughout the building. A reasonable grade, centrally produced, and "polished" locally in specific laboratories to obtain the final quality, may be more cost effective.

1.5.8 Pest Control

Pest control and IPM (Integrated Pest Management) should be considered in all phases of design, construction, and commissioning for any new or renovated building. There are many design features that will minimize or eliminate pest issues and the need for pesticide use once the building is in operation. Some that should be implemented in the various phases are as follows:

Design Phase

- Require door sweeps on all exterior doors.
- Require appropriate dumpster location, water sources, and floor drains for proper housekeeping practices.
- Provide access panels to "dead spaces" (pipe chases, ceilings other than drop ceilings).
- Require sealed hatches or coverings for ejector pits.
- Require bug lights in mechanical spaces that are likely to be wet.
- Exterior ledges, particularly over entrances, should be eliminated or anti-bird/pigeon measures (e.g., netting) considered.
- Exterior fencing around play areas or park-like settings should have 24″ metal extension below grade to prevent rodent burrowing.
- Exterior building envelop should be tight and flush with no gaps larger than 1/8″ to prevent pest access (bees, ants, mice, rats, roaches, etc.).
- Food-service counters, benches, cabinets, etc., should be flush with floors and walls to prevent nesting opportunities underneath and behind.
- Tree wells and raised beds with masonry features should be screened, grated, or meshed to prevent harborage and nesting areas.
- Require door sweeps on all interior mechanical space, food service, loading dock, and other operational doors.
- Require overhead rolling doors to be flush and tight with no gaps larger than 1/8″.
- Require overhead doors to be motion-detection capable to automatically close when no activity is present.
- Waste containers (dumpsters/compactors), particularly animal bedding and food-service compactors, should be watertight and sealed between the rim and container to prevent food sources from leaking.
- Floor-mounted heating and cooling vents should be screened to 1/4″.
- Custodial closet and storage space floors should be finished and door sweeps required.
- Trash/recycling rooms should have floor drains and a water source for proper housekeeping procedures.
- Exterior landscaping features should be kept a minimum of 4″ off the exterior of the building.

- Exterior plantings should be species that rodents and pests do not like and are not attracted to (trees and shrubs that produce berries or nuts, have root systems conducive to burrowing, etc.).
- Sidewalks and parking lots should slope and drain during inclement weather to prevent puddling.

Construction Phase

- Construction project management company or selected contractor should be required to contract a pest-control provider during the construction phase to better coordinate IPM efforts.
- Work site should remain "broom clean" and all waste generated removed daily, particularly food waste generated from coffee/lunch breaks, to prevent harborage and food sources.
- A pest-control survey and clean out should occur prior to the interior of the building being "buttoned up."
- Appropriate rodent control actions must be taken along the perimeter and surrounding areas of the construction site.
- Exterior doors to the job site should be kept closed at all times, particularly before/after deliveries, to prevent access for pests.
- Pest-control inspections of the job site should occur regularly, a written report generated, and corrective actions taken. Penalties should exist to ensure compliance.
- Construction dumpsters need to be emptied on a regular basis and the dumpster location site kept clean to prevent harborage and food sources.
- Exterior and site trash receptacles should be required for use by construction personnel and catering trucks.
- Pest sightings or evidence of pest activity should be immediately reported to Project Management and pest-control vendor for immediate action.

Commissioning Phase

- Prior to the project being turned over to the owner, the project should be inspected and certified as being "pest free." If not, remedial action should take place and the project is not officially handed over until it is deemed pest free.

For Renovations

- Neighbors of the area to be renovated should be notified of the potential for increased pest activity due to the renovations nearby and instructed on how and what they should do regarding pest activity.
- Access points from the perimeter of the project area to neighboring spaces should be sealed and door sweeps installed as much as possible.
- Doors leading to and from the renovation area should be kept closed at all times, particularly exterior doors.
- Debris dumpsters should be emptied as quickly as possible.
- Staging areas should be required to be "broom clean" at all times to prevent harborage and food sources.
- Exterior doors to the job site should be kept closed at all times, particularly before/after deliveries, to prevent access for pests.
- Construction dumpsters need to be emptied on a regular basis and the dumpster location site kept clean to prevent harborage and food sources.

2

LABORATORY CONSIDERATIONS

2.1 GUIDING CONCEPTS

All laboratories, regardless of their specific use, have many similar health and safety requirements that should be considered in all design stages. Consideration of safety issues at the outset save owners and users costs for corrective modifications of the plans and materials during construction. Perhaps more importantly, it mitigates the continuing liability of built-in safety hazards. Neglect of safety principles in design phases leads to laboratories with needless risks to health and safety.

In this chapter, the common requirements for all types of laboratories discussed in this book are reviewed, but specific commonly encountered laboratory types and their distinguishing features are discussed in Part II. In some cases, specialized laboratories may not require one or more of the facilities discussed in this section; in other cases, they require special facilities discussed in Part II. Unless otherwise noted, section numbers refer to items discussed here.

2.1.1 How Laboratory Design Can Affect Operations

There are several laboratory building design decisions that can significantly affect building and individual laboratory operating procedures, and make compliance with environmental health and safety regulations more likely and easier to attain. It is advantageous to consider these during the design phase and obtain feedback from those who will occupy and maintain the facility. These features are referenced throughout the book and key examples appear here.

2.1.1.1 Open Laboratory Design. The concept of open laboratory design is discussed in detail in Chapter 21. This type of laboratory design, while it has many advantages, also imposes some significant operational differences from the traditional modular laboratory. In the event of a hazardous material release, the whole laboratory may need to be evacuated. In addition, there are potential noise and privacy issues that may require different operational procedures. The use of shared equipment can present challenges and result in potential safety issues.

2.1.1.2 Dry versus Wet Laboratories. There has been a recent move to classify laboratories as "dry" or "wet" with "dry" laboratories defined as those where no hazardous materials will be used such as "computational" laboratories. Based on this description, several safety design features such as emergency eyewash and showers, and local exhaust hoods will not be needed. Operationally, this requires enforcement of the prohibition of any hazardous materials use in the laboratory. This will restrict future use and present the temptation to use "small" quantities of hazardous materials in the laboratory without adequate protection. Future use of the laboratory must be considered before designing it as a "dry" laboratory.

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

2.1.1.3 Location of Utilities within the Laboratory. During the life of the laboratory there will be many occasions when repair and maintenance must be performed on utilities or systems within the laboratory. Every attempt should be made to make these easily accessible for the work that may be anticipated. Locations that require the use of ladders or lifts and excessive "reaching" or awkward postures should be avoided. Maintenance personnel should be consulted during the design stage.

2.1.1.4 Location of Desks. Locating desks and workstations within the laboratory as opposed to outside the laboratory has been an ongoing debate for decades. Some disciplines such as chemistry and engineering are more likely to prefer desks outside the laboratory. Others such as biology prefer desks near their research. The location of desks can affect compliance with regulations on eating and drinking in the laboratory and wearing proper PPE (eye protection and gloves) when working with or near corrosive or toxic chemicals. Enforcing operating procedures to attain compliance with these requirements becomes very difficult when desks are located within laboratories. Locating desks outside but as close to the laboratory as possible is desirable. Providing them directly adjacent the laboratory with direct access and a viewing window is ideal (see Figure 2-1).

2.1.1.5 Storage of Flammable Materials. Codes and regulations restrict the quantity of flammable materials by class and height in the building. Increased amounts are allowed for facilities that are sprinklered and also for storage in approved flammable liquid storage cabinets. Operating procedures may need to restrict the use of some materials, particularly on higher floors in the buildings where the allowable limits are lower. For certain types of research such as organic chemistry or research with highly reactive chemicals, this may be a significant burden on the researchers. Providing adequate storage space and separate fire zones can minimize operating restrictions. Locating research that uses higher volumes on lower floors is also desirable. This emphasizes the need for complete, accurate, and up-to-date chemical inventories for each laboratory space and the building.

FIGURE 2-1. View of laboratory staff desks outside laboratory.

2.1.1.6 Confined Spaces. OSHA provides definitions for confined space and the more-restricted permit-required confined space. The latter requires additional personnel to act as attendants to any entry into the space as well as additional procedures and documentation. This can add to the cost and time to perform routine functions and increase the potential for noncompliances and potentially unsafe actions. There are designs that can result in classifying a space as only the less- restrictive confined space and not permit required confined space. These include providing easy access to the space with rigid stairs or platforms, adequate openings for easy entry and exit of personnel, and possibly ventilation.

These confined spaces can be found in mechanical spaces (i.e., HVAC systems) and individual research laboratories with large reaction vessels or other spaces, or equipment requiring entry but not designed for occupancy.

2.1.1.7 Fall Protection. OSHA requires fall protection and special procedures for any work conducted above 4 ft heights. Typically, this requirement is associated with work on the roofs of buildings. Adequate fall protection devices such as "tie offs," anchor points, or railings around the edge of the roof must be provided. However, conditions requiring fall protection might be found in mechanical spaces or in pilot plants or laboratories with large research vessels. Design for these should include platforms and stairs or ladders for access. This will minimize the potential for falls resulting in serious harm, as well as increase compliance with the OSHA fall protection standard.

2.1.1.8 Ductless Hoods. Unlike the exhausted chemical fume hood, ductless hoods have limitations on what materials can be used inside them. This is because the ductless hood needs an air cleaner (filter) that can effectively remove the materials in the exhaust stream before returning the air back into the room. There are not appropriate filters for all the material that may be used

in hoods. This requires identification of what can be used in the ductless hood and strict adherence to operational procedures. Because research may change in future years, this restriction could limit the activities that can be conducted in the space. In addition, this type of hood requires maintenance on the chemical sensors and fitter replacement periodically. This adds to the operational requirements of the facility. Chapter 32, Section 32.12 contains more information on ductless hoods.

2.1.1.9 Start with the End in Mind. At various times during and at the end of the life of the building or laboratory there will be a need to decontaminate and decommission the space. This should be considered in the design stage. This requires consideration of easily cleanable surfaces and easy access to all surfaces. See Common Elements of Renovations in Part 1, Section B for more details on decommissioning laboratories.

2.2 LABORATORY LAYOUT

The laboratory layout is critical for the efficient use of space and the safety of laboratory personnel. The laboratory design must be consistent with the building design guidelines described in Chapter 1. This includes provisions for modular laboratory design, entry and egress, furniture and equipment locations, and access for disabled persons.

2.2.1 Modular Laboratory Design

Modular laboratory design brings the discussion from the large scale of the entire building down to the scale of the individual laboratory, the basic workspace for laboratory occupants. Modular design achieves two functional objectives: standardized locations for distribution of laboratory utilities along module lines, and standardized locations for internal laboratory circulation aisles at centerlines of the long axis of modules, for as many modules as the laboratory is long. As noted in Chapter 1, Section 1.2, some laboratories need change frequently over the life of a building: interior walls go up and come down; benches, and especially equipment, come and go. Whatever replaces these components should continue to follow modular organization with regularly spaced egress pathways that foster laboratory safety.

Five decades ago, the Nuffield Foundation in the UK studied criteria for laboratory work areas in detail (Nuffield, 1961). Since then, although much research has been published in the science of ergonomics, there has been no other comprehensive study of ergonomics and efficiency specifically for laboratory operations. The Nuffield Foundation's time-and-motion efficiency and ergonomic studies led to guidelines for optimal dimensions of standard laboratory features, including circulation-aisle widths and work-surface widths and heights that are still mostly valid. The Americans with Disabilities Act of 1990 (ADA, 1990) has made improvements in a few of the clearance dimension standards first formulated by the Nuffield study (Nuffield, 1961).

2.2.1.1 Laboratory Module Width. Three factors influence a laboratory module's width: aisle width, bench and equipment widths, and typical wall thickness. Module width is the sum of these dimensions as shown in Figure 2-2A for a single module and Figure 2-2B for a two-module lab.

2.2.1.1.1 Aisle Widths. Laboratory circulation aisles are spaces that are generally aligned in the center of modules and flanked on both sides by arrays of work surfaces, benches, and equipment. Laboratory aisles give users access to the equipment and workbenches

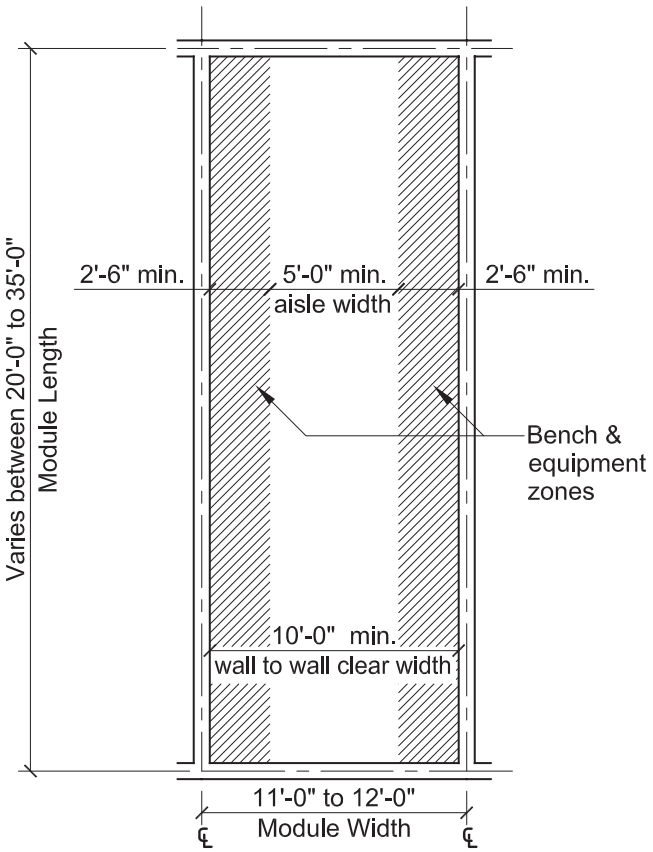


FIGURE 2-2A. Typical single module laboratory dimensions.

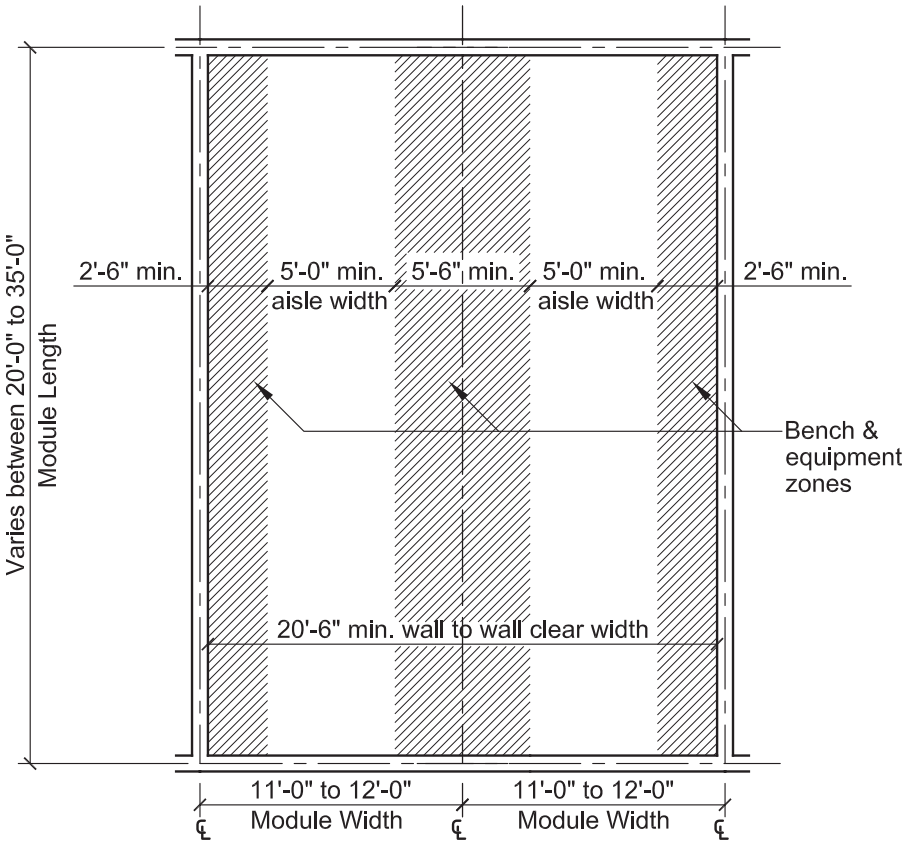


FIGURE 2-2B. Typical double module laboratory dimensions.

that comprise their fundamental workspace. In standard laboratory types, aisles between benches, work surfaces, and equipment should be a minimum of 5 ft (1.5 m) wide. This minimum width enables another person, or a person pushing a laboratory cart, to carefully and safely pass behind and between persons working at benches or equipment on both sides of the aisle. This width also meets the accessibility requirements of the Americans with Disabilities Act of 1990 (ADA, 1990).

Aisle widths narrower than 5 ft (1.5 m) are acceptable only where the aisle is solely for limited access, not for standard circulation, and where laboratory support rooms are normally unoccupied, such as some storerooms (Chapter 28, Section 28.2) and controlled environment laboratories (Chapter 11, Section 11.2). Narrow utility-access aisles are commonly used between split benches in analytical chemistry and in instrument laboratories. Utility-access aisles widths range between 2–3 ft (0.6–1 m) wide, a sufficient space between the backs of equipment benches and freestanding equipment for only one person to get in to make or change utility connections. But note that if compressed gas cylinders are routinely secured in utility-access aisles, widths should increase from the minimum to 3 ft (1 m).

Aisle widths up to 6 ft (1.83 m) are acceptable in most research, development, and testing laboratories. If aisle widths exceed 6 ft (1.83 m) in standard research and testing laboratory types, the aisles tend to get cluttered with equipment and other obstructions, often set up by users to make maximum use of the area close at hand. Safety becomes compromised with clogged aisles, impeding safe egress during emergencies, and increasing the risk of trips and falls. Some equipment requires clearance at the front-facing laboratory aisles, such as in clinical testing laboratories that have automated processing. Widths of those aisles will be determined by clearance requirements for loading and maintenance of the equipment.

Other types of laboratories may require wider aisles to accommodate heavy traffic and/ or bulky materials' handling and equipment to be transported. For example, teaching laboratories (Chapter 16, Section 16.2) benefit from aisle widths from 6.5–7.5 ft (2–2.3 m) due to the need for instructors to move between rows of students working back-to-back, and to respond to students and to emergencies. Generous clearance between benches is highly desirable because students, especially undergraduates, may move awkwardly or in an unintentional

manner. Chemical pilot plant and other engineering and physics laboratories require wider aisle widths to move materials on hoists and around large assemblies of scientific equipment. Section 2 of Chapters 8, 9, and 10 provides specific aisle width recommendations for these laboratory types.

Major laboratory aisles should be aligned in the direction of egress to aid orientation of occupants in case they must evacuate the laboratory in an emergency. Laboratory fires often generate dense smoke and fumes, and occupants may have to crawl below the level of smoke. Safe egress under these obscured conditions is difficult. Laboratory floors can be marked with graphics, patterned, or have small emergency egress lights to assist occupants in finding the closest exit. Laboratories are inappropriate places for irregular circulation patterns. When arrangements of aisles are irregular, and aisles do not clearly lead to exits, occupants can be overcome by smoke and fumes before figuring out how to get out.

2.2.1.1.2 Bench and Equipment Widths. The second variable in determining the best module width is the front-to-back dimensions of benches and equipment on both sides of laboratory aisles. Work surfaces on tables or benches with piped utility chases behind them are typically 30 in. (76 cm), the maximum functional reach for many adult workers. Benches and tables 24 in. deep (61 cm) work well, but if they abut piped utility chases on the back edge, the actual dimension from the front of the bench to the wall behind ranges from 30 in. (76 cm) to 32 in. (76–81 cm).

Some common bench-top and floor-mounted equipment, and the superstructures of some high-performance/low-flow chemical fume hoods, are deeper than 30 in., up to 42 in. (76–107 cm). Chapter 32, Section 32.7 describes the technical characteristics of high-performance hoods. Consider providing wider modules where those items will commonly be found. For laboratory safety, the goal is to maintain 5 ft (1.5 m) of clear aisle width under all normal circumstances.

2.2.1.1.3 Wall Thickness. Wall thickness is the third factor determining module width. Interior partitions dividing laboratory walls vary in their construction assemblies, fire rating, and flexibility. Common construction assemblies used to separate one laboratory from another are concrete blocks, gypsum wallboard on steel studs, metal storefront frames with glass or panels of other nonflammable material, and manufactured metal panels. If these walls require a fire rating of 1 hour or higher, then concrete block and gypsum wallboard/steel stud assemblies can achieve it. One-hour fire-rated glass with a fire-rated frame assembly may also be considered. If the walls need to be demountable so that most of the panels and hardware in the assembly can be reused, then metal storefront frames and manufactured metal panel systems are suitable options.

All of these options range from as slim as 2.5 in. (6 cm) to as thick as 8 in. or greater (≥20 cm). Partition widths may increase if drainage and chilled water pipes are embedded within wall cavities. The module width must include the total wall thickness, so aisle widths cannot be compromised in the future as laboratories are subdivided and more walls are added. Risers of drainage and all other pipes and conduit may also be surface mounted on walls, exposed, or enclosed within finished sheet metal chases so the thickness of the walls does not have to change or expand.

Given all three factors, acceptable module widths for standard laboratories range from 10.5 to 12.5 ft (3.2–3.8 m). For laboratories with extra-wide aisle requirements and fire-rated walls, module widths may be 14.75 ft (4.4 m) or greater. Special-purpose laboratories, such as engineering laboratories (Chapter 8), chemical engineering laboratories (Chapter 9), controlled environment laboratories (Chapter 11), high-pressure laboratories (Chapter 12), microelectronics laboratories (Chapter 23), and other special laboratory types may have area requirements that do not conform to standard module dimensions. Care should be taken to coordinate the building structural grid to these special conditions (see Chapter 1, Section 1.2.6).

2.2.1.2 Laboratory Module Length. Four variables determine the length of standard laboratory modules: (1) the overall dimension of the building enclosure, (2) the preferred structural spans, (3) the desired area per module, and (4) the intended use of the laboratory. Laboratory module lengths commonly vary from 20–35 ft (6–10.67 m). Lengths in excess of 35 ft (10.67 m) can pose problems in complying with building code egress requirements. International Building Code (IBC, 2012) Section 1014, paragraph 1014.3 "Common Path of Egress Travel" limits length of travel to an exit doorway in laboratories to 75 ft in business-occupancy (as opposed to high-hazard occupancy) buildings not equipped with an automatic fire suppression system, and to 100 ft with an automatic fire-suppression system. When a laboratory length is determined, that length should be used for most laboratories, unless the overall width of the building enclosure varies or the main access corridor shifts to one side to increase the laboratory depth. There is an exception in floor plans using central utility shafts for main risers. In this option there will be two standard lengths, varying only by the width of the shaft as shown in Chapter 1, Figures 1-17A and B.

2.2.2 Personnel Entry and Egress

There are many specific requirements for laboratory entry and egress. The key guidelines are given in the resources listed in Chapter 1, Section 1.2.3.1. These codes and standards set directives and good laboratory practice policies for the number and width of exits, the direction of door swings, and permissible door swings into egress pathways. The essential features are summarized below for the IBC and National Fire Protection Association (NFPA) standards.

2.2.2.1 Occupational Safety and Health Administration (OSHA) Regulations. OSHA, 1910.37(a)(2) (OSHA, 2012) contains two specific requirements that are directly applicable to laboratories: "Exit routes must be kept free of explosive or highly flammable furnishings or other decorations," and "Exit routes must be arranged so that employees will not have to travel toward a high hazard area, unless the path of travel is effectively shielded from the high hazard area by suitable partitions or other physical barriers." Other requirements in OSHA 1910.37(a) to (e) (OSHA, 2012) pertain to all building types OSHA regulates.

2.2.2.2 Egress Safety Considerations.

2.2.2.2.1 Two Exits. Sometimes safety considerations mandate two or more exits from a laboratory. Figures 2-3A–D show some options for locating exits opening into the primary personnel corridor from laboratories of 2 and multiple modules wide. When laboratories are designed, there is no assurance that the facility will meet all the conditions listed in the National Fire Protection Agency 45 standard (NFPA 45; 2011) or the building code in the jurisdiction having authority. Therefore, it is recommended that laboratory design teams provide two exits from each laboratory when laboratories are over 500 ft^2 (47 m^2), when there is a chemical fume hood in the laboratory, and when NFPA or building code conditions pertaining to the health hazard rating of compressed gas cylinders or cryogenic containers apply. NFPA 45, Section 5.4.1 (NFPA 45; 2011) recommends a minimum of two exits from each laboratory work area under the following conditions:

- A laboratory work area contains an explosion hazard that could block egress from or access to the laboratory.
- A high fire hazard laboratory unit work area exceeds 500 ft^2 [46.5 m^2].
- Moderate fire hazard and low fire hazard laboratory units' work area exceeds 1,000 ft^2 [93 m^2].

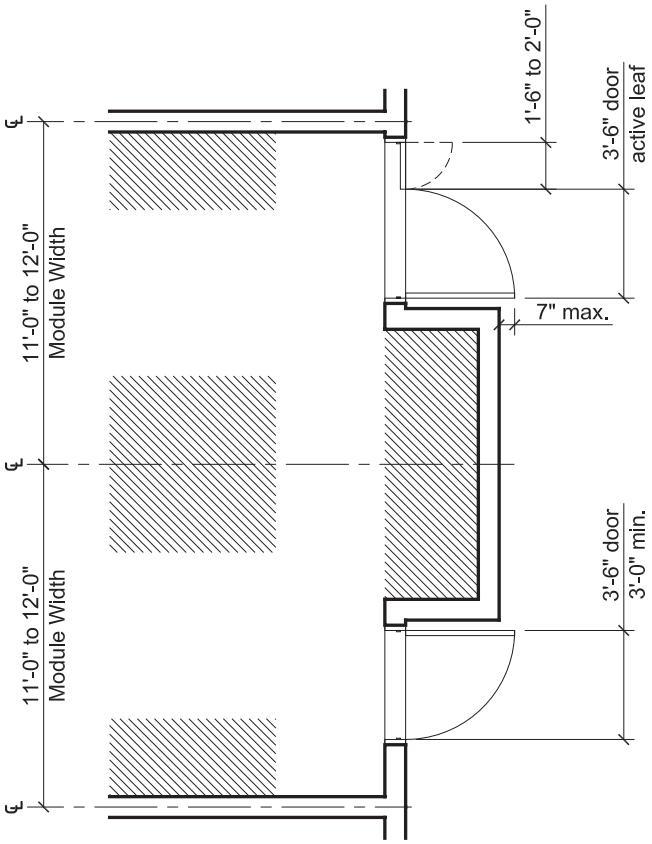


FIGURE 2-3A. Exit/entry door locations and layout for two-module laboratory.

- A laboratory fume hood is located next to a primary exit door of a laboratory. This location is not recommended here, however, as explained in Section 2.2.5.
- A laboratory uses a compressed gas cylinder larger than lecture bottle-size located in a position where "it could prevent safe egress in the event of accidental release of cylinder contents."
- A laboratory uses a cryogenic container that could prevent safe egress in the event of accidental release of the container's contents.

The safest arrangement for laboratory egress is for each required exit door to open into a separate fire zone and for each exit to be located so that pathways within the laboratory or laboratory suite are separated, as far apart as feasible. Thus, when an accident or other emergency makes one laboratory escape pathway impassable, the second could provide an alternative safe route out to a fire-rated building egress passage. Such a building layout is illustrated in Chapter 1, Figures 1-11C and D, and discussed in Section 1.2.3.2.5. In addition, IBC,

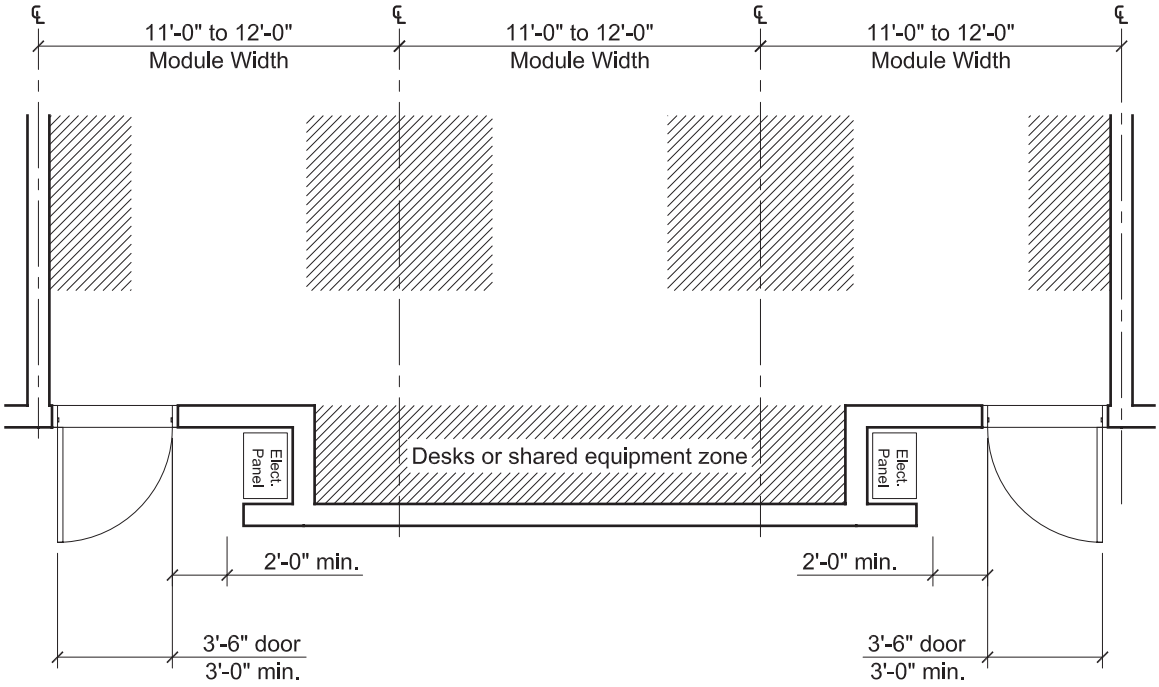


FIGURE 2-3B. exit/entry one-leaf door locations and layout for three-module laboratory.

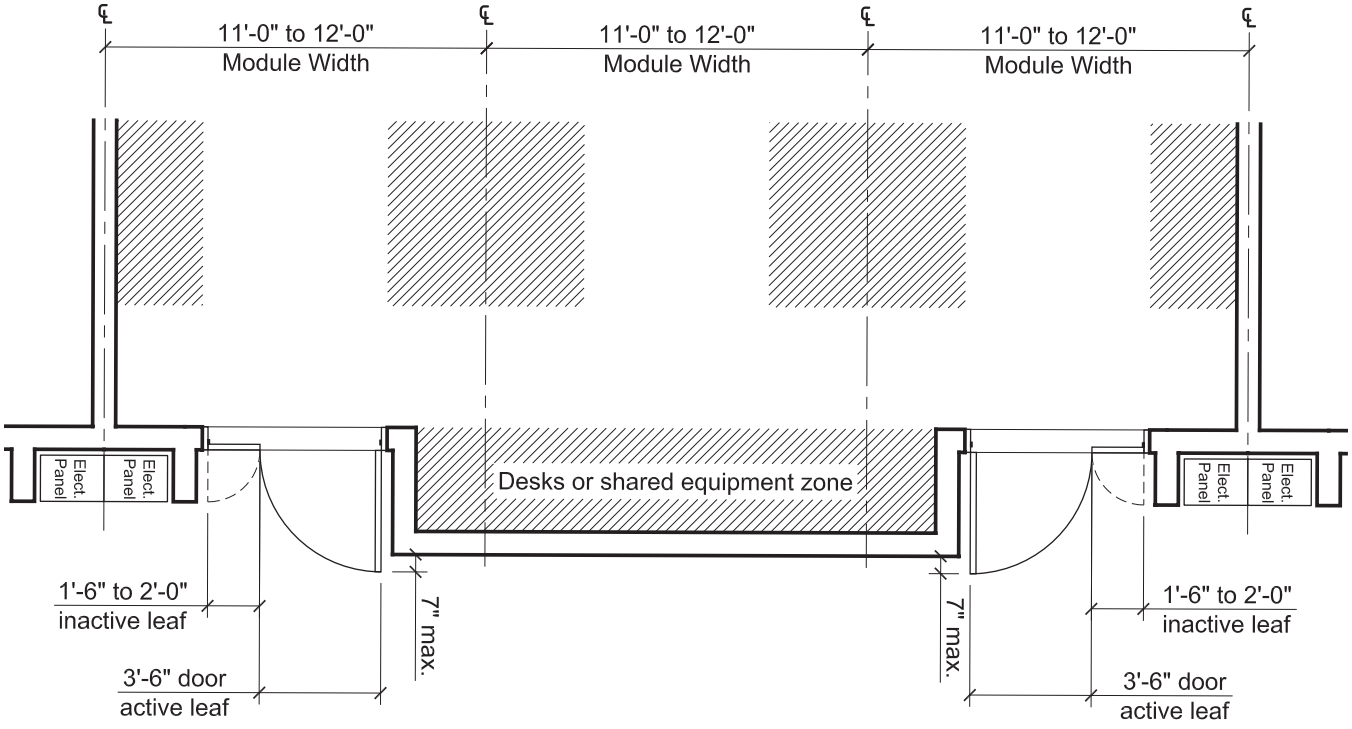


FIGURE 2-3C. Exit/entry two-leaf door locations and layout for two-module laboratory.

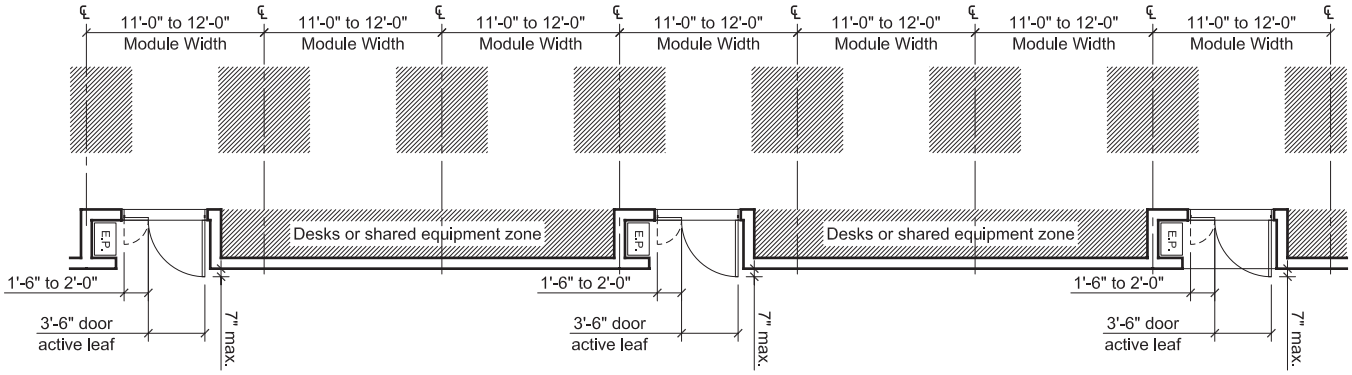


FIGURE 2-3D. Exit/entry door locations and layout for multiple-module laboratory.

Section 1015 "Exit and Exit Access Doorways," paragraph 1015.2.1 (IBC, 2012) has requirements on the separation of two exits from the same space: "Exit access doors shall be placed a distance apart equal to not less than one-half of the length of the maximum overall diagonal dimension of the area to be served measured in a straight line between exit doors." Exit doors are separated far enough apart so occupants have the choice of a clearly shorter pathway out of the laboratory in emergencies, as shown in Figures 2-3A–D.

2.2.2.2.2 Direction of Door Swing. Exit doors should swing in the direction of egress because occupants cannot block out-swinging doors when they panic trying to leave the laboratory. Also, in an emergency, it takes less time to push open an out-swinging door than to pull open a door. Finally, a solvent fire in a tightly constructed laboratory room might raise room air pressure sufficiently to make it very difficult to open an in-swinging door. On the requirement for out-swinging doors, the NFPA 45, Section 5.4.2 (2011) distinguishes between high and moderate fire hazard and low fire hazard laboratory units. Because laboratory designers have no control over how any individual laboratory may eventually be used or its contents and hazards, it is recommended that all doors swing in the direction of egress.

2.2.2.2.3 Door Swing into Egress Pathways. Out-swinging doors should be recessed to make certain that open doors must not diminish the required clear width of egress corridors. When doors are fully open, the maximum protrusion into the corridor is 7 in. (18 cm) again shown in Figure 2-3A. This small protrusion makes it unlikely that persons passing in the corridor could block the opening of the laboratory exit door or bump into the door as it opens. When doors swing fully into the corridor, the minimum required corridor exit width must not be diminished, and the floor area impacted by the door opening must be marked with signs and graphic indicators to warn passersby. In such a circumstance, corridor widths should be 6–7 ft (1.8–2.1 m), or wider.

Glass panels of 100 in.^{2} (0.065 m^2) or less are permissible in B-labeled fire-rated laboratory exit doors, normally used in 1-hour fire-rated corridor partitions, as shown in IBC, Section 715.4, "Fire Door and Shutter Assemblies," paragraph 715.4.4.1 (2012). Glass panels in doors help prevent collisions of persons entering and exiting. The glass should be placed low enough that short people or those who are in wheelchairs can be seen from both sides of the door.

2.2.2.3 Anterooms to Laboratories. Anterooms are small rooms or vestibules directly in front of laboratory entries. Other names for an anteroom are air lock, entry vestibule, and biovestibule. Laboratories may require anterooms at primary entries to provide enhanced access control and security, as well as an airflow buffer when a two-stage pressure differential is needed to enhance laboratory air containment or cleanliness. Anterooms are commonly seen in laboratories using radiation; in microelectronics, cleanroom, high-toxicity, engineering, and pilot plant laboratories; biosafety laboratories at Levels 3 and 4; autopsy and gross anatomy laboratories; and morgues. All of the considerations of accessibility in Section 2.2.3 apply to laboratory anterooms. Figures 2-4A and B show the application of anterooms at primary laboratory entries.

2.2.2.3.1 Security and Controlled Access. Several types of laboratories, including radiation and biosafety Levels 3 and 4, require a minimum of two secured entry doors. The anteroom outer or corridor door is the first secured door, and the inner door to the laboratory itself is the second, meeting Nuclear Regulatory Commission (NRC), National Institutes of Health (NIH), and Centers for Disease Control (CDC) requirements. The doors can be further enhanced for security and access control

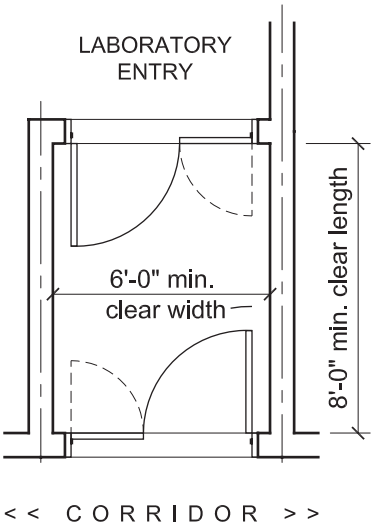


FIGURE 2-4A. Anteroom layout and dimensions, straight entry.

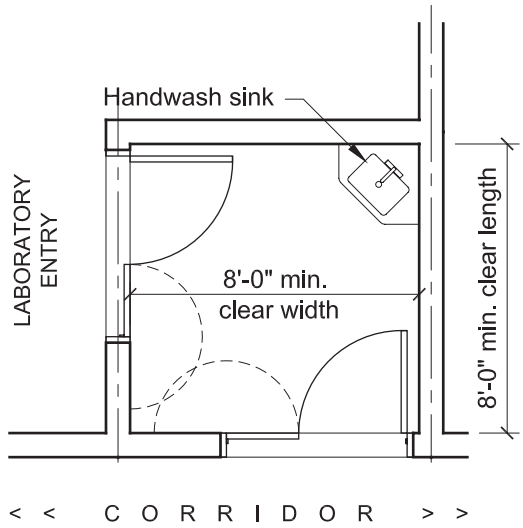


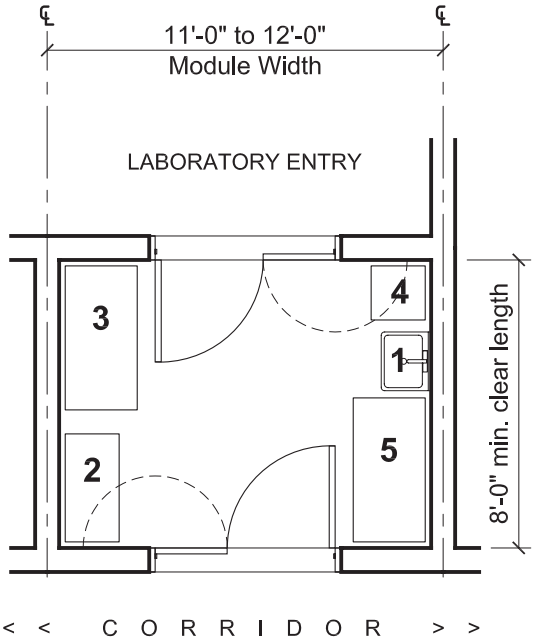
FIGURE 2-4B. Anteroom layout and dimensions, entry with 90° turn.

through various hardware devices such as card-key readers, proximity sensors, monitors and alarms, and interlocking mechanisms that prevent both doors from opening at the same time. Doors should be separated sufficiently, by a minimum of 7 ft. (2.13 m), to discourage someone from holding both doors open at the same time.

2.2.2.3.2 Differential Pressurization Transition. Some exclusion laboratories, such as microelectronics and cleanroom laboratories, require positive pressurization relative to surrounding areas, including corridors. However, as explained later in Section 2.3.2, containment inward airflow is needed where laboratories use hazardous or malodorous chemicals or biological materials. Air normally flows into laboratories from corridors and surrounding spaces. Anterooms make this possible. Anterooms can perform as buffers or "air sinks" for airflow leaking out of exclusion laboratories. Constant exhaust air drawn from anterooms captures and removes possible laboratory contamination before it can migrate or infiltrate through the doors into corridor air. For containment laboratories, air flows from anterooms into laboratories. Anterooms in these conditions are positively pressured in relation to both containment laboratories and other adjacent spaces. NIH research shows that positively pressured anterooms greatly reduce the amount of contaminants that may escape into the anteroom when a laboratory entry door opens and shuts. The positive pressure counteracts a vacuum effect of a door swinging open (Memarzedeh, 2010).

For this reason, anterooms are sometimes called "air locks." Anterooms can provide step-down or transitional airflow. Air-pressure differentials from 0.01–0.05 in. water (2.49–12.44 Pascals [Pa]) occur from corridors into anterooms. Then another 0.01–0.05 in. water (2.49–12.44 Pa) differential occurs from anterooms into laboratories, where additional exhaust is provided. Air flows from corridors into anterooms when doors open; this ensures airflow in the desired direction according to the laboratory use as exclusionary or for containment.

2.2.2.3.3 Other Considerations. Anterooms are often also used as gowning or changing rooms where laboratory occupants can put on clean personal protective equipment (PPE) and wash their hands before entering laboratories. Used as changing rooms, anterooms can store occupants' clothing and be adjacent to shower rooms, where occupants exit from containment laboratories, such as high-toxicity laboratories, as discussed in Chapter 6, or BSL-3 or 4 laboratories, discussed in Chapter 14. Daily supplies and PPE can be stored in anterooms; this is convenient for laboratory occupants and for delivery personnel, who can restock shelves and do not have to enter restricted access laboratories. Figures 2-5A and B show sample anteroom layouts including use as a gowning and changing room and for limited storage. The key considerations for layout are maintaining the aisle width, 5 ft. (1.5 m) minimum, and separating the doors by 7 ft. (2.13 m) minimum. The number of persons entering an anteroom during short periods influences the size of anterooms that will be required. In organizations where laboratory technicians work in shifts, anterooms must be of adequate size to permit smooth flow of persons in and out of busy large laboratories. Anterooms are shown on sample

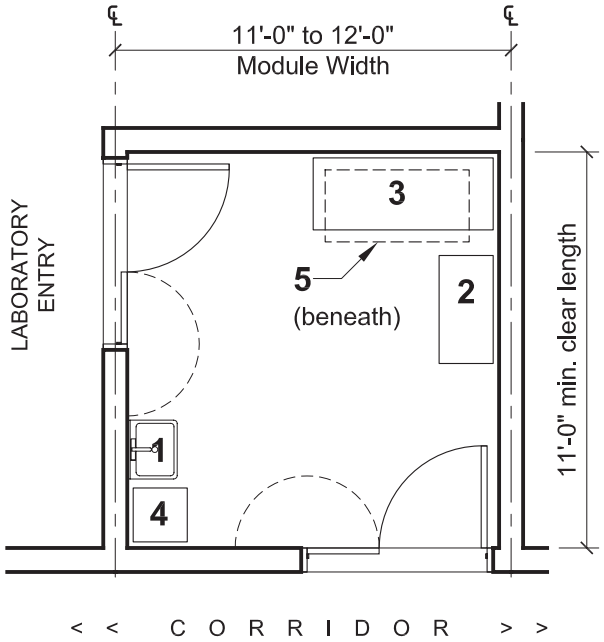


KEY

1 Hand-wash sink
2 Mobile PPE / lab coat rack
3 Mobile PPE storage unit
4 Mobile PPE disposal bin
5 Mobile soiled PPE bin

Note: Size of Laboratory Anteroom is dependent on number of laboratory occupants and any schedule for use. Increase number of faucets and size of sink(s), increase floor area to accommodate average number of users at any one time, and increase storage.

FIGURE 2-5A. Anteroom used for gowning, straight entry.



KEY

1 Hand-wash sink
2 Mobile PPE / lab coat rack
3 Mobile PPE storage unit
4 Mobile PPE disposal bin
5 Mobile soiled PPE bin

Note: Size of Laboratory Anteroom is dependent on number of laboratory occupants and any schedule for use. Increase number of faucets and size of sink(s), increase floor area to accommodate average number of users at any one time, and increase storage.

FIGURE 2-5B. Anteroom used for gowning, entry with 90° turn.

laboratory layouts for biosafety in Chapter 14, gross anatomy in Chapter 17, autopsy in Chapter 19, animal research in Chapter 22, and microelectronics and cleanroom laboratories in Chapter 23.

2.2.2.4 Access for Disabled Persons. If disabled persons work, learn, or teach in laboratories, all parts of the laboratory and its emergency equipment should be accessible. Laboratory emergency eyewashes, deluge showers, fire alarms, fire extinguishers, electrical outlets, switches, emergency alarms, communication equipment, and controls should be designed in accordance with applicable federal and state architectural barriers codes. An example of an essential laboratory safety device, a chemical fume hood adapted for use by persons in wheelchairs, is shown in Figure 2-6. Another safety device is shown in Appendix A, Figure A-1, an emergency deluge safety shower.

FIGURE 2-6. ADA accessible fume hood in a teaching laboratory. (*Courtesy:* LabConco, Corp.)

Many building codes and federal guidelines, such as the Architectural and Transportation Barriers Compliance Board, the Uniform Federal Accessibility Standard (UFAS, 1997), and the Americans with Disabilities Act Accessibility Guidelines (ADAAG, 2010), are concerned with removal of architectural barriers in buildings where handicapped persons work and learn. In laboratory facilities, there are specific accommodations that need to be considered. Lever-action handles on building and laboratory doors are easier to activate than knobs in emergencies. Furthermore, the firm downward motion to release the latch does not require the use of hands, which is a definite advantage in laboratory settings. Architectural barrier standards also limit the pressure required to open doors containing automatic door closer mechanisms. For interior hinged doors, the pressure limit is 5 lb (23 N) of force (ANSI 117.1; American National Standards Institute, 2009).

Minimum dimensions for exit doors are 32 in. wide by 80 in. high (0.8 m × 2.0 m), with a minimum of 78 in. (1.98 m) clear height under door closers. Standard practice and architectural barrier codes such as ANSI Standard 117.1-2009, "Providing Accessibility and Usability for Physically Handicapped People," recommend a minimum of 36 in. × 80 in. (0.9 m × 2.0 m) to facilitate persons in wheelchairs moving in and out. Primary laboratory entry doors (i.e., those used routinely) 42 in. × 80 in. (1.1 m × 2.0 m) in size are even better for passage of equipment, carts, and wheelchairs and reduce damage to doorframes. In addition, adequate clearance between the opening side of the door and any obstruction, such as a wall or lab bench, is required on both the push and the pull sides of the door, as shown in Figure 2-7. Openings such as windows, trap doors, and knock-out panels between adjacent laboratories do not qualify as exits or as secondary emergency exits. Doors from laboratories onto the balconies of multistory buildings are not considered to be legal exits, although in some jurisdictions they may be considered areas of fire refuge where firefighters can reach laboratory occupants, and where they meet safe height and structural requirements of applicable building and fire codes. Exits must be marked in accordance with local and national standards, and exit signs must remain lit even during power failures.

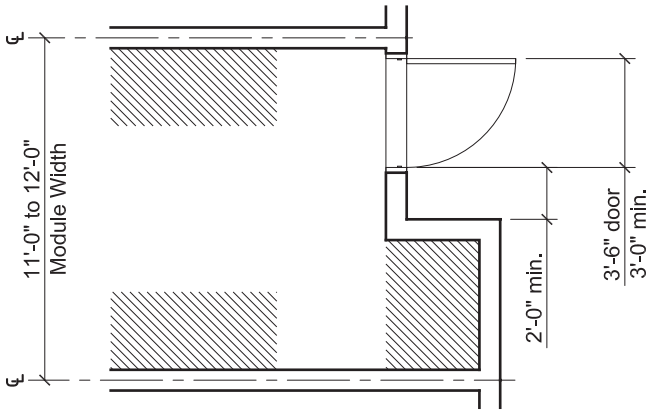


FIGURE 2-7. Exit/entry door clearances for universal accessibility.

2.2.3 Laboratory Utility Distribution

Modular laboratory design emphasizes the need to distribute laboratory utilities uniformly in laboratories, supporting long-term flexibility for use of laboratories. There are four common strategies for distributing laboratory utilities and mounting outlets and fixtures for those utilities: in-wall, surface mounted, bench mounted, and ceiling mounted (Table 2-1).

Although wall- and bench-mounted utilities are traditional installation methods, ceiling-mounted options can enhance laboratory flexibility. As shown in Figure 2-8A, a section diagram of an overhead utility carrier, ceiling distribution leaves the floor and bench levels free of fixed obstructions. Ceiling-mounted devices should be located no lower than 80 in. (203 cm) above the finished floor, so tall occupants will not bang their heads. Ceiling devices can be mounted at 8 ft. (2.4 m), a height that keeps the utilities above most tall equipment, such as freezers, robot enclosures, and biological safety cabinets, as shown in Figure 2-8B, a view of an overhead utility carrier in a laboratory. One great disadvantage of this height is that laboratory users must either be tall, or use ladders and stepstools to reach outlets and fixtures to make changes. Using ladders can be hazardous to occupants, equipment, and benches nearby. Quick disconnect fittings reduce this inconvenience, but not entirely. These are not user-friendly systems if occupants regularly need to unplug equipment, even though cord and gas tubing management can be effective.

Bench-mounted utility installations generally are convenient and safe for users. They occur along module lines so they have a reasonable amount of flexibility to reach any part of the laboratory. Many laboratory casework manufacturers can supply bench-mounted utility distribution systems, outlets, and fixtures, as shown in Figure 2-9. Bench-mounted utilities must be coordinated with large arrays of equipment and arrays of split benches for analytical equipment. In these conditions wall-, bench-, and ceiling-mounted utilities can be used together to supply utilities, where utilities are needed.

2.2.4 Hazard Zoning Concept

Observing the concept of hazard zoning, laboratory benches, desks, and other furnishings are designed and

TABLE 2-1. Pros and Cons of Common Laboratory Utility Distribution Methods

DISTRIBUTION MODE	PROS	CONS
IN WALL	Wall cavities conceal pipes and conduit	Pipes and conduits hard to locate
	Outlets and fixtures can go anywhere	Leaks and problems hard to detect
Fixtures on Access Panel	Access panel removable for service	Outlets and fixtures only mounted at access panel
	Panel is flush with wall surface	Depth of wall may limit bends for pipes and conduits to outlets
SURFACE MOUNTED	Pipes and conduits attached to walls	
Exposed	Pipes and conduits visable	Pipes and conduits not attractive
	Leaks and problems easier to find	Pipe and conduit protrusions in front of wall vulnerable to damage
In Service Chase	Pipes and conduits easily accessible	Standard locations for chases
	Additional depth accommodates bends in pipes and conduits	Service chase cover vuinerable to damage
BENCH MOUNTED	Pipes and conduits mounted on racks behind benches	Need access panels at knee spaces to reach pipes, conduits for service
	Space to add utilities	Need risers to chases behind bench
On Work Surface	Outlets and fixtures are accessible from both sides of island benches	Utility outlets and fixtures subject to damage from spills on work surface
		Outlet bases require cleaning
		Requires many holes in work surface
		Electric cord management difficult
On Service Ledge	Utility outlets and fixtures raised above work surface, less affected by spills	Ledge restricts depth of work surface
	Fixtures and outlets can be mounted on ledge top and on both sides	Ledge requires cleaning
On Shelf Support Panel	Fixtures and outlets on vertical surface	Distribution only at vertical panels
	Easier to add and modify fixtures and outlets	Depth of panel may limit bends for pipes and conduits to outlets
	Electric cord management possible	Limit on quantity of outlets or fixtures
Beneath Reagent Shelf or Wall Cabinet	Continuous wiremold installation with most flexibility of number/type outlets	
	Electric cord management easy to do	Bottom shelf is fixed, not movable
	Outlets and fixtures easy to reach	
CEILING MOUNTED	Less piping and conduit required	Most maintenance done on ladders
	Easy connections to ceiling mounted pipes and conduits	Requires lab users to use ladders to reach outlets and fixtures above
	Greatest flexibility, no utilities on floors or walls, except drain pipes	
On Pedestal Drop In Service Wing	Easier to coordinate with lighting layout	Requires structural support to hang it
	Outlets and fixtures are directly above benches for short cord and tube drops	Linear elements can interfere with light fixture layout. Must coordinate.
		Requires structural support to hang it
On Unistrut Grid	Suitable for multiple, heavy piped utilities and electric buss bars	Lighting must be attached to or beneath the grid

located to facilitate emergency egress and safe circulation in all parts of laboratories. The design team establishes zones in a laboratory by locating benches, utilities, and major fixed equipment in relation to the primary and secondary emergency exits. For example, in laboratories that have chemical fume hoods for conducting potentially hazardous operations, the hoods should be located away from the primary access door, as shown in Figure 2-10A and discussed later in Section 2.2.5. Figure 2-10B shows the direction toward the primary exit allowing occupants to move away from hazards.

2.2.4.1 Seated-Height Workstations. Where chemicals, lasers, or other environmental hazards are present,

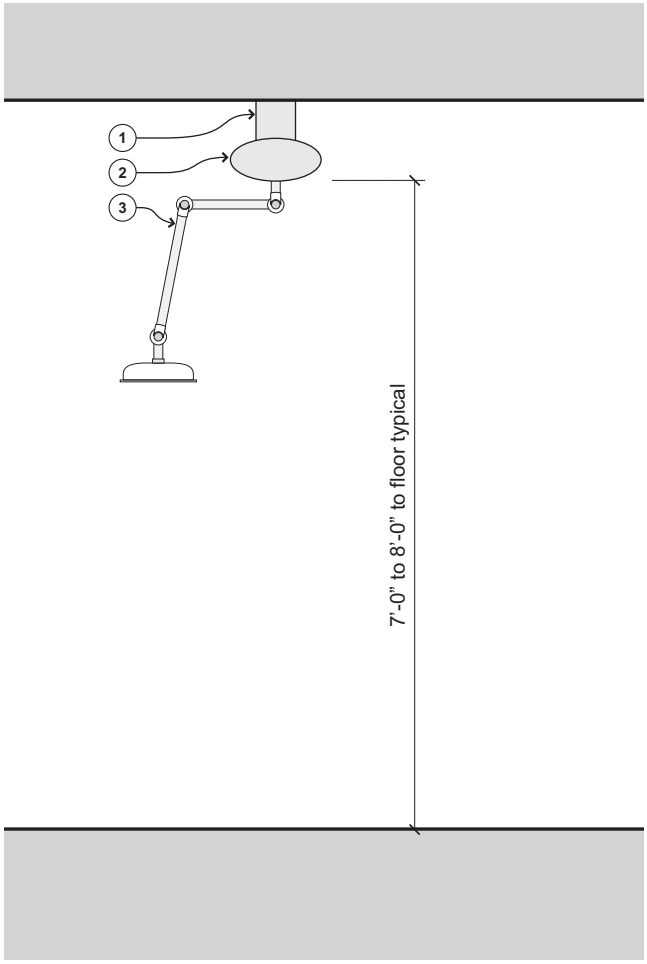


FIGURE 2-8A. Section diagram of an overhead utility carrier.

FIGURE 2-8B. View of an overhead utility carrier. (*Courtesy:* Massachusetts Institute of Technology, Cambridge, MA)

FIGURE 2-9. Bench mounted piped utilities. (*Courtesy:* Washington University, St. Louis, MO)

separate office areas should be provided for laboratory staff outside of the laboratories, to protect them from chronic exposures and other acute exposures, as explained in Chapter 1, Section 1.2.1.2. If seated height workstations are required for microscopy, dissections, computer use, write-up activities, or other laboratory functions, they can be used safely in laboratories if these low workstations are in safe locations. Seated work stations (or desks), where laboratory workers concentrate their attention on a limited field of vision and may not be fully aware of other activities occurring in laboratories, should be located away from potentially hazardous operations and storage of hazardous materials. A hazard zoning diagram is shown in Figure 2-10B. The path from a desk to primary exit should not require movement in toward or past a zone of increasing hazard, as explained in Chapter 1, Section 1.2.2.4.

2.2.4.2 Benches. Benches not installed along walls may be of the island type that has aisles on all sides so laboratory occupants can move around benches quickly to reach emergency equipment or an exit. Island-type benches are required in the layout shown in Figure 2-10A. When there are approved exits on both sides or at both ends of a laboratory space, then peninsula-type benches are acceptable. Single-module laboratories are usually equipped with benches along both long walls and have a central aisle between them, as shown in Figure 2-2A.

2.2.4.2.1 Bench Materials. Laboratory benches should be made of sturdy materials that have finishes that can be repaired easily and that resist chemicals. Base storage units that are secured to the bench on cantilevered or

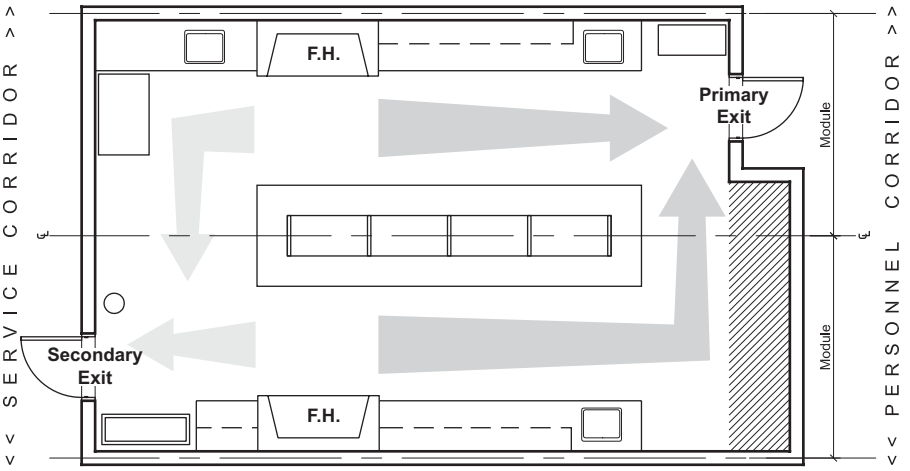


FIGURE 2-10A. Plan of typical two-module laboratory.

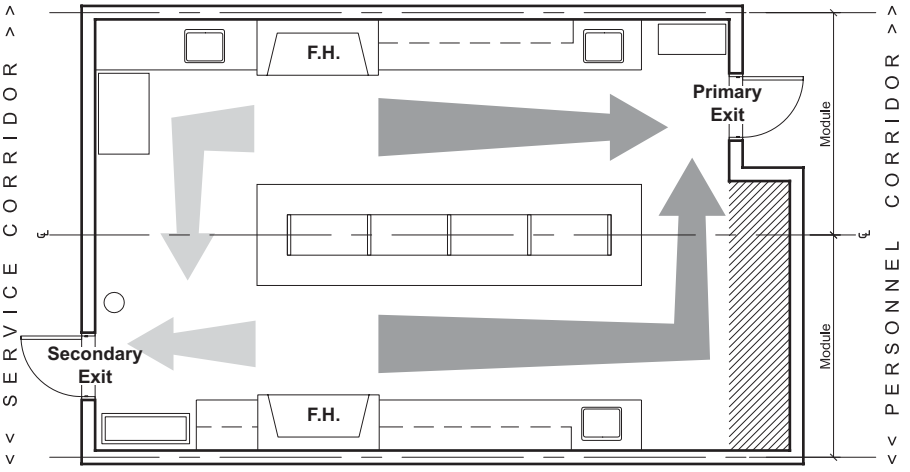


FIGURE 2-10B. Diagram of hazard zoning in a typical laboratory layout.

suspended metal frames should be secured so that they will not fall off when carts or equipment crash against them. Base storage units that are mounted directly on the floor are stable and do not amplify floor vibrations to bench tops.

2.2.4.2.2 Bench Ergonomics. Knee spaces should be provided along laboratory benches to permit workers to sit comfortably and safely if they have to work steadily there for long periods. With knee spaces, workers can put their feet on the floor or onto foot rings of laboratory stools, pull up to the work surface and be able to maintain balanced, upright postures while working, which reduces fatigue and increases manual agility. Persons seated at knee spaces provide more area behind for others moving along aisles. When empty chairs or stools can be pushed all the way into knee spaces this further reduces aisle obstruction. Some laboratory casework systems have movable knee spaces where cabinets can shift readily if the work position needs to move.

Work surface heights in the laboratory are designed generally for two body positions, seated and standing: seated work surface heights are 30 and 32 in. (0.76 and 0.81 m), and standing work surface heights are 35 and 37 in. (0.9 and 0.95 m). At least one seated workstation is recommended in laboratories where techniques require fine hand-to-eye coordination and manual motor control. For many laboratory functions and for disabled persons employed in laboratories, accommodations may be required to change work surface heights and storage components. Many adjustable-height casework systems allow height adjustments at 1-in. (2.5 cm) increments to accommodate most user needs. In those laboratories where one or more occupants use a wheelchair, hand

wash sinks need to be lowered. Also, benches can be installed to move horizontally so as to change the location of knee space. Adjustments to emergency equipment should also be made to meet accessibility standards of the occupants concerned.

2.2.4.3 Work Surfaces. Work surfaces and base storage units should be dimensioned to permit safe reach to access utility outlets, and easy reach to the storage units above the work surface. The standard work surface depth is 2 ft (0.6 m), not including the depth of the utility strip. When deeper surfaces are needed to safely accommodate large pieces of bench-mounted equipment, safe access to utilities must be maintained. Work surfaces should be installed level and be able to withstand heavy loads (up to 120 pounds per linear foot, 400 pounds per linear meter) of equipment and instruments that may be placed on them.

When the clearance between the horizontal work surface and the underside of a wall-mounted storage unit is less than 2 ft (0.6 m), the projection of these units over the work surface should not be greater than 1 ft (0.3 m). With this geometry, it is not likely that intense heat sources from equipment or open flames from Bunsen burners, for example, would be placed beneath the shelf that would burn the wall-mounted storage unit or its contents.

2.2.4.4 Equipment. Layout of fixed and movable equipment is determined by the hazards presented by the equipment, the requirements for utility connections, the area the equipment occupies, the mounting method, and the clearances on all sides required for good performance and maintenance. The most hazardous processes and associated equipment should be placed away from primary laboratory access doors. Equipment posing little or no hazard can be placed closer to primary egress routes. A checklist for the selection and location of laboratory equipment is given in Table 2-2.

TABLE 2-2. Checklist for Selection and Location of Laboratory Equipment

A.	List all major items of scientific and computational equipment in each laboratory according to the following characteristics
	1 Physical Dimensions and Weight
	2 Mounting Method—bench, free-standing, ceiling, wall, or other method
	3 Movable or Fixed
	4 Utility Connections—fixed, flexible, above, below, behind, or beside fixed or quick disconnects above, below, behind, beside
	5 Utilities and Building Services—quantity and volume water, drain, steam, gases, electrical, local exhaust, air supply
	6 Maintenance Clearances and Locations
	7 Operator's Position and Clearances
	8 Equipment Attachments
	9 Equipment Associated Computers and Accessories
	10 Vibration Characteristics—heavy rotary components or vibration sensitivity heavy rotary components or vibration sensitivity
B.	Determine locations and area required for supplies associated with each item
	1 Glassware
	2 Manual Instruments
	3 Chemicals
	4 Disposable Goods

2.2.4.5 Emergency Equipment Locations and Safety Stations. Emergency equipment, including emergency eyewash fountains, deluge showers, fire extinguishers, and fire blankets should be located in laboratories near the hazards. For example, if fires are more likely to occur in or near chemical fume hoods, then appropriate small fire extinguishers should be mounted nearby. Laboratory sinks are good locations to install emergency eyewash fountains; eyewash fountains should be placed near the areas in which major chemistry is performed and where the risk of chemical splashes is higher. Safety equipment is discussed further in Section 2.4.

A laboratory safety station is an installation of safety and limited emergency response equipment that is selected for each laboratory. Typical items include safety goggles and protective glove dispensers, shoe covers and protective garments, a chemical spill kit, a First Aid kit, and a flashlight. Centralized safety stations may have an emergency eyewash fountain, a deluge shower, and a fire extinguisher. Fire extinguishers in safety stations are used to rescue occupants trapped in the laboratory, not to extinguish in-lab fires. Laboratory safety stations also have bulletin boards or other surfaces dedicated for display of safety regulations and announcements.

Safety station locations that are consistent from laboratory to laboratory present a more consistent and reinforced safety message to laboratory users and improve emergency response time and effectiveness because lab occupants know where to find the information they need to appropriately respond to emergencies. Primary laboratory entries are excellent locations for the safety station because laboratory occupants pass by it daily, as shown in Figure 2-11A inside a laboratory and Figure 2-11B in a hall outside laboratories. Figures 2-11C and D show components of a safety station flanking a laboratory entry, with eyewash and safety shower controls on one side, and fire extinguisher and first aid kit on the

FIGURE 2-11A. View of a safety station near the entry in a teaching laboratory (Copyright by HERA Laboratory Planners).

FIGURE 2-11B. View of emergency eyewash and deluge shower in a corridor (Copyright by HERA Laboratory Planners).

FIGURE 2-11C. View of laboratory entry with emergency eyewash and deluge shower. (*Courtesy:* Washington University, St. Louis, MO)

FIGURE 2-11D. View of laboratory entry with first aid kit, fire blanket, and extinguisher. (*Courtesy:* Washington University, St. Louis, MO)

other. In emergencies, occupants do not have to waste time recalling where emergency response equipment is kept. Good signage can draw attention to safety equipment. When equipment is empty or missing from the safety station, occupants will notice it more readily and can contact the laboratory safety officers for replacements. Laboratory entries should be kept unobstructed by equipment, supply boxes, and personal belongings such as coats, boots, and handbags, so that safety stations are always visible and accessible. To reduce clutter at laboratory entries and elsewhere, lockers or secured coatrooms should be provided for occupants. In addition, adequate storage facilities should be provided within laboratories and in the building for bulk storage of supplies and unused equipment. Safety equipment such as self-contained breathing apparatus (SCBA) should be strategically located in laboratory building

TABLE 2-3. Laboratory Cabinet Materials' Health and Safety Performance

Material	Composite[a]	Coated Metal	Phenolic[b]	Plastic Laminate[c]	Polypropylene[d]	Stainless Steel	Wood & Veneers
Chemical Resistance	Good	Good	Good	Fair	Good	Good	Good
Combustibility	Good	Good	Good	Poor	Fair	Good	Poor
Cleanability	Good	Good	Good	Fair		Good	Good
Strength	Good	Good	Good	Poor	Fair	Best	Good

NOTES:
[a]Plastic panels with rigid foam filler.
[b]Solid phenolic resin between craft paper layers.
[c]Chemical-resistant plastic laminates are available for laboratory cabinets.
[d]Other plastic materials, such as polyvinyl chloride (PVC) are used.

corridors, unless it is required within specific high-hazard laboratories.

2.2.5 Location of Fume Hoods

Because hazardous operations are usually conducted in laboratory chemical fume hoods, as discussed in Section 2.2.4, these hoods must be located away from primary laboratory exits for safety reasons. As shown in Figure 2-10A installing hoods at the far ends of laboratory aisles also reduces movement past open faces of hoods, which adversely affects hood performance as described in Chapter 32. Partially enclosed alcove locations may constrict flow to or cause turbulence at chemical fume hood openings; thus alcoves should be avoided. In laboratories that require multiple chemical laboratory hoods, hoods should be arranged to optimize the distance between them, so that airflow to each is undisturbed. The *NIH Methodology for Optimization and Testing of Laboratory Hood Containment, Volumes I and II* (NIH, 1996) documents and evaluates chemical fume hood performance relative to position, using a computational fluid dynamics (CFD) analytical method. The NIH study tested a great number of possible positions of one and two chemical fume hoods in two standard laboratory sizes. The study established several critical factors beyond the laboratory layout and selection of particular chemical hoods. These factors include the distribution of supply air diffusers, diffuser types, and the jet thickness produced by diffusers. Generally, NIH results show that a minimum of 8 ft (2.4 m) between side-to-side hoods and 17 ft (5.2 m) between face-to-face chemical hoods provides good performance, if all other factors of laboratory traffic and diffuser selection and locations are optimized. Two hoods centered on perpendicular walls work well in double-module laboratory layouts that provides from 10–20 ft of separation. Laboratory planners should work closely with mechanical engineers to design optimal conditions for chemical fume hood installations.

2.2.6 Laboratory Furniture and Systems

Laboratory building owners and the design team can choose among a variety of materials for laboratory furniture: metals, wood, composites, and plastic laminates. These materials offer varying degrees of chemical resistance, strength, durability, and the capability of being repaired and refinished to extend their useful lifetime (Table 2-3). These factors depend on the way joints are made, how many joints there are in the cabinet, and on the support system for the cabinetry. Architects who specify cabinets and systems need to carefully inspect actual, full-size examples of major units. It is helpful for architects to visit manufacturing plants where cabinetry is produced to see fabrication methods and gain more detailed information.

In some types of laboratories, common maintenance and housekeeping issues are critical to achieving health and safety goals. For example, in laboratories rated at biosafety Level 2 and above, and in microelectronics labs or other cleanrooms, cleanability is critical. Fewer joints in casework and at work surfaces result in fewer cracks and irregularities that harbor harmful dust particles and microorganisms. In many types of labs, casework strength and sturdiness allow heavy equipment to be installed and used. Collapse of laboratory furniture is an obvious hazard in itself, but this failure can damage or spill materials contained within and upon the casework. Sometimes the failure is not the cabinet, but the mounting method and/or hardware at the wall or at the casework support system.

2.2.6.1 Benches. There are many types and sizes of benches available from many reputable manufacturers.

A good laboratory designer first selects the appropriate support system, and only then selects the cabinet units that form the benches. There are a variety of methods and support systems available. Table 2-4 provides a comparison of the safety performance characteristics of various support systems.

TABLE 2-4. Laboratory Casework Systems Structural Support Safety Performance

System	C-Frame[a]	Fixed[b]	Mobile	Movable	Table Frame[c]	Wall Frame
Chemical Resistance	Good	Good	Good	Good	Good	Good
Combustibility	Good	Good	Good	Good	Good	Good
Cleanability	Good	Good	Good	Fair	Good	Good
Earthquake Resistance	Fair	Best	Poor	Fair	Good	Fair[d]
Flexibility	Good	Poor	Best	Fair	Good	Good
Strength	Varies[e]	Best	Varies[e]	Good	Varies[e]	Varies[e]
Vibration Control	Fair	Best	Fair	Good	Good	Fair

NOTES:
[a]Cantilevered frame, often C-shaped.
[b]Bolted to floor.
[c]Called P-Frame if back support is a panel or continuous spine.
[d]Walls must have seismic supports up to structure above ceiling.
[e]Weight limitations vary from system to system. Review specifications.

2.2.6.1.1 C-Frame Systems. A C-frame is a flexible cantilevered system made of metal; it can be demounted, moved, and modified. Frames are typically steel members assembled into a C configuration, as shown in Figure 2-12. They can be bolted to the floor for greater stability and for earthquake resistance. Top arm members of C-frames support work surfaces; cabinetry is suspended from the top frame elements. Some C-frame systems have horizontal rails from which cabinets are suspended, but not fixed. In these systems, cabinets can slide from side-to-side, providing knee spaces wherever required. In many C-frame systems, work surfaces mounted on top can flex, and the frames transmit vibration from floors. C-frame systems have some load limitations, so check systems' specifications for the weight allowable on countertops. Utility supports can be mounted directly to vertical frame members or to the wall behind. Wall cabinets and reagent shelves are fixed to walls or hung upon upright extensions of vertical frame members.

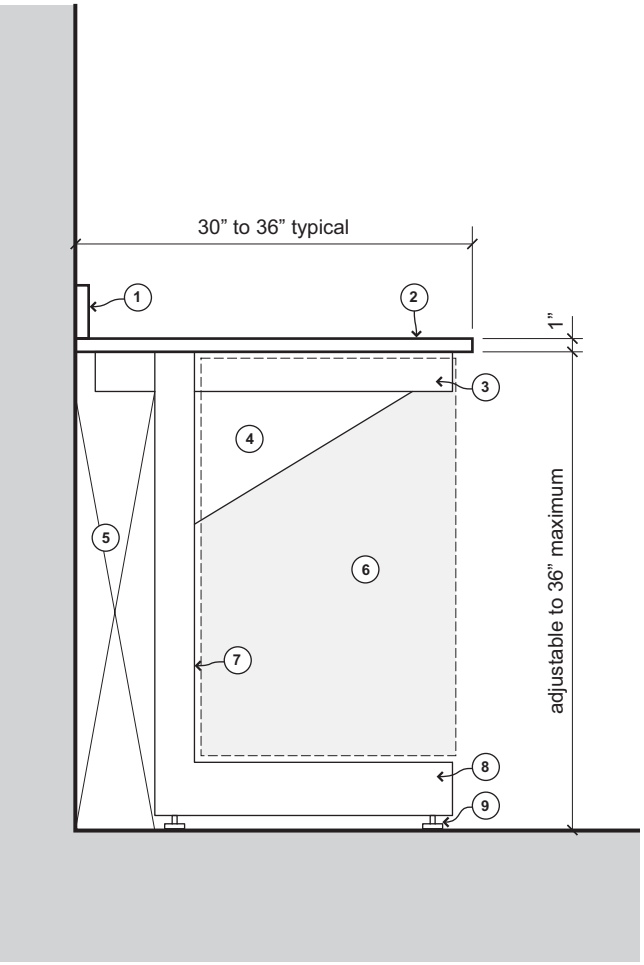


FIGURE 2-12. Section diagram of C-frame bench system.

2.2.6.1.2 Fixed Systems. Fixed cabinets and baseboards are fastened to wood blocking that is bolted into the floor. Cabinets are supported on all four sides, rendering them immobile and stable under most heavy loads placed on countertops as shown in Figure 2-13 as well as under severe earthquake conditions. Work surfaces are supported by and attached directly to the cabinets beneath them. This support is very stable. Sections of countertop can have waterproof sealed joints to make the work surface as long and as wide as required. Utility supports are mounted on separate metal frames or on walls behind fixed cabinets. Wall cabinets are also bolted to walls or hung upon fixed horizontal rails. Vertical extensions of frames can support reagent shelves, or these shelves can be mounted on frames secured to countertops.

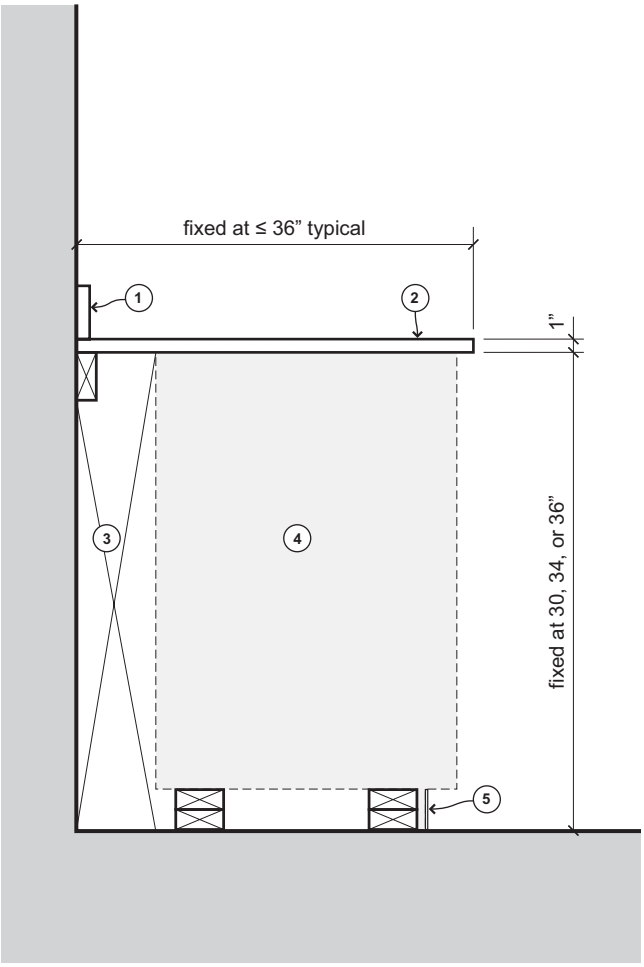


FIGURE 2-13. Section diagram of fixed bench system.

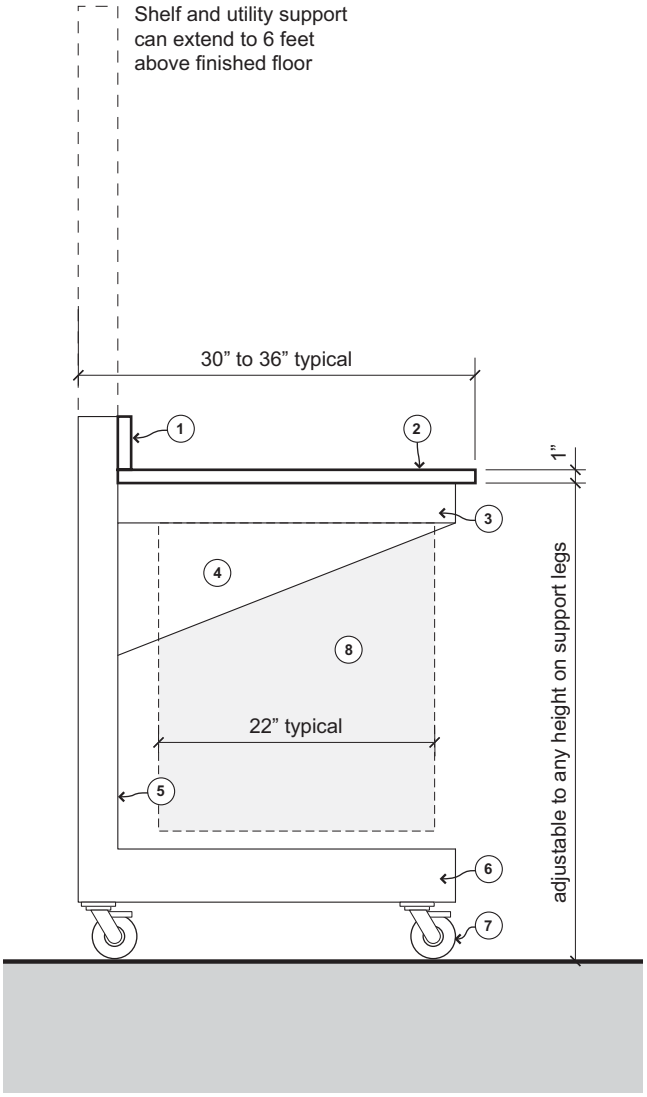


FIGURE 2-14. Section diagram of mobile bench unit.

2.2.6.1.3 Mobile Systems. Cabinets and tables that are equipped with wheels or casters enable users to move them easily as shown in Figure 2-14. Cabinets can be manufactured in any material, but the bottom frames may be reinforced with metal. Some C-frame and table frame systems can be adapted to become mobile by adding casters to support legs. The main limitations are size and weight: one or two people must be able to safely move the unit. Casters and wheels should have brakes to safely stop and restrain unit movement. Mobile cabinets can be used compatibly with other systems.

Mobile systems are not recommended in regions that experience severe or frequent earthquakes. Unrestrained mobile units become juggernauts that can destroy a laboratory during seismic events. Individual mobile units can be aligned, but open gaps will exist between abutting countertops. If long seamless work surfaces are required, this is not the system to specify. Wall cabinets must be firmly attached to walls or wall-frame systems. Reagent shelves are supported on vertical extensions of the frames, where frames exist. Otherwise reagent shelves will be supported independently from mobile units. Attachments should be appropriate in regions that experience seismic events.

2.2.6.1.4 Movable Systems. Movable furniture systems are similar to mobile systems, but use leveling glides instead of wheels or casters to support the cabinet units on the floor, as shown in Figure 2-15, where the countertop is attached to the wall. Because the baseboard is not sealed to the floor, dirty water and dirt can seep under the cabinets; cleaning under movable cabinets on a regular basis may not be practical. But the area should be inspected regularly and any spills of materials or water thoroughly cleaned immediately. Environmental

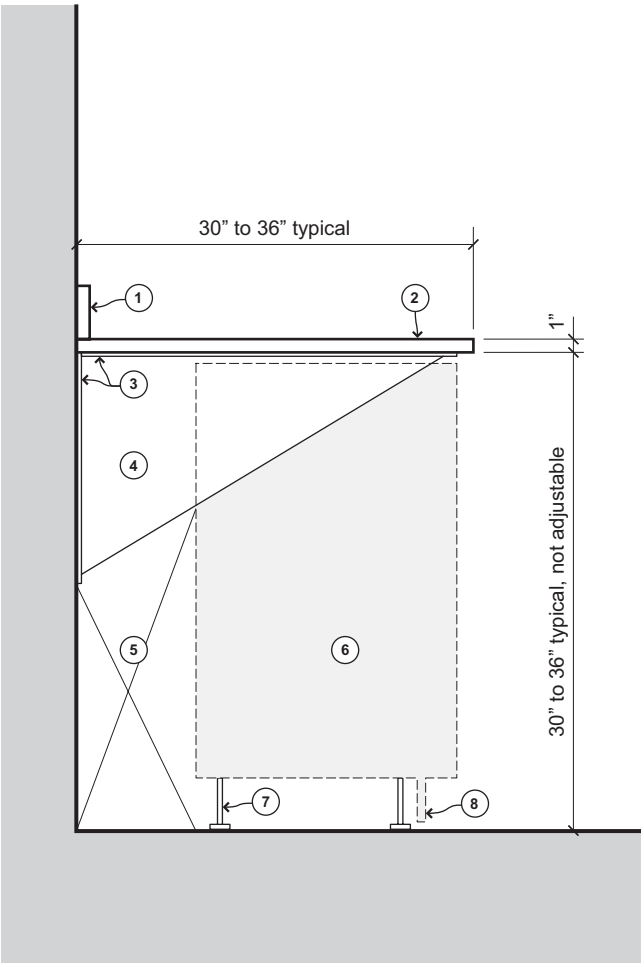


FIGURE 2-15. Section diagram of fixed countertop and movable casework system.

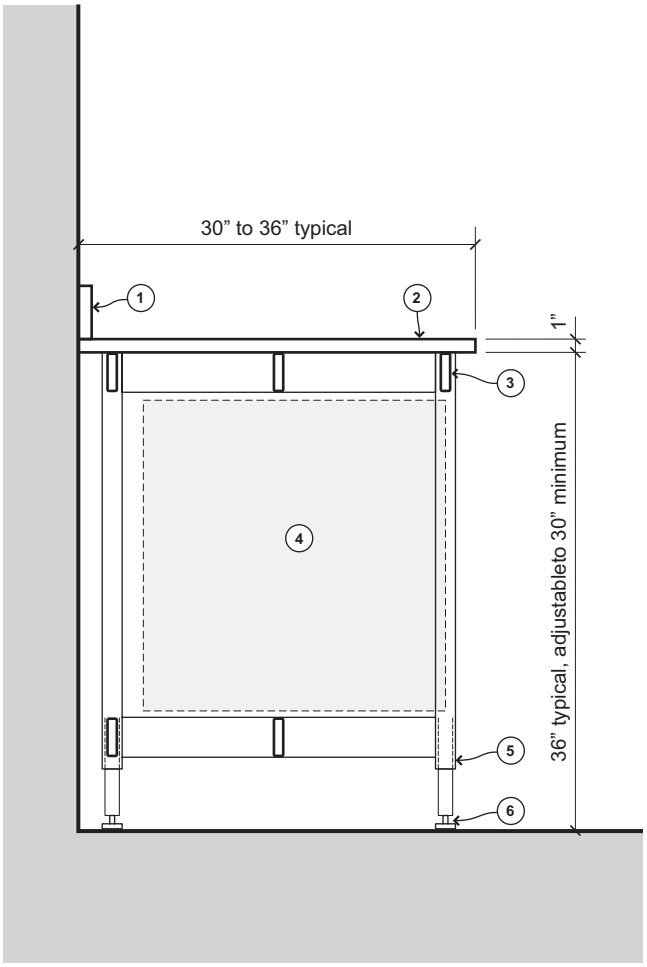


FIGURE 2-16. Section diagram of table frame bench system.

health and safety personnel need to inspect under movable units and test for mold, mildew, rodent, or insect activity that might not be noticed by laboratory personnel. Movable system components may be larger and heavier than mobile components: Skilled maintenance workers, not laboratory personnel, will perform all relocations. Movable cabinets can be used compatibly with other systems. Movable systems also require physical restraints in regions that experience severe earthquakes. Utility supports are mounted on a separate metal frame or on the wall behind the movable cabinets. Wall cabinets are fixed to walls or rail systems. Rails allow quicker and easier relocation and remounting of wall cabinets. Reagent shelves are supported on vertical extensions of the frame, where a frame exists. Otherwise, reagent shelves will be mounted on countertops.

2.2.6.1.5 Table-Frame Systems. Figure 2-16 shows, as its name suggests, in the table-frame system four metal legs support all cabinets and countertops. A variation of this system, the P-frame, uses a structured metal-frame low-wall behind and two metal legs in front as support. These systems are not cantilevered; therefore, they perform with more stability, reducing vibration at countertops and moderately increasing load capacity. Table-frame systems also have many of the positive attributes of C-frame systems. Because table legs are not bolted to the floor, physical restraints are required in regions that experience severe earthquakes. P-Frame low-wall options are better in earthquake zones because these walls are secured to the floor.

As in mobile and movable systems, individual units can be aligned, but open gaps will exist between abutting countertops. If long seamless work surfaces are required, they can be achieved. Utility supports can be mounted to vertical frame members, or on walls behind the countertops. Wall cabinets and reagent shelves are fixed to walls or to upright extensions of vertical frame members.

2.2.6.1.6 Wall-Frame Systems. Wall-frame systems provide a fully enclosed, but unsealed laboratory space. All components, including upper and lower cabinets, utilities, solid (metal) or transparent (framed glass) wall panels, and doors with frames are attached or suspended from this metal frame. Vertical steel frame members extend 8–10 ft above the finished floor level. Metal base tracks supporting the wall frame are attached to the floor, and top tracks are attached to the suspended ceiling grid or braced directly to the structure above. This is required to lend some lateral stability to vertical frame members. Wall-frame systems are not designed to withstand earthquake forces. Building structural engineers must provide earthquake-resistant designs to support the weight and center of gravity of the specific laboratory components and equipment located there.

Wall-frame systems also allow installation of separate suspended ceilings with lighting options. Wall-frame systems are fully demountable and can be moved and resized by adding or removing panels. If the wall-frame system is relocated or expanded, adjustments to or additional ventilation distribution devices may be needed to provide adequate ventilation in new spaces.

Ventilation diffusers and exhaust intakes must be installed within the ceiling assembly to connect to the building HVAC system. Due to the open-joint panel assembly, these systems are not designed to be sealed or pressurized, so they are not appropriate for laboratories that require contaminant containment. Large, floor-mounted equipment and instrument enclosures can look like wall-frame systems. However, these enclosures are sealed, can be pressurized, and may be used in containment or cleanroom applications, as shown in Figure 2-17.

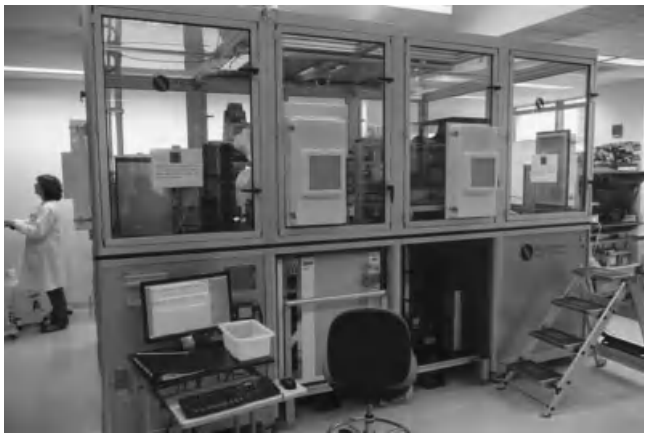


FIGURE 2-17. View of containment enclosure for equipment (*Courtesy:* Massachusetts Institute of Technology, Cambridge, MA).

2.2.6.2 Work Surface Materials. Table 2-5 shows the health and safety characteristics of materials commonly used for laboratory work surfaces. Work surfaces simply do not last as long as cabinetry. It is also often hard to decontaminate, repair, modify, and refinish work surfaces for reuse.

2.2.7 Laboratory Finishes

Chemicals are used routinely in many laboratories for cleaning laboratory equipment and research apparatus. Therefore, chemical resistance, cleanability, and durability of finishes on laboratory surfaces (walls, floors, and ceilings) are important design factors.

2.2.7.1 Wall Finishes. High-performance, institutional grade, water-soluble latex paints are appropriate finish coatings in laboratories where there is minimal to moderate chemical use and where most chemicals used do not produce unsightly stains if spills or splashes are cleaned up quickly. Many latex products generate relatively low volatile organic compounds (VOC) emissions during application and drying periods. Chapter 31 explains sustainable design options for laboratory finishes that have low VOCs.

In laboratories where chemicals can produce unsightly stains if left to dry on wall surfaces or in laboratories where walls must be cleaned regularly to remove particulate contamination, alkyd, solvent-based paints and specific industrial coatings perform better because walls can be cleaned more often and more effectively. Refer to the coatings' comparisons generated by the Master Painters' Institute (www.mpi.org). Many of these coatings generate VOCs. Those fumes must be diluted and exhausted from spaces before the laboratories are occupied. After occupancy, good-quality alkyd and oil-based paints generally do not continue to off-gas VOCs. With cleaning, repainting is less frequent, so over the life span of a building, lower volumes of VOC's are generated. Alkyd and solvent-based paints and anticorrosion coatings are commonly applied on metals and metal trim. Some composite wall material finishes are so durable and cleanable that they do not require refinishing during the entire life span of the wall materials.

Industrial-grade coatings produce very durable, hard, and chemically resistant finishes that can withstand high-pressure hose cleaning or physical abuse. Industrial-grade coatings include epoxies, other types of resins, polyurethane, elastomeric membranes, and fiberglass-reinforced coatings. Each has specific surface preparation and application requirements. Some of these coatings generate high levels of VOC emissions during application and curing. Therefore, additional, temporary

TABLE 2-5. Laboratory Work Surface Materials' Health and Safety Performance

Material	Composite[a]	Epoxy	Phenolic[b]	Plastic Laminate[c]	Polypropylene[d]	Stainless Steel	Solid Wood or Laminate
Chemical Resistance	Good	Good	Good	Fair	Good	Good	Fair
Cleanability	Good	Good	Good	Fair	Good	Good	Fair
Combustibility	Good	Good	Good	Good	Good	Good	Good
Conductivity Resistance	Good	Good	Good	Good	Fair	Good	Good
Durability	Fair	Good	Good	Poor	Fair	Good	Fair
Flexibility	Good	Good	Good	Best	Fair	Good	Good
Level, Flat, Smooth Surface	Good	Fair	Best	Fair	Fair	Good	Fair
Strength	Varies[e]	Varies[e]	Good	Varies[e]	Poor	Good	Varies[e]
Temperature Resistance	Good	Poor [f]	Good	Poor[g]	Poor[g]	Good	Good
Vibration Control	Fair	Good	Good	Fair	Good	Good	Good

NOTES:
[a]Plastic panels with rigid foam filler.
[b]Solid phenolic resin between craft paper layers.
[c]Chemical-resistant plastic laminates are available for laboratory cabinets.
[d]Other plastic materials, such as polyvinyl chloride (PVC) are used.
[e]Weight limitations vary for each material thickness or that of substrate. Review specifications.
[f]Dry ice can crack epoxy work surfaces.
[g]Heat and flame can melt or scorch surface.

ventilation may be required during installation and curing. It is prudent to investigate performance of water-based epoxy products and compare it to the performance of standard latex paints before specifying either product.

2.2.7.2 Floors. Laboratory floor surfaces experience much harder wear and more frequent spills than floors of offices and classrooms, so floor sealants, coatings, and finish materials are important in maintaining health and safety. Floors with cracks, ridges, or uneven surfaces pose trip hazards for laboratory occupants. Housekeeping staff cannot effectively clean floors that have cracks, deep scratches, or eroded surfaces. Most laboratory buildings constructed since 1920 have poured concrete floors. The concrete may be just a topping on a steel floor substrate or an integral concrete structural floor. Wood plank flooring was often used prior to the 1920s. Stamped sheet metal or stainless steel floor surfaces are used in special applications, such as in controlled environment rooms (see Chapter 11). Raised flooring is commonly used in dry laboratories, cleanrooms, and computer laboratory applications. Raised floor systems are not recommended in other laboratory types due to the hazards of chemical spills, the difficulty of detecting spills, and difficulties in adequately cleaning spills.

2.2.7.2.1 Concrete. Concrete floors can be sealed with a range of industrial coatings that are mortar applied, broadcast, or slurry applied. Many of these methods allow installation of the coating up along wall surfaces, producing integral cove bases or wainscots that rise 30 in. (76 cm) above the finished floor. This application permits easy and effective floor cleaning. If oils, strong acids, bleaching, or staining agents will be used in laboratories, or if floors are subject to heavy impact or rolling loads, scraping, abrasion, or other types of physical abuse, then specific industrial-grade coatings and installations are required to keep occupants safe and concrete floors cleanable. A high-polish process performs well for concrete floors. Grit can be added to finishing sealants to reduce risk of slips and falls.

Concrete floors can also be coated with terrazzo, covered with vinyl sheets, or topped with vinyl composition tiles, linoleum, quarry tiles, or carpet materials. Carpet materials are not recommended in laboratories using chemicals or instruments. It is very difficult to clean carpet materials sufficiently to remove deep-seated particulate matter that interferes with operation of some instruments, or to remove chemical stains.

2.2.7.2.2 Terrazzo. Terrazzo, a traditional floor-finishing method, is very durable and appropriate for laboratory use; 70–75% of the material is composed of naturally occurring stone aggregates, glass, or recycled plastic. The binder can be cement or epoxy-based, and terrazzo's off-gas rate is very low for the life of the cured floor.

2.2.7.2.3 Vinyl Sheet. Sheet goods made of pure vinyl perform well in many laboratory types where there is low risk for spills of aggressive, staining chemicals. Vinyl materials are manufactured from petrochemicals. Dura-

bility of these products is based on quality of installation, moderate use, and low abuse of the floor. Vinyl sheets allow heat or chemically welded, waterproof seams and integral cove base installations to hold spilled water or other fluids until cleaned. These floors are also easy to clean, and sheet vinyl can be repaired when damaged or stained.

2.2.7.2.4 Vinyl Composition Tiles. Vinyl composition tiles are utilitarian and relatively inexpensive to install and maintain. Joints between tiles are not sealed, so floors cannot prevent water from leaking to spaces below. In addition, joints collect dirt and tiles weaken at joints, breaking off or loosening from the mastic used to attach the tiles. These are trip hazards. However, damaged and unsightly tiles can be easily replaced.

2.2.7.2.5 Linoleum. Linoleum is another traditional material made of petrochemicals. Linoleum is hard to keep looking clean and stains easily, so it is not recommended for most laboratory types.

2.2.7.2.6 Quarry Tile. These hard-fired clay tiles are a traditional laboratory floor covering, but are not commonly used any longer. Tiles are very heavy and add significant dead load on structural members. Joints between tiles tend to crack, posing trip hazards; therefore, good maintenance is critical. Cleanliness is also harder to maintain due to grouted joints between tiles, and wet tiles are slick, which pose a slip hazard.

2.2.7.3 Ceilings. Laboratory ceilings normally do not experience splashes and spills of harsh chemicals that stain other surfaces, so other criteria determine the selection of ceiling finish materials. The underside of the structure overhead can sometimes simply be painted, and some laboratories require no other ceiling finish.

Suspended, finished ceilings are installed to cover ducts, conduit, and piped utilities that are normally attached to the underside of the structure above or to keep them out of sight from laboratory occupants. Suspended ceiling materials that have good acoustical performance are often used in laboratories to diminish noise levels. Ceiling materials with good acoustical properties are fissured and manufactured with fibrous materials that over time shed particulates. In laboratories where close control of particulate matter is not required, metal suspension systems accept a wide range of acoustical tiles and panels. However, when tiles or panels are lifted, all the particulate that accumulates above the ceiling drifts or most likely dumps down into the laboratory, causing a mess and unintended contamination source.

Laboratories that need to restrict airborne particulates should use other ceiling systems and materials. Common alternative suspended ceiling systems include painted, solid, and seamless gypsum wallboard, sealed metal panels, sheets of formed composite material with impervious surfaces, and sealed fiberglass panels. Because sheets and panels in these ceilings are continuously sealed around the edges and at all ceiling penetrations, solid ceilings help keep the laboratories below clean. Access to utilities above these ceilings is accomplished by installation of access doors. Access doors can be sealed, but when they are opened, dust and debris fall down into the laboratory.

2.3 GUIDING PRINCIPLES FOR LABORATORY HEATING, VENTILATING, AND AIR-CONDITIONING

Laboratory ventilation is closely related to correct overall laboratory building function in the sense that laboratory heating, ventilating, and air-conditioning (HVAC) services will be enhanced or constrained by the design choices made for the building as a whole. It is most advisable to involve the HVAC engineers early in the conceptual phases of design. Otherwise, decisions made at that point may eliminate sustainability and energy-saving options later in the design phase. Prudent design takes into account the unusually rapid changes that are presently occurring in most research areas. Often these changes require the introduction of new hazardous materials, additional instruments and equipment, and/or other instruments and equipment to support new methods of experimentation. By the very nature of research, old restraints on pressure relationships between spaces, chemical composition, toxicity, etc., are constantly being cast off and new demands placed on the provisions of essential facilities. Therefore, reserves should be designed into all laboratory HVAC systems to retard obsolescence. Experience dictates a reserve of 10–25% of new requirements in all cases, although for industrial laboratory systems such as pilot plants, a 35–50% excess reserve is more usual.

2.3.1 Temperature Control

Heating and air-conditioning systems must provide the uniform temperature that is required for the efficient operation of many analytical devices. Although close control of humidity is not necessary in most instances, when close humidity control is required, simultaneous heating and cooling may be needed. Many kinds of HVAC systems have been used for laboratories with success: local heating and cooling reheat units, central

systems, or a combination of both. It is important that all elements of temperature control systems be interlocked so that a uniform temperature can be maintained throughout the year. Often, it is advantageous and in some cases mandatory to install a separate cooling and heating system for a laboratory when it is not the major function of the building rather than incorporating it into the building system. Laboratories have HVAC requirements that are different from those of a normal office or hospital building, and if not separated, a large system must operate to maintain preset conditions in a small space.

2.3.2 Laboratory Pressure Relationships

Good laboratory ventilation requires a careful balance between exhaust discharge and supply air volumes, as well as careful placement of exhaust discharge and supply air locations. This will provide the desired directional airflow into the laboratory space to prevent hazardous vapors, gases, fumes, and particles from escaping from the laboratory. Airflow out of the space is required when it is desired to keep possible contaminants outside the space from entering the space. Even within the same type of laboratory, requirements may vary depending on the hazards of the materials being used, the quantity of hazardous materials being handled, and the nature of the operations involved. Communication with laboratory users at an early stage in planning helps to identify potential hazards before the final design stage (see Chapter 1.1). Laboratories using hazardous materials must be maintained at a negative pressure relative to hallways and other adjacent public access areas. Special-purpose laboratories requiring positive pressure with respect to hallways and other adjacent areas are discussed in Chapter 23, Microelectronics and Clean Room Laboratories. All offices, conference rooms, lunchrooms, and other public areas must be maintained at a slightly positive pressure relative to the laboratories to ensure safety.

2.3.3 Laboratory Ventilation Systems

There are three main components of laboratory ventilation systems based on function:

1. A *comfort ventilation system* is a means of supplying measured amounts of outdoor air for breathing and to maintain design temperature and humidity. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) (ANSI/ASHRAE, 2011) has recommended ventilation rates that are needed to provide an adequate level of indoor air quality. These recommendations are being adopted by many states and agencies for the health and safety protection of people in the workplace. The document has been accepted by ANSI as a consensus standard. It recommends the outdoor air exchange rates for all types of facilities.
2. An *exhaust ventilation system* is designed specifically for health and safety protection.
3. A *replacement or make-up air conditioning system* replaces the volume discharged to the atmosphere through the health and safety exhaust ventilation systems.

These three systems are described in detail in the following paragraphs.

2.3.3.1 Comfort Ventilation Supply Air for Laboratory Modules. All comfort ventilation supply air exhausted from laboratories must be replaced with mechanically supplied air or by infiltration from adjacent areas. An adequate supply of air is essential to meet the desired directional airflow, and maintain temperature and humidity control and safe working conditions.

2.3.3.1.1 Supply Air Velocity and Entry Locations inside Laboratories. Replacement air in equal quantities must be supplied to laboratories when air is exhausted by health and safety protection systems. Most of the replacement air will come in as air supplied directly into the laboratory, but a small amount will infiltrate from adjacent spaces when they are at higher pressure relative to the laboratory space. Transfer grills that allow air to flow into the laboratory from the corridor should not be used. They are sometimes located above or in the door. They can create cross drafts negatively affecting hood containment. The location of make-up air outlets and the temperature of the air supplied are important performance factors. High-velocity supply air jets create sufficient turbulence when directed at a hood face to disrupt exhaust ventilation system performance and can be a source of discomfort to occupants of the laboratory. It is recommended that high-velocity outlets not be used in laboratory design. Low-velocity supply air grilles and diffusers should be selected and located so that the air velocity at the occupant's level does not exceed 50 ft/min (0.25 m/s). CFD simulations have indicated that placing square diffusers offset to one side in front of the hood should be avoided. This increases hood leakage. If there is insufficient space to move a square diffuser away from the hood, development of the jet can be prevented by moving it close to the hood as long as the hood is not in the corner and there is no bulkhead. Guidance on the selection and placement of supply air diffusers can be found in "Methodology for Optimiza-

tion of Laboratory Hood Containment" (Memarzadeh, 1999).

2.3.3.1.2 Air Distribution. Air supplied to a laboratory space must keep temperature gradients and air turbulence to a minimum, especially near the face of the laboratory hoods and biological safety cabinets. Air outlets must not discharge into the face of exhaust hoods. Cross flows that impinge on the side of a hood alter airflow more seriously than do cross flows in front of the hood (Memarzadeh, 1996; Schuyler and Waechter, 1987). Large quantities of supply air can best be introduced through perforated plate air outlets or diffusers designed for larger air volumes (ANSI, 2012). The air supply should not discharge on a fire detector because this slows its response.

Some general air distribution guidelines follow (ANSI, 2012; Caplan, 1978; Memarzadeh, 1996):

1. Terminal velocity of supply air jets (near hoods) is at least as important as hood ace velocity when the face velocity is in the range of 50–100 ft/min (.25–.50 m/s). The terminal throw velocity of supply air jets (near hoods) should be less than the hood face velocity, preferably no more than one-half to two-thirds the face velocity. These terminal throw velocities are far less than those used for conventional room air-supply systems.
2. Perforated ceiling panels provide a better supply system than do grilles or ceiling diffusers because the system design criteria are simpler and easier to apply and precise adjustment of fixtures is not required. Ceiling panels also permit a greater concentration of hoods than do wall grilles or ceiling diffusers.
3. Wall diffusers or registers should have double deflection louvers set for maximum deflection.
4. If the wall grilles are located on the wall adjacent to the hood, the supply air jet should be above the top of the hood face opening. For equal terminal throw velocities, diffusers on the adjacent wall cause less hood leakage than diffusers located on the opposite wall.
5. The terminal throw velocity from wall or ceiling diffusers at the hood face should be less than one half of the hood face velocity.
6. Diffusers should be kept away from the front of the hood face. A larger number of smaller diffusers is advantageous if the necessary low terminal velocity can be maintained.
7. Blocking the quadrant of the ceiling diffuser blowing at the hood face results in less hood spillage. However, diffuser blocking (the blocking off of one or more outlets of a diffuser) can be dangerous and should be avoided if possible.
8. Perforated ceiling panels should be sized so that the panel face velocity is less than the hood face velocity, preferably no more than two-thirds of the hood face velocity. Perforated ceiling panels should be placed so that approximately one-third or more of the panel area is remote (more than 4 ft [1.3 m]) from the hood.
9. Round perforated ducts can be used to supply large amounts of supply air in a small space. These ducts can be either metal or fabric type which inflate under partial pressure. Transfer grilles should not be used to allow for larger replacement air volumes unless their flow rates are less than 100 ft^3/min (2.83 m^3/min)
10. Additional tests are needed to determine laboratory fume hood performance; the only way to determine hood effectiveness is to test the specific hood under actual room conditions.
11. Room air distribution currents should be evaluated to determine whether local air currents are too high and may cause discomfort or disturb experiments.

2.3.3.2 Recirculation of Laboratory Room Air. All hazardous materials should be used in chemical fume hoods or with some other type of local exhaust ventilation. When the amount of exhaust air is reduced to a minimum by the use of well-designed and well-functioning chemical fume hoods and alternative local exhaust systems, less energy is expended and safety and comfort can still be maintained.

In some research laboratories, the room air can be recirculated by local cooling and heating devices (e.g., fan coil units or chilled beams) provided that the minimum amount of outdoor air is supplied through the unit (or from another source) to satisfy comfort, health, and safety requirements when the laboratory is occupied.

All air from local exhaust hoods except for a few discussed below, as well as from lavatories, sterilization rooms, and similar facilities, must be exhausted to the outside with no recirculation allowed. Air from offices, libraries, conference rooms, and similar nonlaboratory facilities can be recirculated with the addition of the minimum amount of outside air required to maintain health and safety and to comply with building codes (ASHRAE 62-2010; ASHRAE, 2010).

2.3.4 Exhaust Ventilation for Laboratory Modules

Exhaust air systems of three types may be needed in each laboratory module: (1) removal of general room

comfort supply air and contaminated dilution ventilation air, (2) health and safety exhaust ventilation air from biosafety and chemical fume hoods contained in the laboratory, and (3) local or spot exhaust ventilation air. Types 2 and 3 emphasize control of exposures at the source of generation. Dilution ventilation relies on supplying a sufficient air volume to dilute the concentration of the material in the room air to levels below those believed to present an adverse health effect. The choice of system(s) will depend on the size of the laboratory, the nature and quantity of materials used, and the type of laboratory equipment installed. These systems may be either constant or variable air volume systems.

2.3.4.1 Exhaust of General Room Ventilation Air from Laboratories. The manner in which general ventilation air is exhausted from each laboratory room depends on its size and the nature of the activities and equipment present. In some cases, a laboratory fume hood or some other local exhaust air system will provide adequate exhaust of general room ventilation air. In other cases, a combination of general room return air facilities, chemical fume hoods, and additional local exhaust air facilities may be used.

The decoupling of ventilation requirements from cooling and heating requirements using supply air systems has allowed the reduction of energy use. During the past 10 years, the trend in laboratory ventilation design has moved towards reducing the volume of air exhausted from the laboratory either through general exhaust or local exhaust hoods. The purpose has been to reduce energy use while not compromising the health and safety of laboratory workers. Early laboratory design guidelines called for general air exchange rates in laboratories to be from 10–15 air changes per hour (ACH), in part driven by heating and cooling needs. As the design of the laboratory fume hoods and laboratory ventilation improved and better work practices were employed, the air exchange rate was allowed to be lowered. Experience to date has not resulted in any adverse health effects reported where proper practices were followed and air exchange rates reduced. Experts in laboratory ventilation indicate that the critical factors in hood performance and personal protection are hood design, laboratory design, location and delivery of supply air and user practices (DiBerardinis, 2003). Note that the air exchange rate is not considered a critical factor. The final air exchange rate for a laboratory is based on the exhaust ventilation required to control exposures at the source, as well as general exhaust for comfort needs.

Although there have been limited exposure assessments studies of laboratory workers with air exchange rates as the variable, several studies of exposure assessment in laboratories with air exchange rates at or slightly below 10 ACH have indicated low or undetectable exposures to laboratory workers under use conditions (Greenley, 2000; Tan, 1999). Theoretical studies using CFD have also indicated lower ACH are possible (Memarzadeh, 1996). For more information on laboratory air exchange rates, see the September/October, 2009 issue of the *Journal of Chemical Health and Safety* published by the American Chemical Society. The entire issue is devoted to a discussion of air exchange rates in laboratories.

2.3.4.2 Ventilation Rate Terminology. In ventilation consensus and building codes, room and laboratory gross ventilation rates are usually expressed in terms of (1) air changes per hour, (2) cubic feet of air per minute per occupant, (3) cubic feet of air per square foot of laboratories space, or (4) a combination of the three.

ACH is a ventilation rate expressed as the number of room volumes exchanged in an hour. It is calculated by dividing the larger of the exhaust or supply volume (ft^3/h; m^3/h) by the volume of the room (ft^3; m^3). This is the theoretical number of ACH. The actual number of ACH depends on how well mixing occurs, and this is critically dependent on the quality of the design of supply and exhaust systems. Mixing can be evaluated by measuring the decay rate of a tracer gas such as sulfur hexafluoride (SF_6). The ratio of the actual to the theoretical ACH is referred to as the *K factor*; it describes the efficiency of air mixing. K factors are assigned in the American Conference of Industrial Hygienists' (ACGIH) *Industrial Ventilation Manual* (ACGIH, 2010a) for various locations of the room supply and exhaust points.

Another criterion of ventilation rate is the number of cubic feet of air per minute (ft^3/min; m^3/s) supplied per occupant of the room space. Maximum occupancy must be used in the calculation, and the room ventilation system will be designed based on this number. This is not commonly used for laboratory spaces.

In both cases, the room air volume rate used to calculate ACR or ft^3/min per person is the outside air fraction, not the total recirculated air that may contain some recirculated air.

Regulations. Few regulations exist that specify ACR. Some consensus recommendations or guidelines (i.e., ASHRAE [62–99], ANSI, or IMC) may be adopted as local or state regulations.

OSHA requires a minimum of 6 ACH in chemical storage rooms ("Design and Construction of Inside Storage Rooms," General Industry Standard 29 CFR 1910.106; OSHA, 2012). Because most laboratories store some quantities of flammable chemicals, this regu-

lation may apply; in some cases, OSHA has cited university chemical storerooms for inadequate ventilation under this regulation.

Rationale for Existing ACH Recommendations—Empirical Approach. Originally, ACH recommendations for laboratories were based on heating, general ventilation, and cooling requirements rather than being based on health and safety concerns. Recently, new recommendations for minimum outside air requirements have been addressed to reduce indoor air quality complaints that have followed. The "tightening" of buildings in response to energy conservation goals has increased the need for careful evaluation of ventilation needs. The ACH values in Table 2-6A have been arrived at empirically, and for the most part are based on anecdotal evidence.

Ventilation Rates: Consensus Recommendations, Codes, and Standards; Government Regulations. Professional organizations and government agencies provide recommendations for ACH/h or ft^3/min per person for various room types and buildings. Those that pertain to laboratory buildings are summarized in Table 2-6B.

Experimental Approach. Los Alamos National Laboratory (LANL; Los Alamos National Laboratory, 1991) performed an experimental program to determine acceptable ACR values for radiation laboratories subject to the buildup of hazardous airborne radiation levels from visually undetectable spills. Results indicated that 8 ACR is the minimum to maintain radiation exposure levels below current health standards even should a small spill of radioactive materials occur. Recent experimental studies (Kline, 2010) have demonstrated similar results.

Theoretical Approach. Another way of estimating ventilation requirements for laboratories is to calculate the concentration reduction on the basis of theoretical air changes and to correct the result by introducing an appropriate K factor. On this basis, it takes approximately 7 ACR to reduce the initial concentration by 90% in 1 hour assuming perfect mixing in the laboratory. Assigning a K factor of 1.5 for a well-designed laboratory ventilation system (ACGIH, 2010), the required exchange rate is 10 ACH. This method has been used by some to establish minimum exchange rates based on an assumed generation rate in a given room volume. See also, "Specification for Airflow Rates in Laboratories" in

TABLE 2-6A. Air-Change Rates Recommended in Various Standards and Codes

ANSI/AIHA z9.5-2012	The specific room ventilation rate shall be established or agreed upon by the owner or his/her designee.
NFPA-45-2004	Minimum 4 ACH unoccupied, occupied "typically greater than 8 ACH."
ACGIH Ind. Vent 24th Ed., 2010	The required ventilation depends on the generation rate and toxicity of the contaminant – not on the size of the room in which it occurs.
ASHRAE Lab Guide, 2001	4-12
OSHA 29 CFR Part 1910-1450 Appendix A	4-12
AIA	4-12
United States Environmental Protection Agency (U.S. EPA)	4 ACH unoccupied lab 8 ACH occupied lab
Nuclear Regulatory Commission National Research Council Prudent Practices	4-12 ACH

Note: ACH = air changes per hour.

TABLE 2-6B. Air-Change Rates Recommended in Various Standards and Selected Projects

Code	Ventilation Rate	Comment
1. IBC-2004	1 CFM/ft^2 for H-5 occupancy	Section 415.9.2.6
2. IMC-2004	1 CFM/ft^2	Rate required for storage areas that exceed maximum allowable quantities of hazardous materials. Section 502.8
3. UBC-1997	1 CFM/ft^2 for H-6 occupancy	Uniform codes have been replaced by International codes beginning in 2000 in many jurisdictions. Section 120
4. OSHA-2008 1910.106	6 ACH	Flammable storage rooms

Note: ACH = air changes per hour.

the September/October, 2009 edition of the *Journal of Chemical Health and Safety* (Smith, 2009).

Industrial Hygiene Approach. Traditionally, the industrial hygiene approach is to evaluate the source strength of hazardous materials and to control exposure by the use of custom-designed local exhaust ventilation systems (e.g., chemical fume hoods, glove boxes, slot-ventilated work benches) and work practices. Dilution ventilation is seldom used to control chemical hazards. The major source of assigned ACH standards for laboratories relates to building code concerns to reduce odors from people and materials and not to the specific needs of laboratories.

However, in older facilities (circa 1995 and older) operation of a constant volume chemical fume hood generally provided a laboratory air change rate in excess of 10 ACH so that minimum dilution needs were always met and the establishment of a minimum number of ACH for laboratories was usually not addressed. The introduction of variable air volume systems for laboratory hoods and other exhaust-ventilated facilities and high performance, low flow hoods has created a potential to reduce the total volume of dedicated health and safety exhaust air to levels approaching zero. A minimum amount of comfort air exchange is always necessary; therefore, there is a need to establish minimum air exchange requirements for health and safety. As noted earlier, heating or cooling requirements often dictate the minimum, and it may not be necessary to set minimum air exchange rates based solely on health and safety considerations.

It is recommended that ACH not be established based on health effects, but rather the potential sources of exposure be controlled locally by the use of adequate local exhaust hoods. The following recommendations are provided. Actively involve environmental health and safety (EHS) professionals in laboratory design and operation.

- Use a decision logic or process flow diagram such as the one outlined in DiBerardinis et al. (2009, p. 12) to achieve a proper balance between conservation and health and safety.
- Focus on control of exposure at the source.
- Commission the space following the guidelines in ANSI Z9.5 (ANSI, 2012) and ASHRAE Commissioning Guideline 0 (ASHRAE, 2005)
- Recommission the space periodically, perhaps every 2–5 years or whenever the laboratory use or assignment changes.
- Ensure that both the lab occupants and those responsible for maintenance of the space are adequately educated and trained on the facility design intent, the proper use and maintenance of containment control ventilation, energy-saving setbacks, any system limitation, and proper laboratory practices.
- Establish a mechanism to enforce the rules established for safe operation of the laboratory.
- Perform initial and periodic exposure assessment for laboratories designed at lower exchange rates to verify capture at the source.
- Provide adequate EHS resources to match the changes in the lab's use/experiments as well as in the lab's design. Do not compromise health and safety.
- Encourage project design teams to work more closely with researchers and EHS professionals to develop better flexible designs, perform more specific laboratory programming, and provide better feedback to users on energy use and on energy conservation techniques.

Opportunities for energy conservation are discussed in Chapter 35.

2.3.4.2.1 Velocities for Removing Room Ventilation Air. Exhaust grilles for general room ventilation should be sized so that the inflow face velocity is between 500 and 750 ft/min (18 and 26 m/s). Wall-mounted grilles should be placed to provide an airflow direction within the laboratory from the entrance door toward the rear of the laboratory to minimize the escape of gases and vapors to the corridor.

2.3.4.3 Air Rates for Laboratory Hoods and Other Local Exhaust Air Facilities. Because air exhausted from laboratory hoods and most other containment devices cannot be recirculated but must be discharged into the atmosphere, the energy cost for moving and treating the air is high. Opportunities for energy conservation are outlined in Chapter 35.

2.3.4.4 Chemical Fume Hoods. Laboratory hoods, sometimes called *chemical fume hoods or fume cupboards*, are a form of local exhaust ventilation commonly found in laboratories using toxic, corrosive, flammable, or malodorous substances. The purpose of a laboratory fume hood is to prevent or minimize the escape of contaminants from the hood into the laboratory air, and to provide containment. Successful performance depends on an adequate and uniform velocity of air moving through the hood face, commonly referred to as the *face velocity* or *control velocity*. Hood performance is adversely affected by external high-velocity

drafts across the face, large thermal loads inside, bulky equipment in the hood that obstructs the exhaust slots at the rear or creates eddy currents at the opening, and poor operating procedures on the part of personnel using the hood, e.g., failure to work 0.5 ft (0.2 m) or more inside the hood face. Some normal operations such as constantly moving hands or equipment in and out of the hood can also adversely affect the hood performance. With the sash closed, the hood can minimize the effects of small explosions, fires, and similar events that may occur within, but it should not be depended on to contain fires or explosions other than minor ones. To function correctly, a chemical fume hood must be designed, installed, and operated according to well-established criteria. Adequate training of hood users on the proper use of hoods will help to minimize potential exposures.

The chemical fume hood is the laboratory worker's all-purpose safety device. It is probably the single item that most definitively characterizes a laboratory, and its importance for the safety and health protection of laboratory workers cannot be overstated. This being so, it is essential for the laboratory designer to understand thoroughly the functions that characterize a satisfactory laboratory hood and the several designs that are on the market. Not all are equally effective or efficient in the utilization of airflow.

Well-designed fume hoods have several important characteristics in common:

1. Air velocity will be uniform—that is, ±20% of the average velocity over the entire work access opening.
2. All the hood surfaces surrounding the work access opening will be smooth, rounded, and tapered in the direction of airflow to minimize air turbulence at the perimeter of the hood face.
3. Average face velocity will be a minimum of 80 ft/min (0.4 m/s) for work with any of the chemical, biological, and radioactive materials usually encountered in university, government, industrial research, and commercial consulting laboratories.

   When substances associated with a somewhat higher hazard level are handled, 100 ft/min (0.6 m/s) average face velocity is recommended. OSHA calls for, but does not require, average face velocities in excess of 150 ft/min (0.75 m/s) for laboratory hoods used with any of the 13 carcinogens listed in OSHA 1910.1003 et seq. (OSHA, 2012). Under OSHA Laboratory Standard 1910.1450, promulgated in 1990 (OSHA, 2012), OSHA does not specify a hood face velocity, recognizing that face velocity alone may not be a good indicator of protection (DiBerardinis, 1991, 2003; Maupins, 1998; Smith, 2007). Hood face velocities in excess of 120 ft/min (0.6 m/s) are not recommended because they cause disruptive air turbulence at the perimeter of the hood opening and in the wake of objects placed inside the work area of the hood (ANSI, 2012; Chamberlin, 1982; Ivany, 1989).
4. The face velocity of constant-volume hoods with an adjustable front sash will be maintained at a constant velocity (within reasonable limits) by an inflow air bypass that proportions the air volume rate entering the open face to the open area or by some other method that produces a similar result.

Use of a totally enclosed and ventilated glove box or specially designed total enclosure is recommended for handling very hazardous materials. The use of glove boxes minimizes the escape of exhaust air volume into the atmosphere and simplifies air treatment for environmental protection.

There are a number of distinctive types of laboratory hoods in widespread use. Each is identified in the following sections and described more completely in Chapter 32.

2.3.4.4.1 Standard Chemical Fume Hoods. The basic chemical fume hood incorporates the four principles enumerated in the above section that characterize a well-designed fume hood. Most laboratory furniture suppliers have one or more models that will meet the listed criteria.

Conventional Type (Constant Volume). The conventional-type fume hood is one of the oldest forms of laboratory fume hoods. It is designed so that all exhaust air is drawn in through the front face opening. As a result, as the sash is lowered, reducing the face opening, the air velocity is increased proportionately. This can result in excessive face velocities and poor containment. This type of hood is not recommended for use in laboratories and is rarely seen in newer laboratory facilities designed after 2000.

Bypass Type (Constant Volume). This type of hood permits laboratory air to enter the hood chamber through a "bypass" when the sash is closed. This bypass is designed so that a constant face velocity through the hood work opening is maintained as the sash is lowered. This prevents excessive face velocities when the sash is nearly closed (one-third open).

Auxiliary Air Type (Constant Volume). The major difference between the bypass chemical fume hood and the auxiliary air hood is the method employed to provide

make-up air to the hood. Auxiliary air fume hoods are rarely used in new construction or renovations and are recommended for laboratory use only under the specific conditions described below. The advent of hoods that can operate with variable air volume exhaust has virtually replaced the use of auxiliary air hoods. For bypass hoods, all of the make-up air is provided by the room HVAC system, whereas for supply air hoods part of the air is introduced from an air supply grille just above and exterior to the hood face. Some manufacturers state that up to 70% of the total hood exhaust volume may be supplied in this manner, with the remainder coming from the laboratory HVAC system. When auxiliary supply air is introduced behind the sash (an incorrect hood design), the hood chamber is likely to become pressurized and blow toxic contaminants out the open front into the laboratory. Only auxiliary air hoods that introduce auxiliary air to the outside and above the hood face are acceptable.

Auxiliary air hoods have two advantages over conventional constant volume bypass hoods. First, the air supplied to the hood does not have to be cooled in warm climates, which is a significant energy savings. Second, auxiliary air hoods can be used in laboratories that contain so many hoods that the volume of supply air required, were they all standard constant volume chemical fume hoods, would result in many more room ACH than are desirable and may create excessive drafts. Providing auxiliary supply air, even to only some of the hoods, can reduce room air velocities and supply air quantities to acceptable levels. The use of variable air volume hoods will also resolve the problem.

There are disadvantages to the use of auxiliary supply air hoods. First, they are more complex in design than the usual chemical fume hood and their correct installation is more critical to safe and efficient operation. Often, only a small imbalance between room air and auxiliary air supplies can result in unsafe operating conditions. Second, unsafe conditions occur when the velocity of external auxiliary air supplied to the face of the hood is excessive because high-velocity air sweeping down across an open hood face can produce a vacuum effect and draw toxic contaminants out of the hood. Third, this type of hood must have two mechanical systems (separate exhaust and supply systems) for each hood. Inasmuch as some additional supply air will need to be added to the laboratory anyway, the auxiliary air hoods require two supply air systems instead of the one supply system that standard chemical fume hoods require. Therefore, the equipment maintenance is doubled.

Generally, safety and health professionals discourage the use of auxiliary air hoods (ANSI, 2012). When the advantages outweigh the disadvantages, auxiliary air fume hoods may be used because energy savings through reductions in summer cooling and winter heating can be realized even in moderate-temperature climates. Energy savings during the heating season occur because the auxiliary air need not be heated to as high a temperature as the comfort ventilation air. Use of auxiliary air hoods might be applicable for renovations when one or more fume hoods must be added to a laboratory with limited amounts of central system supply air capacity and the use of variable air volume hood systems is not feasible. Because of the complexity of this type of hood, the performance specifications are more stringent than for standard chemical fume hoods. It is extremely important to specify the auxiliary air hood to be installed before the supply air system is designed because not all auxiliary air hoods have the same requirements for room and auxiliary air volumes, and some meet containment performance requirements at less than 70% auxiliary air.

2.3.4.4.2 Horizontal Sliding Sash Hoods. Economy in the utilization of conditioned air for laboratory hoods can be achieved most satisfactorily by maintaining the required safe face velocity, but restricting the open area of the hood face. A transparent horizontal sliding sash arrangement can cut overall air requirements by 50% if two half-width panels are used on two tracks. Similarly, if three panels are used, the minimum open area reduction is 67% for a two-track setup and 33% for a three-track arrangement. This design also has an advantage over the conventional vertical sash because the full height of the hood opening is always available. When horizontal sliding panels 14–16 in. (0.36–0.41 m) wide are used, they can also serve as safety shields because they can be placed directly in front of the person working in the hood.

Under most conditions, a fume hood with horizontal sliding sashes gives personnel protection equal to that given by a hood with a vertical sash, provided that it is designed and operated to have a minimum average face velocity of 80 to 120 ft/min (0.4 to 0.6 m/s) at the maximum face opening. All velocities in the plane of the hood face should be greater than 80 but less than 120 ft/min (>0.48 but <0.6 m/s) under operating conditions. Sometimes, turbulence occurs at sharp panel edges when inflow velocities exceed design values. Visual smoke trails may be used to test for inward airflow across the entire face opening and an absence of turbulence at sash edges.

2.3.4.4.3 Perchloric Acid Hoods. Perchloric acid hoods require special construction, construction materials, and internal water-wash capability. Problems reported with hoods heavily used for perchloric acid digestions are

associated with the accumulation of explosive organic perchlorate vapors that condense while passing through the hood exhaust system. They can detonate from percussion during cleaning, modification, or repair. Therefore, use of specially designed fume hoods is required for use with perchloric acid that is heated or aerosolized. Perchloric acid hoods should meet the same contaminant retention capabilities as the chemical fume hoods described in the preceding sections. In addition, they should be constructed of stainless steel and have welded seams throughout. No taped seams or joints and no putties or sealers can be used in the fabrication of the entire hood and duct system.

The perchloric acid hood also requires an internal water-wash system to eliminate the buildup of perchlorates. The water-wash system should consist of a water spray head located in the rear discharge plenum of the hood plus as many more heads as are needed to ensure a complete wash down of all surfaces of the ductwork from the hood work surface to the discharge stack on the roof. To drain all of the water to the sewer in a satisfactory way during normal wash-down operations, it is important to have the exhaust duct go straight up through the building to the exhaust fan with no horizontal runs. A straight vertical duct run also facilitates periodic examination for maintenance purposes.

When only small amounts of perchloric acid are used, it is possible to construct an air scrubber in the hood. This can be done when the point of generation of perchloric acid vapors can be identified and a small capture hood designed. The National Safety Council (NSC, 1985) recommends such a system.

2.3.4.4.4 Biological Safety Cabinets. The biological safety cabinet is a special form of containment equipment that is addressed in more detail in Chapters 14 and 32. It is used for work with cell and tissue cultures, parenteral drugs, and forensic evidence when the materials being handled must be maintained in a sterile environment and the operator must be protected from toxic chemicals and infective biological agents. The dual functions of protecting the worker and maintaining sterility are achieved by two separate cabinet flows: (1) a turbulence-free downward flow of sterile HEPA- (high-efficiency particulate air) filtered air inside the cabinet for work protection, and (2) an inward flow of laboratory air through the work opening to provide worker protection. In addition, all air exhausted from biological safety cabinets is filtered through HEPA filters to provide environmental protection. The inward airflow and the downward airflow are delicately balanced in the biological safety cabinet; great care must be exercised to maintain the design flow rate of each, as well as the ratio between the two. Biological safety cabinets have achieved (a) widespread work protection use for recombinant DNA research, and (b) worker protection use for working with infected body fluids and cultures.

2.3.4.4.5 Special Local Exhaust Containment Control. Effective exhaust ventilation must be provided for all apparatus and procedures used in the laboratory that generate hazardous contaminants or create excessive heat. In some cases, it may not be possible or desirable to conduct the operations in a chemical fume hood. For example, when the equipment is large, it may not fit into a hood or it may fit, but occupy too much hood space and affect hood performance adversely. These cases call for special or supplementary ventilation arrangements that often take the form of high-velocity, low-volume local exhaust points consisting of open-ended exhaust hoses or ducts. Flexible exhaust ducts of 4- to 6-in. diameter (0.1–0.15 m), often referred to as "sucker hoses," "snorkels," or "elephant trunks," are useful for this service because they can be moved to locations where they are needed. An advantage of local exhaust hoses is their ability to reduce the total amount of air removed from the laboratory as a result of capturing contaminants at the source at high velocities, thereby using less total air volume than would be required for a fume hood. An ASHRAE study found that local exhaust systems are much more energy conservative than dilution ventilation. DeRoos (1979) was one of the earlier proponents of this approach. This has subsequently and regularly been verified in project energy modeling.

Examples of local exhaust hoods are presented in Chapter 32, Section 32.10. There are almost an infinite number of hood and systems designs that can be made. The design factors include the type and size of the equipment, the location of the generation source(s), the quantity and physical properties of the material generated, and the access to the equipment needed by laboratory personnel. The design guidelines provided in Chapter 3 of the American Conference of Governmental Industrial Hygienists' *Industrial Ventilation Manual* (ACGIH, 2010) and ANSI Standard Z9.2, Design of Local Exhaust Systems (ANSI, 2009) should be followed. In addition, some of the specific hood "types" described in Chapter 10 of the ACGIH manual may be applicable to some of the operations performed in the laboratories. Table 2-7 lists some of the applicable design guidelines from the American Conference of Governmental Industrial Hygienists (ACGIH) manual.

Spot exhaust facilities may require a high-static-pressure exhaust system that must be provided by a system separate from the one serving the hoods. This is because laboratory hoods are low-static-pressure devices whereas spot exhaust points may require negative static pressures from 2–5 in. (520–1300 Pascal [Pa])

TABLE 2-7. Ventilation Design Guidelines for Specific Operations Found in Laboratories

Operation or Process	Design Plate (VS-number)*	Type Chapter
Autoclave	99-03	Biology, Pathology
Hot Processes	99-03	Biology, Glass Washing
Autopsy Table	99-07	Autopsy
Single Drum Sander(s)	95-10, 11, 12, 13	Support Shops
Lathe	95-15	Support Shops
Jointer	95-20	Support Shops
Barrel Filling	15-01	Hazardous Waste Room, Foundry
Welding	95-01, 02	Support Shops
Swing Saw	95-04	Support Shops
Band Saw	95-01	Support Shops
Radial Arm Saw	95-03	Support Shops
Table Saws	95-02, 05	Support Shops
Silk Screening, Acid Etching	95-01, 02	Printmaking
Soldering	95-01, 02	Support Shops, Physics
Spray Painting	75-01, 02	Support Shops
Grinding, Polishing	80-10, 12, 13, 18	Support Shops
Glove Box	35-20	Radiation, High Toxicity
Clean Room	10-01, 02, 03	Microelectronics
Ethylene Oxide Sterilizer	25-10, 11, 12	Biology, Autopsy
Laboratory Hood	35-01, 02	All
Perchloric Acid Hood	35-03	All
Horizontal Laminar Flow Hood	35-30, 31	Biology, Clean Room
Small Laboratory Oven Exhaust	35-40	All
Slot Hoods	35-40	All
Canopy Hoods	99-03	All
Foundry Shakeout	20-01, 02, 0 3	Foundry
Milling Machine Hood, High Toxicity Materials	45-02	Foundry
Lathe Hood	45-05	Foundry
Melting Furnaces	55-01, 07	Foundry
Pouring Stations	55-10	Foundry

*From *Industrial Ventilation Manual: A Manual of Recommended Practice*, 27th edition, 2010, ACGIH, Cincinnati, OH.

of water (inches water gauge [in. w.g.]), depending on design factors such as the quantity of air and air velocity at the opening. It is essential to include suitable local exhaust systems in the planning stages of the overall lab design because it is almost impossible to upgrade the system after installation except by total replacement.

It is possible to plan for flexibility by providing the high-static-pressure exhaust system discussed above and a variety of local exhaust hoods that can be selected and installed as necessary. If the process or equipment changes, it would then be possible to disconnect the "hood type" and install a more appropriate one.

2.3.4.4.6 Variable-Air-Volume Hoods. Variable-air-volume hoods can be any one of the standard hoods discussed in Section 2.3.4.4.3 that uses a variable air volume fan as an exhaust. The major difference is that the exhaust quantity is not constant. Generally, the exhaust quantity decreases as the hood face opening decreases. This can be accomplished by a variety of techniques that are discussed in Chapter 34, Variable-Air-Volume Systems.

The major advantage of this type of system is reduced operating cost in the form of energy savings. Another advantage is an increase in containment efficiency, as the fume hood face opening is decreased. The disadvantages relate to the relative sophistication of the control equipment, needed maintenance, and potential issue of long-term repeatability of the control systems. Variable-air-volume systems can be either on a single hood or part of a manifold system.

A more thorough discussion is provided in Chapter 34 (Section 34.2). HVAC engineers should evaluate the quality of available variable air volume (VAV) equip-

ment because there may be a large difference in quality and repeatability from one manufacturer to another.

2.3.4.4.7 Ductless Fume Hoods. A ductless fume hood is one that treats the exhaust air and returns it directly to the laboratory space. The air treatment mechanism is usually an integral part of the hood structure.

Ductless fume hoods have limited use in most laboratories because of the wide variety of chemicals used (ANSI, 2012; NFPA Standard 45, Standard on Fire Protection for Laboratories Using Chemicals, National Fire Protection Association [NFPA], 2011). They discourage the recirculation of laboratory exhaust with flammable materials. The potential contaminant concentration is generally unknown, and the appropriateness of the air purification system installed in ductless hoods must be evaluated for each chemical used. In addition, the warning properties (i.e., odor, taste) of the chemical being used must be adequate to provide an early indication that the air purification unit is effectively preventing emission of toxic vapors back to the laboratory. Alternatively, a continuous monitor that can detect concentrations below the appropriate health standard allowed such as the threshold limit values (TLVs) established by the ACGIH (ACGIH, 2012) for *each* chemical used in the hood could be used to reduce the risk of exposure. The TLVs indicate the maximum exposure an individual can have for a period of time without suffering adverse health effects.

Ductless fume hoods may be more applicable when the contaminant is particulate, and provisions can be made for changing filters without excessive contamination of the laboratory. Biological safety cabinets (Class II, Type A) are examples of a type of ductless hood used successfully for control of particulate biological hazards.

Activated charcoal is not efficient for fine particles and is only useful for adsorbing certain gases or vapors. Many gases and vapors of low molecular weight can be displaced from activated charcoal by higher-molecular-weight organic molecules and reenter the room air with continuous flow of clean air under these conditions. Ductless hoods, if designed properly, serve to protect workers at the hood face, but if not selected and maintained properly may spread the contaminant into the room air over a long time span at lower concentrations (Keimig, 1991).

An appropriate performance test must be selected and conducted prior to purchase and use to verify that the ductless hood will provide adequate and continuous protection. See ANSI Z9.5-2012 section 4 (ANSI, 2012). A more thorough discussion is provided in Chapter 32.

2.3.4.5 Air Flow Monitors. For safety, especially when working with hazardous materials that give no sensory warning by odor, visibility, or prompt mucous membrane irritation of their escape into the laboratory from the laboratory hood, it is advisable to provide each hood with an airflow monitor capable of giving an easily observed visual display of functional status. This is required by ANSI (ANSI, 2012) and is inferred by OSHA (OSHA 1910. 1450; Occupational Safety and Health Administration, 2012). Installation of a hood airflow gauge at the site of use has the special advantage of placing responsibility for day-by-day monitoring of hood function with the primary users. Devices that may be used to monitor hood function include liquid-filled draft gauges or Magnehelic® gauges, which measure hood static pressure. Other devices measure airflow velocity in the exhaust duct where velocity is high or at some point at the side of the hood opening as a surrogate measurement of total exhaust. In all cases, the type and location of monitors should be evaluated carefully because incorrect positioning of static pressure taps can give false readings and in-line airflow devices may become clogged or corroded. A hood monitoring and airflow control system that has important energy conservation aspects is described in Chapter 35.

2.3.4.6 Diversity. As used in ventilation design, diversity refers to designing and operating a system at a lesser capacity than the sum of all the included hoods when running at peak demand. With respect to laboratory chemical hoods, diversity can be thought of as the expected percentage of full flow demand on a manifolded system in active use at any time. A system using 70% of the peak demand is said to operate at "70% usage factor" or 70% diversity. A system that is designed with full flow capacity for all hoods is designed for 100% diversity. For example, a system with 10 hoods all capable of exhausting 1,000 ft^3/min (0.5 m^3/s) for a total of 10,000 ft^3/min (5.0 m^3/s) is at 100% diversity when the fan is sized and the system expected to operate at 10,000 ft^3/min (5.0 m^3/s) at any given time. However, if it is determined that at any point in time no more than seven hoods will be used (three will be off) then the fan can be sized for 7,000 ft^3/min (3.3 m^3/s) and the diversity is 70% (ANSI, 2012).

Both existing and new facilities can benefit from applying diversity to the HVAC design when laboratory chemical hoods are used for only a small portion of the day. Diversity may, therefore, allow existing facilities to add laboratory chemical hood capacity without adding new mechanical equipment. In new construction, diversity allows the facility to reduce capital equipment expenditures and space requirements by downsizing equipment and other infrastructure. Diversity also reduces operating expense because of lower airflow requirements. Common approaches for creating diversity include VAV hoods, sash management aids (such as

building management system trending, horizontal sliding sashes and automated sash closers), and hood use detection (e.g., motion sensors).

Designing with diversity should be done with extreme care and preplanning as it may result in a limit to the number of hoods that can be used or limit sash openings for everyone. This situation creates a potential for personnel overexposures and prevents future expansion opportunities. Diversity approaches may be undesirable under certain circumstances:

- Sash management is difficult to predict and often unreliable. Dependence on historical sash management patterns may be insufficient for any given facility. The use of building management systems to monitor sash management may help, but this requires significant commitment by operating personnel to effectively regulate the users. Automatic sash closers, designed to improve sash management habits, may be overridden and lose their effect on diversity.
- Laboratories with extremely high use patterns, such as teaching laboratories, may be candidates for full-flow or very-high-usage factor designs.

The following issues should be evaluated when considering diversity design for a laboratory with chemical hoods:

- Use patterns of hoods
- Type, size, and operating times of facility personnel
- Number of hoods and researchers
- Sash management (sash habits of users)
- Maintenance of a minimum exhaust volume for each hood on the system
- Type of ventilation system
- Type of laboratory chemical hood controls
- Minimum and maximum acceptable ventilation rates for each laboratory
- Capacity of existing equipment
- Expansion considerations
- Thermal loads

The following conditions should be met to design a diversity-based system.

- Acceptance of all hood use rules by user groups. Designers must take into account the common work practices of the site users.
- A training plan must be in place for all laboratory users to make them aware of limitations that may be imposed on their freedom to use their hoods at all times.
- An airflow alarm system must be installed to warn users that the system is operating at the maximum capacity allowed by diversity and to refrain from adding to the load until the alarm goes off.
- Restrictions on future expansions or flexibility must be identified.

2.3.4.7 Automatic Sash Closing. Automatic sash-positioning systems have been developed to lower the hood sash when no operator is present. Occupancy sensors or access control systems can also be used to identify when the laboratory is empty and the hood is not being used. The purpose is to save energy when using VAV systems by not having to rely on users to close the sash when they leave. Having the sash closed is a safety measure because this condition provides additional containment in the event of a release of hazardous materials within the hood. The decision to use automatic sash closing devices should be based on whether users can be trained to close sashes voluntarily, energy savings, and whether there can be any adverse consequences. The following factors should be considered before automatic sash-closing devices are installed on a laboratory chemical hood:

- There may be adverse consequences of the sash closing when the hood operator is not present to observe it.
- All users must be aware of all limitations imposed on their ability to use hoods at will.
- Automatic sash positioning must have obstruction sensing capability so as to reverse travel during sash-closing operations without breaking glassware, etc.
- Automatic sash-positioning systems must permit manual override of positioning with a force no more than 45 Newton (N; 10 lbs) both when powered and in a fault mode during power failures (ANSI, 2012; OSHA, 2012).

For laboratories with VAV and good sash management (users are trained to close the sash whenever possible), these systems should not be necessary.

2.3.4.8 Hood User Motion Sensors. Motion sensors may be used to determine when there is no one at the hood. If no one is actively using the hood, there is less likelihood of leakage and personnel exposure; therefore, the exhaust volume can be reduced if the hood is VAV. There is an added upfront cost.

Before using such a system, the following considerations should be made.

- Can the users be relied upon to close the sash when they leave the hood? If so, then there is no need for this feature.
- What is an acceptable reduction in exhaust volume and thus face velocity? Some testing has indicated a reduction in face velocity to 60 ft/min (.3 m/s) when no one is working at the hood is acceptable (Greenley, 1999).
- Ongoing need for system maintenance and testing to verify proper operation.
- Initial cost versus estimated savings during the life of the hood

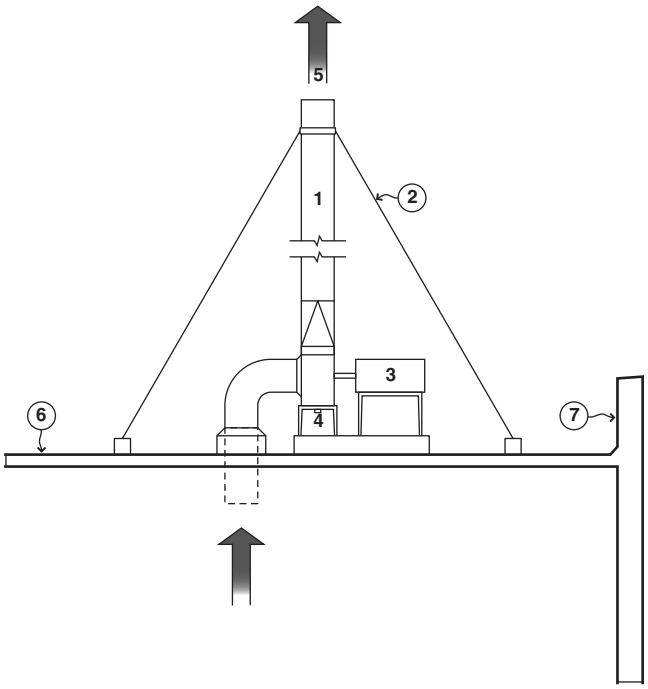
2.3.5 Exhaust Fans and Blowers

After total air volume and static pressure requirements have been established, fan selection for a laboratory fume hood or spot exhaust system will depend on the following factors: (1) ability to fulfill application requirements, (2) ease of maintenance, (3) initial cost, (4) life expectancy, and (5) availability of spare parts. Exhaust fans should have a discharge velocity of at least 3,000 ft/min and a stack extending at least 10 ft above the roof parapet and other prominent roof structures. Exceptions to these minimum conditions can be made if computer modeling or wind tunnel studies can demonstrate other appropriate conditions. Under no circumstances should weather caps be used on local exhaust system stacks. To take care of precipitation into the open stack when the fan is idle, there should be a drain connection at the low point of the scroll casing that can drain directly to the roof. Alternative designs to prevent rain from entering the system can be found in the ACGIH industrial ventilation manual (ACGIH, 2010).

- Belted fans should be double-belt driven, the shaft bearings should contain standard grease fittings for lubrication, and the fan should have a drain at the low point of the scroll casing. Vibration isolators are required to minimize noise transmission through the connecting ducts and building structure. The entire installation exposure to the weather must be built to withstand wind loads of 30 lb/ft^2 (1.5 kilopascal [KPa]) applied to any exposed surface of the fan and ducts rigidly attached to it. Explosion-proof motors and nonsparking, coated wheels are required when it is possible for the effluent air to contain more than 25% of the lower explosive limit (LEL) of any combination of vapors and aerosols. All fan motors must meet the requirements of the National Electrical Code (NFPA 70; NFPA, 2011) and conform to applicable standards for load, duty, voltage-phase frequency service, and location. Motors should be mounted on an adjustable sliding base. Motors of 0.5 horsepower and larger should be of the squirrel cage induction or wound rotor induction type and should have ball or roller bearings with pressure grease lubrication fittings. Drives for belted motors should be as short as possible and equipped with a matched set of belts at 150% of capacity. A weatherproof metal guard with angle iron frame securely fastened to the fan housing and fan base should be provided for protection.
- For small fan-motor sets and for induced draft fans mentioned below (Section 2.3.5.2) there is a distinct advantage associated with selecting a direct-drive blower with a totally enclosed, weatherproof motor of the correct rpm value. This selection eliminates belts, belt guards, and motor enclosure and results in a compact, maintenance-free installation. See Chapter 30 for more details on fans.

2.3.5.1 Centrifugal Blowers. Cast-iron fans are ideal for all exhaust air applications, including spot exhausts, because they are of excellent quality and reliability, have an extended life span, and require very little maintenance. Whenever long life expectancy and freedom from maintenance are not critical, steel plate fans are acceptable. Whenever the effluent air from fume hoods customarily contains large amounts of severely corrosive gases plus condensing water vapor, exhaust fans constructed of fiberglass-reinforced polyester (FRP) located on top of the building to minimize positive pressure duct sections are highly recommended. Fume hood exhaust fans handling contaminants composed of dust and mist, or containing flammable, toxic, or corrosive materials, should be located outside occupied areas of the building and as close as possible to the point of discharge to the atmosphere, preferably on the roof of the laboratory building.

2.3.5.2 Induced Air Fans. Another option for an exhaust fan is the direct-drive, high-velocity induced-air fan. These fans are specially designed to discharge exhaust air at a very high velocity. The overall effect is enhanced by the presence of openings in the bottom of the exhaust fan housing. As its exhaust plume discharges upward, additional air is induced through these openings, making the overall amount of air discharged from the fan greater than the amount of air directly exhausted from the ductwork through the fan. The additional air mass in the plume and its added velocity impart an added momentum to the plume, which increases its



KEY

1 Stack Discharge Directly Upward
2 Guy Wires to Roof if Required (3 lines/stack)
3 Directly Connected, Totally Enclosed Weather Proof Motor
4 1 Inch Diameter Hole at Low Point in Fan Scroll for Drainage to Roof
5 Exhaust Air
6 Roof
7 Parapet

FIGURE 2-18. Exhaust fan stack diagram.

height before dispersion starts. Care must be taken to ensure that the exhaust fan stack is located at a height adequate to provide unrestricted plume dispersion. See Figure 30-3 for an illustration of this fan. Tests have shown that the momentum of the discharge air forms an almost vertical plume for a considerable height (see Figure 2-18).

2.3.5.3 Exhaust Air Cleaning for Laboratory Effluent Air. Generally, exhaust air from laboratories is not cleaned before release because of the relatively low concentration of contaminants in the exhaust system and the excellent dilution capability of the atmosphere when the air is discharged straight upward, starting 10 ft or more above all roof obstructions. However, certain laboratory procedures may require special effluent gas treatment to avoid polluting the atmosphere. Specific instances are described in Part II of this book, where detailed descriptions of common laboratories are found.

2.3.6 Exhaust Ducts and Plenums

2.3.6.1 Construction of Exhaust Ducts and Plenums. Exhaust ducts for fume hoods and local exhaust systems should preferably be of the high-velocity (2,500–3,000 ft/min; 10–15 m/s) type to avoid settlement of particles in horizontal runs. Additionally, high-velocity systems reduce duct cross section and save space in vertical chases and above-ceiling utility areas. Stainless steel of a high chromium and nickel content is the material of construction for hard service in a corrosive, erosive, and high-temperature environment, but the cost is high. Other materials of construction, such as epoxy-coated steel, can be used for less-demanding applications. Plastic piping has exceptional resistance to many commonly used corrosive chemicals, but physical strength and flame-spread ratings are less than that for metals. It may be excessive, but California regulations require a 2-h-rated separation between fume hood exhaust ducts from different floors within the same chase. All fume hoods and local exhaust system ducts should be constructed of round piping with the interior of all ducts smooth and free of obstructions. All joints should be welded or otherwise sealed airtight.

Flexible ducts used for spot exhaust service should be kept to minimum lengths because flexible duct has an airflow resistance that is as much as two to three times that of metal duct of the same diameter. Poorly formed flexible elbows can increase system resistance to the point where function is lost. To reduce energy loss and air noise levels, the open ends of sucker hoses should be tightly capped when not in use. Flexible tubing must be selected from among the noncollapsible types.

2.3.6.2 Duct Leakage. All local exhaust system ductwork located inside the laboratory building must be maintained under negative pressure to prevent leakage of contaminated air into occupied spaces. Maximum duct leakage not greater than 2% at design negative pressure should be specified in the building design documents and the installation carefully supervised. To ensure that this standard is achieved, the ducts should be tested, without fail, after installation by capping the ends of duct runs, putting the ducts under the design negative pressure specified in the construction documents, and measuring the volume of inflow air carefully with a sensitive, variable head airflow meter. Inflow rate should not be greater than 2% of the maximum design airflow rate for the duct run under test. Note that balancing measured airflow rates into a system against

measured airflow at the discharge end is not an acceptable way of ensuring leakage of no more than 2% because field measurements cannot be relied on to less than ±10%, at best (see ASHRAE 90.1, 2010). If condensation inside the ducts is possible, all sections must be pitched to drain to a sewer connection.

Ideally, exhaust ductwork should be designed to be self-balancing without the use of trimming dampers. Dampers inside exhaust air systems serving laboratories (with the exception of those required for emergency fire-suppression purposes) are prone to failure from corrosion, vibration, and maladjustment by unknowledgeable service personnel. Maladjusted dampers are frequently observed to seriously compromise the safety objective of the exhaust systems in which they are installed. Therefore, experienced ventilation engineers design systems that will meet building and laboratory design objectives without trimming dampers. To be effective, however, installation contractors must follow directions with sufficient exactitude to accomplish the desired results. Meticulous testing of completed systems is the only way to ensure quality installations. However, the future flexibility of any installation may be compromised without dampers.

If condensation can occur inside exhaust ducts because of changes in temperature from warm general building space to a cold mechanical or fan room, consideration should be given to draining from the low point of the duct before it leaves the building and trapping this condensation and draining it back into the plumbing system.

2.3.6.3 Noise Suppression. Air noise in laboratory ductwork can be minimized by keeping velocities within acceptable ranges (2,000–3,000 ft/min; 10–15 m/s) and by using flexible connections between fans and ducts. Use of sound attenuators in exhaust ductwork is not an acceptable solution to noise problems, although their use is acceptable in supply air systems. Control of noise from sucker hoses (a potential major noise source) is discussed in Section 2.3.6.1.

2.4 GUIDING CONCEPTS FOR LABORATORY MODULE LOSS PREVENTION, OCCUPATIONAL SAFETY, AND HEALTH PROTECTION

The eight safety systems discussed in this section are specific to laboratory units located within a building with only laboratories or a mixed use facility. In some cases, these loss prevention, and occupational safety and health protection systems provide additional information for topics discussed in Chapter 1, Section 1.4 (Laboratory Buildings). Readers are encouraged to read both sections before proceeding with design considerations for laboratory units.

2.4.1 Emergency Considerations

A clear objective of any laboratory design is to avoid and prevent unsafe conditions that could lead to personal injury of the user occupants, guests, or emergency responders; damage to the laboratory facility, materials, or equipment; or to the environment. Despite the best planning, emergencies sometimes occur from unforeseen events. Therefore, the prudent building designer takes all reasonable steps to contain possible emergencies by the installation of loss control services and equipment. With emergency systems, personnel and physical plant losses can be avoided or at least reduced to a tolerable level. All of the following emergency considerations should be included in the basic design. Rejection of any must be documented and justified. Those not required by law or code represent good practice standards.

2.4.1.1 Fixed Automatic Fire Suppression. Standard wet pipe water sprinklers are considered the normal protection for most laboratories. The system should be designed and installed in accordance with NFPA 13 (NFPA, 2013). For laboratory modules with unique hazards, other systems may be substituted for water sprinklers. Each of the laboratory type and specific room chapters discuss this issue.

2.4.1.2 Hand-Portable Fire Extinguishers. Hand-portable fire extinguishers in laboratory modules are provided to assist room occupants in fighting the fire to exit the room and possibly the building. For this reason, the placement of the extinguisher or extinguishers is better located remote from the exit doors—perhaps in the back of the laboratory. The extinguisher type can vary with the activities of the laboratory, but the size should be such that a small person can lift and handle the unit. It is recommended that a minimum size of 10 BC be provided, and perhaps more than one extinguisher depending on the layout of the lab. A clean agent such as 1,1,1,3,3,3-hexafluoropropane (FE 36, developed by E.I. DuPont Inc., Wilmington, DE) or carbon dioxide will give the laboratory user a tool that they will be more likely to use to extinguish a small fire than an extinguisher comprised of a messy agent. Although the extinguishers are there to assist in escape, many laboratory persons will try to combat a fire instead of leaving. For that reason, size counts and the FE 36 is much more effective than carbon dioxide, pound for

pound. Laboratory personnel untrained in firefighting techniques and methods should not attempt to extinguish anything other than a small insipient fire.

2.4.1.3 Emergency Fuel Gas Shutoff. The use of Bunsen and Fisher burners is diminishing in laboratories, but not gone. Consequently, in facilities in which fuel gas is piped throughout the building to these laboratories, a method of shutting off the flow of gas at the laboratory module or group of modules must be installed for emergency use. The preferred method is to run the gas supply pipe to a wall just outside the laboratory and locate an emergency shutoff valve station at that point. A secondary method would be to place one shutoff on each floor of the laboratory building to control all the laboratory modules on that floor. These should be placed at an end of the corridor and be well marked. The station should consist of a simple ball valve located in a box with a breakable glass or easily removable cover and a clear sign announcing its function. Although a major building gas shutoff must be provided along with an excess-flow check valve to serve the entire building, the major building cutoff valve may be too remote from the laboratory room involved in an emergency and the building excess-flow-check valve too large to sense and to stop the flow of fuel into small laboratory areas. For both reasons, local valve stations are necessary.

The requirements for fuel gases do not apply to nonfuel laboratory gases that are piped into laboratories through small piping systems from a central source. However, nonfuel gas pipes, valves, excess-flow-check valves, and other materials and installations must meet applicable codes and standards of the NFPA 55 (NFPA, 2010) and the Compressed Gas Association.

2.4.1.4 Ground Fault Circuit Interrupters. Ground fault circuit interrupters (GFCIs) for normal line voltage, 120 vac, should be installed and available for use at all laboratory benches and where portable or nonstationary equipment is used. Ground fault circuit interrupters are devices that compare the current flow in wires feeding and returning from electrical devices, such as mixers, ovens, meters, blenders, pumps, and stirrers. When an imbalance of more than 5 milliampere (mA) occurs, the electrical power to the device will cut off. This is predicated on the assumption that the leakage, or lost current, could pass through the body of an operator. The circuit interrupter functions to limit the amount of "shock" to nonlethal levels. This is in contrast to the electrical fuses and circuit breakers normally found in a laboratory building. They do not open until the power requirements of the equipment on-line, or the electrical circuit, are exceeded. Therefore, fuses and circuit breakers cannot prevent an electrical shock to personnel; they function only to protect equipment and the building against fire.

GFCIs tend to sum up all the leakage of devices plugged into the circuit being monitored. Installation of more interrupters, or fewer electrical appliances per circuit, can help to reduce nuisance tripping. Old electrical devices or appliances, whose insulation is not as good as when they were new, also can trip the interrupters, indicating a need for these appliances to be renovated or replaced. Fuses and circuit breakers, GFCIs, and a comprehensive electrical safety program are all necessary to provide maximum freedom from shock, electrical fire, and electrical equipment problems.

GFCIs should be available for use at all laboratory benches, and there should be no more than three duplex outlets connected to any one interrupter. GFCIs should also be available for use near wet operations such as sinks. GFCIs are required by the National Electrical Code NFPA 70 (NFPA, 2011) for all outlets that are located within 6 ft (2 m) of wet sinks and should be used within 3 ft (1 m) of emergency showers or eye-wash units.

The use of a circuit-breaker-type GFCI unit in a central box at the main electrical panel for the laboratory encourages prompt attention to standing line leaks and other potential problems in the system. These problems result in the inappropriate shutdown of the circuit, which compromises the value of the safety system. The use of no more than three duplex outlets placed close to each other and attached to a GFCI on the same bench is ideal because this arrangement minimizes long wire runs with many junction boxes that have a leak potential. In addition, when ground faults occur that shut the system down, they can be corrected easily and the system can be turned back on again quickly.

Stationary electrical equipment, such as refrigerators and ovens, should be equipment grounded through hard wiring; therefore, these devices need not be ground fault circuit interrupted in addition. One duplex plug outlet on each laboratory bench might be installed without GFCIs to provide a means of temporarily using equipment that would otherwise break the circuit. This outlet should be clearly identified.

2.4.1.5 Master Electrical Disconnect Switch. In each laboratory area, electrical services should be identified and sited in such a manner that all electrical power to the laboratory (except lighting and other life safety-critical items such as exhaust systems and alarms) can be quickly disconnected from one easily accessible location. When such an arrangement is not possible or feasible, a shunt trip-breaker system should be installed that will accomplish the same thing on depression of the

master mushroom kill switch. This switch should be located near the normal emergency exit route, but not in a place where it can be activated inadvertently.

Adequate electrical outlets for standard line voltage equipment should be provided within each laboratory to facilitate the use of all pieces of anticipated electrical equipment. Older laboratories often have many extension wires draped around the laboratory, resulting in an unsafe condition. Unsafe extension wire conditions can be avoided in new laboratories by adequate preplanning that includes a systematic and realistic evaluation of current and future electrical outlet requirements. Many electrical outlets in laboratories should be equipped with GFCIs (Section 2.4.1.4).

2.4.1.6 Emergency Showers. Emergency deluge showers are used to dilute and wash off chemical spills on the human body. Because many chemicals attack the body rapidly, the location and reliable functioning of the showers is of critical importance. Specifications for emergency showers are given in Appendix A.

Primary emergency deluge showers must be located within 10-s travel time from the place of contact. Doorways that must be traversed must open in the direction of travel and be equipped with hardware that cannot be locked in the direction of travel.

Deluge showers, when properly installed, provide a minimum of 20 gallons (57.7l) of water per minute and deliver this volume at low velocity because high-velocity showers can further damage injured tissue. For this reason, only low-velocity deluge shower heads are recommended. The valve operating the shower should be a type that requires a positive action to close, such as a ball valve with a non-spring-loaded lever arm. Rigid pull bars of stainless steel stand up better under corrosive conditions than do chains and other metals.

When testing is not performed routinely, valves often become so difficult to operate that a pull chain can break before the water valve is turned on. The preferred location of a shower is just outside the hazardous area. This could be in a hall not more than 25–50 ft (7–15 m) from the laboratory. The valve should be located close enough to a wall that normal traffic will not bump into the operating rod. The shower head should be far enough out from the wall to allow a second person to move around it to help an injured person. It has been demonstrated that persons who need to use an emergency shower frequently need help in several ways: finding the on/off valve, getting the effected—perhaps all clothing—off, standing in very cold water alone, and keeping onlookers away. Placing showers in locations where a privacy curtains can be installed, while leaving adequate room for two people, the affected and an assistant, will encourage an injured person to adequately remove clothing for the required fifteen minute shower.

A large contrasting spot should be painted on, embedded in, or affixed to the floor directly beneath the shower to indicate its location. At least one shower in each area of the building should be tempered to provide water at 60–100°F (16–38°C) to accommodate an injured person, who should remain in the shower for the recommended 15-min period. Normally, in some areas, cold water temperature is substantially below 70°F (18°C) and immersion in water at this temperature, for a long period, would be painful for an injured person. For economy, the remainder of the deluge showers can be connected directly to the potable cold water system. Another way of providing a tempered water deluge shower is to use a nearby toilet facility with a shower stall already in place. In this case, a standard emergency shower deluge head should be installed that uses the correct pipe size and an antiscald mixing valve. The shower head should be replaced to provide a copious flow of water at low velocity, avoiding injury that can be inflicted by high velocity jets. With this arrangement, the injured person would be able to have a degree of privacy for the 15-min shower, especially important when it becomes necessary to remove contaminated clothing, as it most often is.

Another advantage of using a shower stall in a rest room for a tempered emergency shower is that the runoff water can go through a floor drain. Floor drains are not normally installed in corridors under emergency showers because they are used so infrequently that the traps become dry and allow sewer gases to enter the area. If the tempered water shower is to be in a hall corridor or laboratory and a drain is deemed necessary, a floor drain capable of handling the entire output of the shower should be installed with it. Because of evaporation from the drain trap, the occupants should be alerted to the need to pour water every 2 weeks, or ethylene glycol every 6 months, into the drain. For additional information, see ANSI Standard Z358.1 2009, "Emergency Eyewash and Shower Equipment" (ANSI, 2009).

Contrary to popular opinion, emergency deluge showers are not installed to extinguish clothing fires. The best method of extinguishing a clothing fire is to "stop, drop, and roll," then remove the burned clothing, and seek help. Nevertheless, if one is within a step or two of a deluge shower, this device can be used as an effective fire extinguisher for a clothing fire. The hazard associated with moving from the laboratory to a shower with burning clothes is the probability of inhaling burning gases and searing the breathing passages, including the deep parts of the lungs, to a fatal degree. The "stop, drop, and roll" method is preferred. See Appendix A for

shower guidelines according to the Americans with Disabilities Act and additional information.

2.4.1.7 Emergency Eyewash. The reaction of many chemicals with the human eye is very rapid. For example, the interior chamber of the eye can be reached within 6–8 s after a splash of concentrated ammonia. Therefore, most physicians agree that an immediate flush with copious quantities of water is the best first aid treatment for chemical splashes to the face and eyes.

There are two basic types of emergency eyewash devices available: plumbed and portable. Because many portable units do not have the capacity to deliver the recommended 15 min of copious flushing, this discussion is limited to plumbed emergency eyewash units. It is acknowledged that portable units have value when they can be located very close to the user and result in a very quick start to eye flushing that can be completed at the plumbed eyewash station once the initial flush has been accomplished.

There should be at least one eyewash facility per laboratory module if the occupants use strong chemicals. The eyewash units may be located at sinks or at any other readily accessible area in the laboratory within 10 s of travel time. Travel through a door to get to an eyewash should not be allowed. Laboratories using strong acids or bases should have an eyewash within 10–15 ft (3–5 m) of the hazard area. A tempered water unit should be installed for each contiguous group of laboratories. It should be between 60–100°F (16–38 C). This is necessary because most physicians recommend a 15-min wash before transportation to a medical facility. Holding one's eyes open to 35–40°F (2–4 C) water for more than a minute or 2 can become painful and ultimately impossible.

As chemical splashes seldom affect only one's eyes, the best units for washing eyes and face are the multistream, cross-flow types. They flush the face and both eyes at the same time with near-zero-velocity water. Hand-held units on a hose, such as a kitchen spray, have the advantage of serving as a minishower for splashes of the arms, hands, and other small body spills.

Emergency eye wash units must be tested periodically and when placed in areas with no floor drain, consideration should be given for locating a waste-water discharge nipple under the eye wash and above the floor high enough to place a collection pail under it.

Specifications for emergency eyewash facilities appear in Appendix B. See also ANSI Standard Z358.1 (ANSI, 2009), Emergency Eyewash and Shower Equipment.

2.4.1.8 Chemical, Radioactive, and Pathology Material Spill Control. A means for effecting prompt spill control should be provided for all laboratories using hazardous materials. They include making provisions for (1) establishment of convenient clean-up stations; (2) one or more storage locations of adequate size to hold the requisite quantity of neutralizing chemicals, adsorbents, disinfectants, and other equipment needed to deal effectively and rapidly with the maximum anticipated spill; and (3) diking materials, consisting of fixed dikes or dike bags. The locations of clean-up stations need to be clearly identified in the building design stages. A central station with materials appropriate to the entire building may be necessary due to space and cost limitations. Materials at a central station will need to be stored on wheeled carts for rapid deployment to any spill area.

2.4.1.9 Emergency Cabinet. Emergency cabinets should be provided for all laboratories and located in an area that will be readily accessible under stress conditions. The cabinet should be sized to hold items specific to the work of the laboratory as well as a number of general items. General and specific items may include:

General	*Specific*
Emergency blanket	Medical antidotes
Emergency response information	Chemical spill kits
First aid kit	Protective clothing
Stretcher	Escape breathing equipment
Resuscitation equipment	

2.4.2 Construction Materials

The fire-resistive construction requirements of IBC Article 9 for Class A buildings should be followed (IBC, 1999). Selection of wall coverings, bench materials, and other furnishings of some laboratories will require special consideration. Examples are installation of materials resistant to fire; consideration of the potential for electric shock in the use of metal furnishings; and reflectivity of building materials for certain operations involving light, darkness, and lasers (see Tables 2-3 and 2-4).

2.4.3 Control Systems

Equipment using hazardous materials, such as constantly flowing toxic or flammable gases, as well as electricity-dependent operations should have alarm and automatic shut-off circuits capable of rendering the process and equipment safe in case of failure. To build these safeguards into a laboratory requires that potential problems be defined by the expected users of the

laboratory during the design stages of the building and laboratory.

2.4.4 Alarm Systems for Experimental Equipment

A system of electronic communications should be installed in laboratory modules so that when necessary, monitoring of key laboratory operations can be initiated to signal equipment malfunctions. The system should connect the laboratory to control points selected by the laboratory manager. Selected control points may be the office of the investigator, a hall outside the laboratory, a security guard station, or the fire station. The alarm system is not intended to be a control system; it should be for the transfer of information only. If there are firm regulations against leaving experiments, reactions, and all other laboratory activities unattended, and if no other need exists, alarm systems for experimental equipment may be put in later if the need dictates. In an operation in which hazards are controlled by outside services, such as water for a still, ventilation, or electricity, provisions should be made for shutdown of the operation in emergency situations. Emergency electrical systems are described in more detail in Section 2.4.1.5.

2.4.5 Hazardous Chemical Disposal

Discarded hazardous materials, including flammable liquids, strong reagent chemicals, biological and radioactive wastes, and highly toxic chemicals, should be segregated into specific areas within the laboratory for eventual disposal. The hazardous waste storage area should not be located where an unexpected reaction could immediately involve persons working at normal workstations, and it should not block normal egress routes. In addition, the hazardous waste storage area should be chosen so that, should an undesired reaction occur, it would not affect other areas of the building. Chapter 27 contains detailed information on rooms used for hazardous waste of all kinds.

Hazardous wastes should be stored in appropriate safety containers. Flammable liquid wastes, for example, should be stored in approved waste safety cans that carry Underwriters Laboratory (UL) or Factory Mutual (FM; a casualty insurance group) approval for this use. They should be placed in a location in which spills can be caught and retained without damaging the floor or creating slippery work and walking surfaces. Local ventilation may be necessary for especially toxic, malodorous, and volatile waste materials. Because some waste containers are large and bulky, the architect and laboratory designer should consult manufacturers' catalogs to get a good idea of the space that will be needed and to make provision for movement of the accumulated wastes by cart or some other suitable means. For more on chemical storage, see Chapter 1, Section 1.4.6.

2.4.5.1 Chemical Waste Treatment before Disposal. Laboratory sinks and floor drains should be tied into a chemical process waste system for the disposal of nonhazardous chemicals, some requiring neutralization, to make them suitable for ultimate disposal in the sanitary sewer system. Local, city, and state regulations should be examined to determine the extent to which neutralization tanks must be used.

2.4.6 Chemical Storage and Handling

Determining chemical storage and handling locations and methods should be considered during the design phase of the laboratories. Experience has shown that site inspection of currently used facilities of the potential users of new laboratories is the best way to determine the amounts of chemicals that must be stored in the new laboratory. When an inspection is not possible, the needed information should be obtained from the expected users and from similar laboratory operations. Current needs figures should be increased by a safety factor of 1.5–2.0 to allow for growth, and space should be provided accordingly.

2.4.6.1 Storage in the Laboratory. For safety, the quantity of chemicals stored in a laboratory should be kept to a minimum at all times and they should be stored by methods and locations appropriate to their hazard classification. Large supplies of chemicals should be stored in a central storage area serving the entire laboratory complex (see Section 1.4.7 and Chapter 28. The laboratory director or principal investigator should be consulted to determine maximum storage quantities for each laboratory, and space should be provided in the new facility for adequate chemical stocks based on the information obtained. Each laboratory and the entire facility should maintain an up-to-date chemical inventory.

2.4.6.2 Standard Reagents, Acids, and Bases. Strong acids and bases may be stored in the ventilated base of chemical fume hoods, but separation should be provided to prevent cross-mixing in the event of breakage or leakage. Mild acids and bases such as citric acid and sodium carbonate may be stored with other low-hazard reagents. Open shelves for chemicals should be located out of normally traveled routes and have a 1/2- to 3/4-in. (1–2 cm) lip to prevent movement over the edge caused by vibration or an earthquake.

2.4.6.3 Flammable Liquid Storage Cabinets. Contrary to a commonly held belief, flammable liquid storage cabinets are intended to protect the contents from the heat and flames of an external fire rather than to confine burning liquids within. Flammable liquids should be kept in UL-approved flammable liquid storage cabinets. The cabinets should be remote from other operations within the laboratory that could become involved in a fire. In addition, they should not be located where they could impede access to an exit in case of fire. Whether flammable liquid storage cabinets should be ventilated depends on several factors; opinions are mixed. When a flammable liquid cabinet must be located under a chemical fume hood (although this is not desirable), it should be provided with minimal ventilation by being connected to the hood exhaust system through a flash arrestor. Typically, an exhaust connection is made into the back of the hood with one or two 1 1/2-in. (4-cm) diameter pipes that extend from the underhood storage space through the work surface and into the hood plenum. When a storage cabinet for flammable liquids is to be located in some other part of the laboratory, remote from a chemical fume hood, and it is feared that it may generate flammable vapors and malodors from spills, it should be ventilated at a rate of three to five air changes per hour. Another plan is simply to leave the vent ports open with the flash arrestors in place and let the room exhaust handle whatever vapors escape from the cabinet. Each of the methods cited is legally acceptable. The concern over the use of forced ventilation inside the cabinet is a fear of overcoming the effect of the flash arrestors in protecting the contents of the cabinet from an exterior fire. Local codes and statutes vary on the requirement for ventilation of flammable storage cabinets. A check with the local authority having jurisdiction, normally the fire department, is advised. If ventilation is required, the cabinets must be ventilated to an outside area. The use of plastic piping for this purpose is not advised and in some locales, not allowed. A room fire can quickly burn through such pipes and potentially involve the contents of the cabinet.

2.4.6.4 Special Chemicals. Especially hazardous chemicals, "select agents," and other chemicals, biological agents and radioactive materials requiring security control, should be stored in locked cabinets located within the laboratory or in a central chemical storage room. The locked storage cabinets should be adequate in size and contain internal separations to provide for the storage of incompatible chemicals such as perchloric acid and cyanide compounds. Lecture bottles and full-sized cylinders of compressed gases should be stored in a ventilated storage area. Mechanically ventilated hood bases, and other types of vented cabinets, are suitable for this purpose.

2.4.7 Compressed Gas Cylinder Racks

When full-sized compressed gas cylinders are required inside a laboratory, special facilities must be provided for their safe use. They include strapping and anchoring devices, adequate room ventilation to remove leaking gas, and easy accessibility for periodic exchange of cylinders. The area should be large enough to accommodate an extra tank of each gas type in use (or at least the most used gases) with adequate room for empties awaiting collection. The direction of ventilation airflow should be out of the room and building immediately after passing the gas storage area. Local piping systems for gas cylinders located in the laboratory should meet the criteria cited in Chapter 1, Section 1.4.8. Local spot exhaust ventilation can also be used to satisfy gas cylinder exhaust ventilation requirements. Special gas cabinets should be used for particularly hazardous gases. See Chapters 11 and 23 for more information.

2.4.8 Safety Locations for Equipment and Materials

2.4.8.1 Safe Equipment Locations. All equipment installed inside and outside laboratories should be located in such a manner that its failure will not involve other pieces of vital equipment, block egress routes, or create situations that overwhelm the capabilities of the ventilation and sprinkler systems (see also Chapter 1, Sections 1.3 and 1.4.4).

2.4.8.2 Material Locations. Secure locations should be established for materials that could become involved in creating or worsening emergency situations. They include trash and waste baskets, waste chemicals, stored chemicals, and normal combustibles, such as supplies of single-use disposable laboratory materials.

2.5 SPECIAL SERVICES

Special utility services, such as high-electrical-voltage, high-pressure steam, and hydraulic systems, must be installed in accordance with applicable codes and standards when these are available. When experimental use of special services is not covered by standards or codes, a review team of experts is needed to generate guidelines for installation and use of special services to substitute for the absence of codes and standards. This is an important safety provision. The more the special laboratory services deviate from those normally provided to all laboratories, the greater is the need to seek review and guidance on the equipment and procedures. The review team should include members of the industrial safety and industrial hygiene professions, building maintenance personnel, the user, and the building design team leaders.

Part III of this book reviews several laboratory support services.

2.5.1 Security

Some laboratories will require lock-up capability for certain materials such as hypodermic syringes and needles, controlled substances, select agents, explosives, radiochemicals, and proprietary items. Planning to meet this requirement should be done early in the design process. Many laboratories will need to have lockable entrance doors. Using a consistent lock system throughout a facility reduces access problems when emergency situations arise. Combination locks that have a master key override for emergency response and management personnel are commonly used. See Chapter 1, Section 1.5.4.1 for more information on security issues.

PART IB

COMMON ELEMENTS OF RENOVATIONS

The two chapters that make up Part I, Section B of this book address the many elements of the design process as they are applied to laboratory buildings and modules that are under consideration or scheduled to undergo an upgrade, renovation, or retrofit. Renovation is a generic term that refers to changes and improvements of an entire building or part of a building that involve construction of sufficient magnitude to require a considerable degree of planning and design. It does not include such activities as relocating equipment, normal maintenance, and upkeep or improvements such as painting walls and repairing floors, important as all these activities are for preserving function and serviceability. In this book, *renovation* refers to constructed improvements in laboratory building's or nonlaboratory mixed-use buildings that contain laboratories. It covers a fairly wide range of possibilities from straightforward retrofits to thorough-going decontamination, decommissioning, and reconstruction.

Renovations differ from original construction in two important ways: (1) the existing structure must be partially disassembled and entirely cleared of hazardous materials before reconstruction can begin; (2) sometimes, it is necessary to conduct disassembly operations and reconstruction in only one part of a building while the rest remains in continuous occupancy and under more or less normal operation. Both situations call for careful planning and scrupulous attention to safe operations during all phases of decommissioning and decontamination as well as throughout the period of reconstruction whenever a portion of the building undergoing renovation remains in continuous normal operation.

It is convenient for discussion purposes to divide the broad range of renovation activities into a few subcategories based on the magnitude of the reconstruction effort. *Upgrades* are minor renovations of a laboratory building or a single laboratory that do not significantly modify the building structure, ventilation systems, fire rating, or life safety systems. Examples of upgrades include relocation of a laboratory hood, installation of a new hood in a single laboratory, and rearranging bench spacing.

Modernization refers to upgrading an entire old building or one or more outmoded laboratory spaces within an old laboratory building. This may occur without changing the laboratory type, for example, upgrading an obsolete chemistry laboratory building to a modern chemistry building. Alternatively, it may involve a change from one laboratory type to a different laboratory type, for example, converting chemistry laboratory spaces to cell biology spaces. More complex and difficult modernizations are termed *retrofits*, changes that convert from one occupancy and function to another, such as from a nonlaboratory use to a laboratory use and the reverse, for example, converting a warehouse to laboratories or an old engineering laboratory building to classrooms and administrative offices. One of the factors that makes retrofits and upgrades especially complex is that building code and zoning ordinance requirements pertain to

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

specific permitted activities and occupancy. A change of occupancy or hazard level almost always triggers different code requirements. Therefore, local code requirements should be thoroughly researched to confirm acceptance of the new use.

Just as in construction from the ground up, covered in Part IA, when the changes are substantial, international, state, and local building codes, health and safety requirements, and environmental protection regulations will be the same for renovations as for new construction, although allowances are often permitted under grandfathering. Recent emphasis on fire protection, occupational safety, and environmental protection usually means that minimum requirements for such essential building and laboratory protective services as means of egress, fire-protected construction, fire protection systems, sustainability, energy efficiency, occupancy, and chemical-use limits are likely to have changed radically during the interval since the original construction. These changes often pose severe challenges to successful renovation of old structures to meet modern laboratory standards. The challenges can sometimes turn out to be insurmountable, especially when contemplating converting old nonlaboratory buildings to laboratory use. However, with thoughtful planning, assembly of a competent and experienced design team, careful construction, and an adequate budget, most fundamentally sound buildings can be successfully renovated to become modern, functional laboratory facilities. Renovations of any significant magnitude, e.g., an individual laboratory or an entire laboratory building, must comply with current codes and regulations unless a variance or exemption is approved by the building authorities. Local jurisdictions require building permits and perform thorough plan reviews for most renovations. Additional permits may be required for zoning, for city utility connections, and other features of the proposed construction. Building codes and local jurisdictions closely regulate design and construction of major renovations, and, even when only a part of a building is reconstructed, they can require that the entire building be improved to comply with current codes and regulations.

SAFETY CONSIDERATIONS

Safety professionals know that change is a major factor in accident causation in all of industry. It occurs also in nonindustrial situations such as during renovations when the presence of change intensifies the accident potential normally present during construction activity. Risk analysis and job hazard evaluations are two of the important tools used to identify potential accident situations during renovations and to initiate preventive measures intended to avoid unexpected events that may result in death, injury, and loss of property. These can help to eliminate or minimize creating avoidable hazards, for example, relocating pieces of emergency equipment such as hand-portable fire extinguishers without notifying remaining occupants and construction workers, or storing hazardous materials next to incompatible construction supplies and activities. When laboratory personnel continue to work during renovations they are exposed to hazards they would not normally encounter. For example, they will be exposed to changing conditions such as doors leading to unsafe locations. In short, renovations taking place in a laboratory building where, concurrently, laboratory operations continue present additional hazard control requirements.

Controlling and eliminating safety hazards associated with change depends more on enhanced communication and construction management than design, although awareness on the part of the design team helps find solutions. Renovations usually involve the same hazards that occur during new construction. There are also the hazards of personnel returning to what seems to be a familiar building that they no longer thoroughly recognize, and they may experience a rash of accidents due to the changes. Disorientation can be reduced by planning, communication, and education of the returnees regarding what changes have occurred and how they may be affected by them. When Sweden changed traffic laws to require driving on the right instead of the left, planning, communication, and education resulted in not a single fatality attributable to the change, a splendid demonstration of how to employ change analysis constructively. In conclusion, a thorough risk analysis must be conducted for the planned renovation.

PRESERVING INDOOR AIR QUALITY DURING RENOVATIONS

During construction activities, when a part of the building remains occupied, care must be taken to maximize the isolation of the construction activities from other occupants of the building. This must be considered in the planning stages because it may affect how and when specific work tasks will be conducted and the ultimate cost of renovation. The objective should be to minimize stress to all of the building's nonlaboratory occupants, construction crews, and remaining laboratory occupants. In addition, some normal activities may be adversely affected by construction-generated odors, aerosols, gases, noise, and vibration. Building occupants engaged in their normal activities should be aware of the construction work that will be occurring in the vicinity, what measures are being taken to minimize the impact of the

construction on them and their normal activities, and what to do if they have concerns. Prevention of indoor air quality degradation in a building being partially renovated or in adjoining buildings involves preplanning and a continuing program of timely communication to all potentially affected occupants. Some effective control methods that may be used to prevent intrusion of contaminated air from the construction area into operating areas include

- Isolation of activity with physical barriers and directional airflows that protect nonconstruction areas
- Use of local exhaust ventilation to prevent escape of dust and gases
- Protection of the occupied area HVAC system
- Temporary relocation of building air intakes
- Filtration at air intakes
- Conducting some construction activities during unoccupied periods

DECOMMISSIONING AND DECONTAMINATION

Once the decision to renovate or demolish a laboratory building or one or more laboratories within the building is made the decommissioning process must be initiated. There are many hazardous materials or equipment that may be present in the laboratories that must be addressed as part of the decommissioning process. A partial list of these materials and equipment appears in Table IB-1. These issues should be addressed in a systematic and thorough manner. A comprehensive methodology for laboratory decommissioning has been adopted as a national consensus standard ANSI-Z9.11 (ANSI, 2008). Decommissioning is defined as a process to ensure a facility and its associated infrastructure meets environmental health and safety requirements for its next use. Its next use could be another laboratory or an office space or even a day care center. The level of decommissioning needed will vary depending on the intended use. It is important to distinguish decommissioning from decontamination and cleaning. Decontamination is the removal of a hazardous substance(s) from a surface or equipment to reduce the risk to an acceptable level. Cleaning is the removal of nonhazardous, but unwanted substances (e.g., dirt and dust) from surfaces or equipment to render it aesthetically acceptable.

The decommissioning process can be triggered by demolition or renovation, laboratory group moves or significant changes in activities, end of a space lease, capital equipment replacement, or a major fire or release of a hazardous material.

TABLE IB-1. Potential Hazards in Laboratory Spaces that Need to Be Identified when Planning Renovation

Building Materials
- Asbestos
- Lead paint
- Fiberglass or other MMMF
- PCBs (polychlorinated biphenyls)

Hazardous Materials Used in Laboratory Work
- Radioactive agents
- Microbiological agents
- Chemical agents

Toxic Reactive
Flammable Explosive

Chemicals of Particular Concern
- Perchloric acid and compounds
- Mercury
- Azides
- Metals having pyrophoric and highly toxic properties, e.g., arsenic
- Toxic organic compounds, e.g., acrylamide, aflotoxin, organic mercury
- Picric acid
- Ethyl ethers and other peroxidizable chemicals

Physical Hazards
- Broken glassware
- Needles and syringes
- Compressed gases

Equipment that May Be Contaminated and Contain Leftover Hazardous Materials
- Refrigerators
- Freezers
- Experimental apparatus
- Laboratory hoods
- Biological safety cabinets

An effective decommissioning process can

- Prevent or reduce exposure
- Reduce cost
- Reduce liability
- Address regulatory requirements
- Achieve consistency in project execution
- Promote environmental stewardship and sustainability
- Enhance community confidence and relationships

Figure IB-1 depicts a process flow with decision making steps that may help to provide guidance. ANSI Z9.11

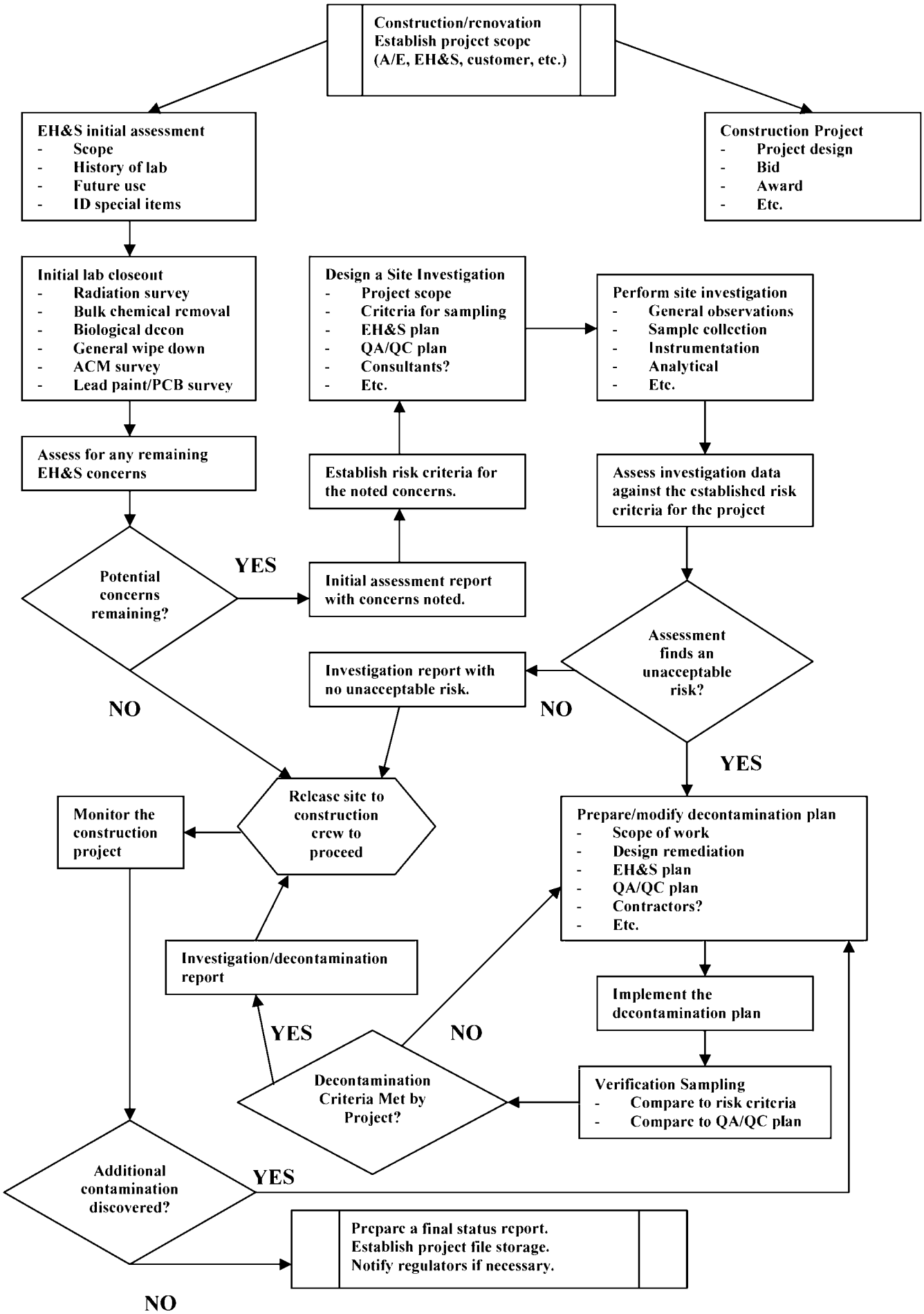


FIGURE IB-1. Decommissioning process flow. (Reproduced with permission from the Z9.11-2008 standard, ANSI, 2008)

defines the following steps in the decommissioning process.

1. Identify area for renovation
2. Determine scope of project
3. Collect historical data (interviews, documentation, etc.)
4. Review data and determine potential contaminants of concern (PCOC)
5. Occupants or staff familiar with specific area hazards clean area in preparation for work including
   a. Disposal of hazardous wastes
   b. Removal of hazardous materials
   c. Decontamination and removal of experimental equipment
   d. General cleaning of work surfaces using soap and water or materials appropriate for agents in use
   e. Final survey with EH&S to determine adequate removal of general hazards

   Note that after this step circumstances may indicate no further action is necessary (skip Steps 6–12) and one can proceed to Step 13.
6. Develop sample and analysis strategy for PCOC using field methods where possible to control costs with validation of field processes where not previously employed
7. Perform site survey and initial sampling (as demolition is performed this may be an ongoing process to fully access the space—mercury, for instance, is often undetectable when hidden by cabinets, molding, and floor tiles)
8. Complete any analytical analysis
9. Review site surveys and analytical results
10. Determine remediation required and develop standard operating procedures for implementation paying particular attention to adjacent occupied spaces and the potential impacts that require mitigation including sealing of contaminated items prior to removal from the project area
11. Perform remediation incorporating continued field sampling as necessary to further identify hidden contaminants
12. Once remediation is complete, confirm the project meets cleanup levels determined during SOP development.
13. Document the final results detailing contamination discovered and cleaned to acceptable levels and contamination left in place due to nondisturbance

BUILDING MATERIALS

Asbestos

Federal, state, and local regulations strictly control the identification, disturbance, and removal of asbestos-containing material (ACM) during the ongoing operation, renovation, and demolition of a building. The applicable regulations are identified in Table IB-2. ACM can be found in many structural materials in old laboratory buildings, as shown in Table IB-3. Before any renovation activity begins, a thorough survey must be conducted by a qualified and in some states a licensed asbestos inspector to identify all ACM that need to be removed and to identify any ACM that are to remain undisturbed during the renovation. Even when removal is not necessary, consideration should be given to removing all ACM during a renovation inasmuch as this is likely to be the most favorable time to conduct this procedure.

Lead Paint

Federal Environmental Protection Agency (EPA) regulations only require identification and control of lead-containing paint in residential property housing children under the age of 6, whereas OSHA regulations (OSHA, 2012) define the permissible lead exposure to workers during demolition and renovation activities. Therefore, it is required that the presence of lead paint be identified whenever structures (e.g., walls, ceilings, doors, windows) are to be demolished or disturbed. When lead paint is identified, the issues of concern are whether (1) workers will be exposed above the permissible exposure level (PEL is 0.05 mg/m^3), (2) lead dust will be generated and emitted to the exterior environment, and (3) the construction debris will have to be disposed of as hazardous waste because of its lead content. The regulations do not specify how to handle these issues. Choices include (1) strip off the lead paint before demolition begins, (2) remove lead paint-containing structural pieces intact as the first step in demolition, and (3) control lead dust exposure to workers and release to the environment during demolition by exhaust ventilation, filtration, and the use of respirators. Factors such as cost, time, and labor availability will influence the choice.

Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) are found in electrical transformers and light ballasts. There are identification and labeling requirements for transformers, but ballasts may not be labeled. Therefore, they, as well as

TABLE IB-2. Regulations Applicable to Laboratory Decommissioning and Decontamination

Hazard	Government Agency	Regulation	Comments
Asbestos	OSHA	29CFR1926-1001	Worker protection
		29CFR1926.1101	Work practices
	EPA	40CFR part 61 NESHAPS	Asbestos in schools
		40CFR part 763 AHERA	Waste disposal
			Accidental releases
	MA DLWD	453CMR 6.00	Worker protection
			Work practices
Lead	OSHA	29CFR1926.62	Worker protection
		29CFR1919.1025	Worker practices
	EPA	40CFR part 141 & 142	Lead in drinking water
		40CFR part 261	Waste disposal
		40CFR part 50.12	Lead in ambient air
		40CFR part 745	Training & disclosure
			Identification of dangerous levels of lead
	MA DLWD	454CMR 22	Work practices
			Worker protection
	MA DPH	105CMR 460	Lead poisoning, prevention, & control
Hazardous			
Waste	EPA	40CFR part 261, 262	Accumulation, disposal
	MA DEP	310CMR 30.00	Heavy metals
Unknown	EPA	40CFR part 261	Identify unknowns, disposal limited
Chemical Containers	MA DEP	310CMR 30.00	May present unforeseen hazards
Unknown Gas	EPA	40CFR part 261	Identify unknowns, disposal limited
Containers	MA DEP	310CMR 30.00	May present unforeseen hazards
Perchlorates	EPA	40CFR part 261	Reactive waste
	MA DEP	310CMR 30.00	Reactive waste
PCBs	EPA	40CFR parts 302.4, 761	Disposal & reportable quantites
	MA DEP	310CMR 30.00	Accumulation & disposal
Hazardous	EPA	40CFR parts 261, 262	Accumulation & disposal
Waste	MA DEP	310CMR 30.00	Accumulation & disposal
Drain Types	EPA	40CFR 261	Mercury contamination
	MA DEP	310CMR 30.00	Mercury contamination
	MWRA	360CMR 10.0	Plumbing codes
Radiation	NRC	10CFR	Radiation standards
	DOT	44CFR	Transportation
	EPA	40CFR	Mixed waste
	MA DPH	105CMR 120	Radiation standards
Biohazards	HHS	71CFR part 71	Transportation of materials
	OSHA	29CFR part 19910.1030	Bloodborne pathogens
	USPS	39CFR part 124	Transportation of materials
	MA DPH	105CMR 480	Waste disposal

Note: MA refers to an agency regulation in the Commonwealth of Massachusetts.

other items of small electrical equipment that contained fluids for cooling, may need to be tested. When PCB-containing items must be disturbed, a safe removal procedure should be established and provision made for environmentally acceptable disposal such as release to an EPA-approved and registered hazardous waste disposal company. An emerging issue has been that some caulking materials used for windows and some joints may contain PCBs. These are strictly regulated if they are disturbed or even once they have been identified as present.

CONTAMINATED CONSTRUCTION MATERIALS AND BUILDING SYSTEMS

The materials previously used and the activities conducted in the building to be renovated may have resulted

TABLE IB-3. Suspect Asbestos-Containing Materials

Acoustic Plaster	Flooring - Asbestos Tiles
Adhesives - especially flooring	Flooring - Backing
Base Flashing	Flooring - Joints for Vinyl Tiles
Caulking & Putty	Flooring - Vinyl Sheet
Ceiling Tiles, Lay-in Panels	Gloves - Laboratory
Cement Pipes	Gaskets - High Temperature
Cement Wallboard	Hoods - Laboratory (Table Top)
Cement Siding	Insulation - Blown-in
Chalkboards	Insulation - Boiler
Compounds - Joint	Insulation - Breeching
Compounds - Spackle	Insulation - Ducts (HVAC)
Compounds - Taping	Insulation - Electric Wires
Construction Mastics	Insulation - Pipes
Cooling Towers	Insulation - Spray Applied
Ducts - Flexible Fabric	Packing Materials
Ducts - HVAC	Paints & Coatings - Textured
Electrical Cloth	Plaster - Acoustic
Electrical Conduit	Plaster - Decorative
Electric Panel Partitions	Roofing - Felt
Elevator Brake Shoes	Roofing - Shingles
Elevator Equipment Panels	Thermal Paper
Fire Blankets	Vinyl Wall Coverings
Fire Doors	Wallboard
Fireproofing Materials	

Note: This does not include every product or material that may contain asbestos. It is intended as a general guide to show which types of material that may contain asbestos.

in the contamination of many surfaces and building systems. This means that all suspect materials that are likely to have been used in the building, as well as past work practices, must be researched carefully. The systems most likely to have been affected include the heating, ventilation, and air-conditioning (HVAC) equipment and plumbing. The usual types of contamination include microbiological agents, radionuclides, and persistent chemicals. They are discussed in Chapter 4, Section 4.4 in more detail for laboratories, but it should be recognized that there may be some areas of the building being demolished or renovated that may be overlooked when focusing only on individual laboratories. All construction materials that may be encountered need evaluation to determine a need for special methods of removal or for specific renovation activities when the materials are to be left in place. For example, fluorescent lighting and ultraviolet germicidal lamps contain small amounts of metallic mercury.

Radioactive Agents

The Nuclear Regulatory Commission (NRC) requirements for decommissioning, testing procedures, and methods of decontamination for radioactive materials are the following (NRC, 2012):

Measuring Exposure Rate: Ambient Radiation Levels

1. Determine background radiation levels in μR per hour by choosing an on-site building of similar construction that has no history of radioactive materials.
2. Measure exposure rate levels at 3.3 ft (1 m) from floor and lower wall surfaces. The measurements may be averaged over a 108-ft^2 (10-m^2) area (the approximate size of a small office).
3. Maximum exposure rate should not exceed two times the guideline values above background.
4. Guideline values are determined by federal or state licensing agencies.

Surface Activity: Fixed Radiation Contamination

1. Survey all surfaces and equipment for fixed contamination, including bench tops, drawers, floor, hood base, hood walls, ductwork, sink basins, and sink drain traps.
2. Contaminated areas should be cleaned to the best extent possible.
3. Results should be averaged over a 0.11 ft^2 (100-cm^2) area and should not exceed guideline values.

4. Do not cover contaminated areas with paints, cement, or other forms of covering to reduce contamination levels to guideline levels.

Surface Activity: Removable Radioactivity Contamination Levels

1. Grid the laboratory into approximate 10.8 ft^2 (1-m^2) sections.
2. Do wipes for removable contamination by rubbing a 1- to 2-in. filter disk over approximately 0.11 ft^2 (100-cm^2) of area to be tested.
3. Analyze wipes for the radionuclides of interest and compare results with guideline values.
4. Decontaminate any areas of removable contamination above the guideline values. It is advisable to decontaminate removable contamination to background levels when possible with a reasonable effort.

Note: It is important to thoroughly survey the inside of hoods and ductwork if volatile radioactive materials were handled. Likewise, it is important to thoroughly survey sink basin and sink drain traps for contamination. Some laboratories contain individual waste neutralization "chip" tanks at each sink drain. The inside of these tanks and the calcium carbonate chips may be a source of radioactive contamination and should be tested. A detailed map showing location of testing and a description of how the tests were performed should be kept with the results of the surveys.

Survey Instrumentation

The following are examples of instruments that may be used in laboratory decommissioning efforts.

Exposure Rate

1. Pressurized ion chamber with sensitivity to 1 μR/h
2. Geiger Muller (GM) end window counter with sensitivity to 50 μR/h

Fixed Contamination

1. GM pancake detector for beta/gamma emitters with a sensitivity of 1000–2000 dpm/100 cm^2)
2. Scintillation detector (NaI) for gamma emitters with a sensitivity of 1000–2000 dpm/100 cm^2)
3. Proportional counter or beta/gamma emitters with sensitivity of 500–2000 dpm/cm^2 dependent on detector area

Removable Contamination

1. Liquid scintillation counting of wipe tests with sensitivity to 50 dpm/0.11 ft^2 (100 cm^2)
2. Gas flow proportional counting of wipes with sensitivity to 10 dpm/0.11 ft^2 (100 cm^2)

Note: Some radioactive materials, in particular naturally occurring radioactive materials such as uranium and thorium, do not require the user to be licensed or have a permit. Many chemistry, biology, and materials science laboratories use these materials routinely without the knowledge of the radiation safety office. It is important to identify whether a laboratory used forms of these radionuclides before they become mixed with other chemical wastes (*Chemical Health & Safety*, 1996, p. 39).

Biological Agents

Requirements for decontamination are the following.

Class 1 and 2 Biological Agents

1. Select a disinfectant appropriate for the agent(s) in use. For example, although a quaternary ammonium compound would be adequate for *Escherichia coli*, it would not be effective for *Mycobacterium tuberculosis*, when a phenolic-based disinfectant would be necessary.
2. Identify areas that need to be disinfected. These include bench tops, surfaces of equipment, and other potentially contaminated places (hoods, water baths, centrifuges, etc.).
3. Wear personnel protective equipment (long-sleeved lab coat and gloves); there should be a barrier between yourself and the disinfectant chemical(s).
4. If the disinfectant in use does not contain a surfactant, wash the areas to be decontaminated with soap (detergent) and water first to remove oily dirt that may prevent the disinfectant from contacting and killing the microorganisms.
5. Pour the disinfectant on the areas to be decontaminated or onto toweling. Rub the areas and repeat. Let a film of disinfectant remain on the surface to air dry. If using a phenolic-based compound, follow up with a water rinse to remove the residual phenolic (if desired). For this procedure to be effective, the disinfectant must contact the organism and be in contact for a sufficient time to kill it.

Class 3 Biological Agents

1. If all Biosafety Level 3 procedures had been rigorously adhered to, contamination would be confined to biological safety cabinets. However, because of the inherent risk of a Class 3 agent, it is advisable to decontaminate the whole laboratory before moving equipment.
2. Remove or seal all cultures gas-tight. Have an outside contractor, your environmental safety personnel, or other qualified personnel perform a gaseous decontamination of the entire laboratory space by using formaldehyde gas, vaporized hydrogen peroxide, ozone, or chlorine dioxide.

Chemical Agents

Perchloric Acid If perchloric acid was often used in chemical fume hoods, particularly if the acid was heated or aerosolized, all interior surfaces, including piping, fan, and stack, must be tested for perchlorates and washed clean when perchlorate contamination is found. It must be kept in mind when potentially contaminated structures are to be disturbed that perchlorates are explosive and may be detonated by impact. Fortunately, there is a simple check for the presence of perchlorates that uses methylene blue (Oak Ridge National Laboratory [ORNL], 1993; Phillips, 1994). When perchlorates are detected by this test, surfaces should be flushed with water until the methylene blue test is negative. Because of the simplicity and ease of the testing method, it is advisable to test all laboratory hoods unless it is absolutely certain that perchloric acid was never used. Additional information on returning perchlorate-contaminated chemical fume hoods to service after disassembly, decontamination, and disposal of the hazardous contents is contained in Phillips (1994).

Mercury Inorganic mercury was used extensively in laboratories in thermometers, pressure gauges, etc., and when they broke and spilled mercury behind a bench or in a drawer, it was common to leave it there. After mercury becomes coated with dirt, it does not evaporate and can remain for years. If disturbed during a renovation, it could result in an excessive mercury exposure to construction workers. It could also be tracked throughout the building and even be taken home on workers' shoes and clothing. A thorough visual and air sampling inspection of all laboratory areas must be made to look for the presence of mercury, and when found, it must be removed by the use of a specially designed mercury vacuum device and the use of mercury spill kits.

Mercury in plumbing systems presents an even more difficult cleanup task. When it is in a drain trap covered with water, it cannot be detected with a standard mercury air sampling device (American Conference of Governmental Industrial Hygienists [ACGIH], 2001). However, if a trap is removed without adequate precautions to retain the mercury, it may spill out and contaminate a large area, including any construction debris present, which may all then have to be disposed of as hazardous waste. The cost of just one such event resulted in an added cost of $100,000 for a laboratory building renovation (Edwards, 1999). A procedure for removing drain traps safely, checking them for mercury, and disposing of all mercury found must be established before renovation begins and workers performing this activity must be trained in safe removal methods. A suitable procedure involves removing a trap with a large container directly underneath to catch all the trap contents and then performing a visual inspection for mercury. When mercury is found in a trap, the next step is to use a mercury vapor detector to determine whether mercury is present in the rest of the (now dry) piping system, paying special attention to horizontal drain pipes (Edwards, 1999). Other likely sources of spilled mercury are equipment items such as water baths where mercury thermometers may have been used and broken.

Azides Sodium azides are an explosion hazard when plumbing materials are made of lead. There is a standard test method for azides (OSHA, 2012).

Toxic Solids Nonvolatile toxic solids such as acrylamide, arsenic compounds, metals, and their compounds (e.g., beryllium, lead) are frequently used in laboratories, machine shops, equipment rooms, and weighing rooms, and often contaminate surfaces and equipment. Surface sampling can be used for detecting their presence. When found, they must be decontaminated. Suggested clearance levels can be found in ANSI Z9.11 (ANSI, 2010).

Compressed Gases All compressed gas cylinders should be carefully removed to a safe area before a renovation. The premises should be carefully inspected for hidden "lecture bottles" containing toxic, reactive, radioactive, or flammable materials, and all compressed gases should be stored in well-ventilated areas.

Miscellaneous A detailed inspection must be made of the entire area that will be involved in the renovation to identify and remove broken glassware, needles, syringes, abandoned chemicals, and all other contaminated and hazardous equipment.

TABLE IB-4. Equipment Decontamination Record Sample Form

Principal Investigator Name _____
Dept _____ Phone _____ Date _____
The piece of equipment was used with the following materials:

Equipment Decontamination Record Sample Form

[ ] No hazardous materials
[ ] Chemicals
[ ] PCBs surveyed by IHO Name _____ Date _____
[ ] Radiation surveyed by RPO Name _____ Date _____
[ ] Other hazards (specify) _____
[ ] Decontaminated with _____
Name _____ Date _____
[ ] Equipment OK for removal or reuse Yes_____ No_____

REMOVE THIS LABEL BEFORE REUSING THIS EQUIPMENT

Laboratory Decontamination Certification

Because all equipment, apparatus, and fixed structures must be decontaminated in preparation for moving, it is advisable to have an "Equipment Decontamination Record" label (Table IB-4). This is a sign-off by the appropriate authority responsible for radiation, biological, and chemical hazards that decontamination was not necessary or was adequately performed. Movers should be instructed not to move anything out of the space without such a label. For the remainder of the space a "Room Decommissioning Record" label (Table IB-5) should be placed on all entrances after decontamination of the space is complete and all the hazards noted in this chapter have been resolved. Once this is done, it is advisable to change the locks on the doors to prevent occupants from putting unwanted materials or equipment in the space.

ACCIDENT PREVENTION CONSIDERATIONS FOR RENOVATION PROJECTS

Fatalities and Fire Hazards from Electrical Changes and Temporary Wiring

Electricity is responsible for approximately 10% of all industrial fatalities: the result of electrocutions, secondary effects of electrical shock (involuntary movements into the way of harm), and fires that occur from circuit overloading. Provisions for temporary wiring during renovations should include a system of deenergizing all unused circuits, even those that will be brought back into service at a later time, to provide assurance that an unused circuit will not inadvertently become energized and result in a fire. OSHA requires this to be done in both their General Industry Standards and their Construction Standards; it is referred to as "lockout-tagout" (OSHA Part 1910.147, 2012). Temporary wiring should be routed to avoid abrasion and impact damage. It should be protected against overload by selecting the correct wire sizes and the conservative use of fuses and circuit breakers. Compliance with the National Electric Code NFPA 70 (NFPA, 2011) should be verified by site management during the entire period of temporary wiring use. In addition to meeting all requirements of the National Electric Code, temporary wiring should be well marked and identified regarding voltage, use, and controlling breaker or service disconnect panel location. Temporary wiring should be strain relieved and run where building inhabitants cannot come in contact with it and equipment movement will not damage it. No exposed live conductors should exist in any building area except when it is under constant supervision. All temporary circuits must be checked for correct connections and polarity.

Fire Hazard from Welding, Cutting, Leading, and Soldering

Welding, cutting, leading, and soldering pose a fire hazard at the time work is conducted and for several hours afterward from hot spots and glowing embers. The hazard is controlled by the use of a "hot work permit" system that should be a part of the project management plan. Issuance of a hot work permit is intended to examine contemporaneous operations for increased hazard potential and to alert security forces to the lingering hazard including the need for a fire watch. The use of compressed acetylene, propane, oxygen, and other gases for these operations must be addressed from the standpoint of danger to or from an adjacent operation, safe storage when the cylinders are not in use, and correct handling procedures when they are being transported and used.

TABLE IB-5. Room Decommissioning Survey Sample Form

Room #(s) _____ has been visually surveyed for the following contaminants

Hazardous Materials	[ ] NA	[ ] cleared	[ ] Decon required (see comments)
Surveyor's Name	_____	Department	_____
Date	_____		
Chemicals	[ ] NA	[ ] Cleared	[ ] Decon required (see comments)
Surveyor's Name	_____	Department	_____
Date	_____		
Radiation	[ ] NA	[ ] Cleared	[ ] Decon required (see comments)
Surveyor's Name	_____	Department	_____
Date	_____		
Biological	[ ] NA	[ ] Cleared	[ ] Decon required (see comments)
Surveyor's Name	_____	Department	_____
Date	_____		
Chemical Fume Hoods	[ ] NA	[ ] Cleared	[ ] Decon required (see comments)
Surveyor's Name	_____	Department	_____
Date	_____		
Drain Traps	[ ] NA	[ ] Cleared	[ ] Decon required (see comments)
Surveyor's Name	_____	Department	_____
Date	_____		
Sharps	[ ] NA	[ ] Cleared	[ ] Decon required (see comments)
Surveyor's Name	_____	Department	_____
Date	_____		
PCBs (except ballasts)	[ ] NA	[ ] Cleared	[ ] Decon required (see comments)
Surveyor's Name	_____	Department	_____
Date	_____		

Comments _____

_____

_____

_____

[ ] Ready for cleanout, abatement, and demolition

Fire Suppression Systems

Fires are more likely to happen during construction than during normal use of a laboratory building, and because walls and other fire stops may have been removed, such fires can spread farther than expected. The fire hazard is made even more critical when sprinklers and other fire suppression systems are shut off or temporarily removed during certain phases of the renovation project. In fact, fires have destroyed many buildings that had installed sprinkler systems that were in place, but were not functional because they had been temporarily shut off and not returned to service or only returned to part of the building. Renovation planning should address the hazard associated with shutting off fire protection systems temporarily and make an effort to find ways to avoid doing so. When it is not feasible to maintain the suppression system in a continuously activated condition, only the specific zone where the need to shut down arises should be shut off and the remainder of the system left intact. A permit system, similar in function to the hot work permit system for welding and cutting, should be provided in the project management plan to accommodate the need for a fire protection system shutdown while maintaining cognizance and control of the risk. A fire watch may be required in some cases. The cost of an alternative temporary fire suppression system should be provided for during the planning stage when a clear need is foreseen. The chosen alternative must be compatible with the activities going on in adjacent areas; for example, a dry chemical total flooding system may be harmful to the

chemical experimental procedures and sensitive electronic equipment in close-by active areas.

Hand-Portable Fire Extinguisher Placement

Hand-portable fire extinguishers, one of the most important fire control devices for the small or incipient fire, are often misapplied during renovations. They sometimes get moved, are used for door stops, or become partially or fully discharged and not recharged. Maintenance and control of hand-portable fire extinguishers are important functions during the entire renovation period and should be the continuous responsibility of construction management. The selection and location of units should be determined in the planning stage. For temporary use in construction areas, dry chemical extinguishers are the most versatile and effective on a pound-for-pound basis. Chapter 1, Section 1.4.4.2.2 has more information on the use of hand-portable fire extinguishers.

Extinguishers should be placed to assist in making an exit from an area on fire. This means that units should be placed in the farther corners of a room rather than just at the exit door. During construction activities, units should be within a few yards of hazards, such as places where copper pipes are being soldered.

Synergism with Ongoing Building Operations

During the planning phase of renovation work, special thought should be given to protecting higher-hazard areas such as toxic gas or flammable chemical storage cabinets and rooms because activities on the part of construction personnel may create unusual situations, especially when materials are being brought into or removed from the facility. Movement of high-hazard materials to a safer location or temporary provision of greater protection during certain periods should be planned.

Temporary Storage of Combustible and Flammable Materials

Items brought onto the site by construction personnel are likely to include combustibles such as lumber, fabrics, and carpets in addition to highly flammable materials such as paints, paint strippers, mastics, and gasoline. Safe storage locations and quantity limits for these materials should be established during the planning stage and monitored throughout the construction period. All storage areas should be provided with appropriate fire suppression capability as well as adequate ventilation.

Construction Material and Equipment Movement and Storage

Construction materials and equipment, even when storage locations have been provided, are likely to find their way into halls and corridors that serve as passageways for normal building use, as well as into emergency exit ways intended for all building occupants. These items may be building materials, debris for removal, welding-cutting carts, and electrician carts. During an emergency evacuation these misplaced materials become barriers to a smooth exit. Should they become a fire source, they could completely block egress. Such conditions are a clear violation of OSHA regulations and should not be permitted. When the movement of equipment and materials through corridors cannot be avoided, it can be handled best during nonworking hours of the laboratory. Construction-phase policing of these issues is important, and construction personnel should be required, within their contracts, to police these practices and be responsible for where their equipment and materials are placed.

Movement of Walls, Corridors, and Doors

When construction and laboratory activities are concurrent, there is a frequent need to establish temporary corridors, walls, and doors. Sometimes temporary walls will be hanging curtains and doors will be slits in the fabric. These changes are not likely to become a concern provided the temporary layout is communicated adequately to all laboratory workers and unsafe areas are physically restricted to construction personnel. Control of circulation and off-limits areas for both laboratory workers and construction crews should be planned during the design phase and preparation made for taking appropriate action during construction. Emergency lighting should not be removed or rendered inoperative, but when it must be disturbed, provision of substitute emergency lighting should be addressed during the planning stage.

Removal or Deactivation of Stairways or Elevators

When stairways and elevators need to be removed, blocked off, or temporarily taken out of service, the adequacy of emergency egress is likely to be affected and temporary steps must be taken to maintain compliance with the life-safety code NFPA 101 (National Fire Protection Association [NFPA], 2012). This may involve making provisions to evacuate upper-floor personnel by rerouting or by constructing temporary stairs. Temporary removal of elevator service should be communicated to building management and handicapped personnel, and alternative methods of evacuating handicapped people should be developed and practiced.

Emergency Power-Off Control

Many laboratory units are provided with an emergency power-off switch, usually in the form of a large mush-

room button located near the entrance to the laboratory unit. This switch operates a transfer switch that shuts down all room power except lighting and ventilation. Because laboratory personnel are advised to depend on these controls to help them during emergency situations, they must remain functional. If there is a need to shut down the transfer switch system, the laboratory occupants should be notified and the emergency mushroom switch labeled as out of service. Alternative circuit controls should be identified and labeled and the information provided to laboratory occupants. Shut-down emergency power-off switches should be brought back into service as soon as possible.

Back-Up Power for Critical Systems and Experiments (Anand—please review)

Emergency back-up power needs to be provided for many critical laboratory systems and experiments. Uninterruptible power supplies (UPS) for data processing equipment are usually battery powered. Emergency backup for critical systems and experiments is usually provided by a separate electrical feeder or emergency generator. If any of these systems need to be deenergized, notification to building management needs to be established well in advance of the shutdown time. Where UPS are used, signs warning of the hazardous output voltage should be posted.

Loss of Evacuation Alarms

Methods of preventing smoke/fire detector heads from becoming inoperative because of dirt need to be considered during the planning phase and provisions must be made to maintain their sensitivity. Covering smoke detectors to protect them from dirt will prevent them from sensing when there is smoke in the area. Heat detectors, on the other hand, will function as soon as the covering melts off, provided it is made of plastic. When a detector or alarm system needs to be taken out of service, even temporarily, an alternative should be employed. A human fire watch is practical when out-of-service time is short and the risk is high.

Damage to Utilities

Construction sometimes results in interruption of utilities such as electricity, chilled water, and fuel gas. Fire or explosion could result from release of fuel gas. Other utility damage could shut down safety systems, creating evacuation and other hazards. Excavation must be planned with utility companies so they can assist in locating underground pipes and cables and be prepared to disconnect the facility should an emergency develop.

Fire Departments' Building Drawings

Under conditions of fire, stress it may be necessary to evacuate injured laboratory or construction personnel within the building or get to main emergency gas shut-off valves. When, because of fire, smoke, or toxic release, conditions are not favorable for the facility owner or construction management personnel to accompany firefighters into the facility, fire service personnel must depend on prior knowledge of the layout to rescue personnel or perform a safety task. Therefore, in addition to obtaining permits from the local fire department, renovation plans need to be communicated to them so they will have an up-to-date picture of the facility. Final drawings should likewise be provided for their use in an emergency response.

Emergency response vehicles need to get close to buildings to provide services, and some of their equipment needs a turning radius and back-up space beyond the norm. Therefore, a review of the recommendations of the landscape architect should be conducted during the planning stage to make sure that the services of the fire department are compatible with the landscaping plan.

As-Built Electrical Riser Diagrams

The building owner should insist on up-to-date electrical diagrams after completion of the work, regardless of the size of the renovation. Not to have these diagrams may result in unrealized hazards during later renovations and circuit changes. Electrical receptacles on emergency power must be identified on the drawings as well as at the receptacle.

3

RENOVATIONS: BUILDING CONSIDERATIONS

3.1 GUIDING CONCEPTS

3.1.1 Introduction

This chapter addresses the issues associated with renovating laboratory buildings and other building types scheduled for renovation for laboratory use. It outlines a wide range of building renovation strategies and provides information on the special design and construction requirements that are seldom encountered with new construction. Chapter 4 deals with similar issues but specific to renovating laboratory modules, and details the basic design requirements that change from one laboratory type to another. In both chapters, the treatment of laboratory building and laboratory module renovation issues will cover the topics that are likely to apply most generally to all such activities, leaving it to the chapters on specific laboratory types in Part II to cover issues of a unique nature that pertain to each laboratory type. When important design topics are omitted in this chapter it may be safely assumed that they do not differ from the requirements for new construction and are found in Chapter 1.

The extent to which renovations must comply with current local and state codes, which differ from those in effect at the time the building was constructed, influences many factors. One such factor is whether projected construction associated with code compliance will call for more extensive renovations than originally anticipated. Another factor is whether the integrity of the structure or any life safety feature of the building may be found inadequate and need to be significantly changed. Certain jurisdictions allow owners to proceed with minor renovations the building department performing a complete plan review to obtain a building permit when life safety is not affected and the cost of construction is less than a specified dollar amount or lower than a specified percentage of the whole building value. Even when building code requirement compliance is not in question, the design team, owner, and occupants should ensure that renovations improve health and safety, and avoid introducing new hazardous conditions. When the renovation construction cost or the percentage of gross area will exceed a statute-specified threshold, most jurisdictions require that the entire building be improved to comply with current codes and standards. This requirement applies when a portion of the building will undergo renovation. In addition, there may be other code, ADA accessibility, and functional requirements that must be met because of changes of building occupancy, function, and hazard level. Particular care must be taken when proposing other building types for laboratory conversion. Often the fundamental building structure and the mechanical and electrical systems will be totally inadequate for the demands of safe, cost-effective laboratory installations. For example, normal office building construction standards fall far short of the minimum specifications for many laboratory functions. Therefore, a thorough feasibility study should be undertaken to examine the concept viability,

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

building structural capacity and integrity, fire-resistive construction and fire protection, the program fit, health and safety deficits, and the expected cost premium to install laboratories in buildings not originally designed to serve as modern laboratories.

All renovations should strive to improve health and safety. Unsafe egress conditions, inadequate aisle width, and lack of emergency equipment and fire protection systems are often neglected when minor renovations focus only on simple cosmetic upgrades. Needed improvements to fire protection, detection, and alarm systems should be a top priority in even minor renovations of laboratory spaces or buildings. Some health and safety improvements that can be accomplished with limited additional funds during minor renovations are

- Improvements to ventilation systems performance by rebalancing
- Improvements to hazard zoning and hood performance by relocating chemical fume hoods away from exit doors and high-traffic areas
- Installation of fixed gas cylinder racks or provision of other approved gas cylinder storage
- Provision of laboratory safety stations, and safety and emergency equipment recommended for and located near the activities conducted
- Provision of area for chemical storage cabinets in laboratories and chemical stock rooms
- Separation of high-hazard chemical, radiological, and biological activities
- Improvements to signage
- Improvements to exhaust stacks to reduce effluent reentry
- Decontamination of surfaces and equipment
- Removal of asbestos-containing materials
- Addition of emergency showers and eyewash fountains
- Wash down of hoods and ducts of hoods in which perchlorates were used

3.1.2 Diagnostics

The first task to complete in the diagnostics phase for renovation projects is to conduct a thorough code compliance analysis or a facility conditions analysis (FCA) that is described in Chapter 1, Section 1.2.1.2.1. These types of analysis give building owners fundamental information on the cost to occupy (or continue to occupy) the facility, based on the extent of code-mandated upgrades. Life-expectancy estimates of major building equipment and systems will influence decisions to retain, buy, sell, or demolish and replace a facility. The financial aspect of renovation project planning is a critical consideration.

A second task, when a building under study is currently occupied, is to review accident histories that are available from the institution's environmental health and safety office and from insurance and legal records. Based on health and safety issues, this review will often provide clear indicators for specific building renovations and functional improvements.

A third task is to ask occupants and maintenance personnel to carefully document poor conditions they observe. An incident log that lists date, duration, and detailed nature of facilities failures and deficiencies, including photos, is a very effective method of documentation. The importance of carefully documented observations is illustrated by the following example.

An imbalance of air pressure between the inside and the outside of the building, in which the inside is highly negative, can cause the following bad conditions that may be revealed in incident logs.

- Ugly stains on suspended or plaster ceilings and obnoxious odors from the decomposition of certain types of acoustic ceiling tiles, both caused by roof leaks
- Soot and water infiltration at windows
- Entry doors that are hard to open or close and produce loud whistling noises
- Rust on metal hardware on casework and plumbing and electrical fittings
- Deterioration of exterior building materials caused by wind and water damage, including rotted or corroded window frames, leaking seals on thermal windows, and erosion of mortar in masonry

When a record of incidents lists these conditions in more than one location, it is probable that the building renovation will have to correct major ventilation problems as well as restore the integrity of the building enclosure to resist outdoor weather conditions.

More often, renovations are driven by internal obsolescence and functional changes. Reorganization of research objectives and addition of personnel (or a whole new group) and new equipment can each lead to a decision to upgrade or reorganize the facility to meet the new needs or to overcome building obsolescence, overcrowding, and poor facility performance.

3.1.3 Planning Strategies

Planning strategies must be consistent with the degree of project complexity, budget, schedule, and quality

objectives. Some of the factors that add to the complexity of the planning process include:

- Need for an extensive decontamination program before the start of the renovation
- Need to install new utilities through occupied areas while maintaining the safety of the remaining laboratory
- Need to conduct renovation activities in a continuously occupied building area
- Need to schedule a sequence of relocations to vacate and reoccupy successive areas to be renovated
- Short planning and completion schedule, forcing use of overtime that escalates construction costs
- Choice between a minor renovation "on the cheap" or a moderate or major renovation that will improve the building for a longer period of use
- Tough choices to be made, for example, replacing obsolete benches and fume hoods or improving a borderline heating, ventilating, and air-conditioning (HVAC) system

The *key* decision for renovation project planning is the determination of whether the existing building will require minor, moderate, or major renovation. When the facility maintenance manager and occupants have documented the nature, extent, and severity of ongoing deficiencies, the renovation project team can provide a more accurate assessment and recommendations to the owner or the owner's administrators.

3.1.3.1 Walkthrough and Detailed Surveys. Using a code-compliance report or a facilities condition analysis (FCA) as a guide, a quick walkthrough survey of the facility by the renovation project team provides a first impression of the existing conditions and problem areas. The building design documents, when the full set is available, can provide valuable information. In an old building, it is a fair assumption that many renovations have taken place and it is helpful when documents of prior renovations or systems' upgrades are available for review as well.

A more detailed survey of the area to be renovated should include HVAC, mechanical (plumbing, fire protection), and electrical systems. Section 3.3 provides guidance for this survey. Field verification of certain information, such as supply chilled water and domestic hot water flow capacities, and supply and exhaust air volumes and balancing, are critical because this kind of information can quickly confirm that pressure imbalance and temperature control problems exist. When available, the maintenance history provides valuable information on the level of maintenance provided to these systems. What is visible can be quickly noted. However, ducts, pipes, and other mechanical, electrical, and plumbing (MEP) equipment hidden behind walls and ceilings may need to be inspected. Exploratory openings in walls and ceilings assist this part of the investigation. It is not sufficient just to look at the drawings. Systems, site, code-compliance, and FCA evaluations will provide information needed for renovation planning.

Buildings under review for renovations may have space limitations with respect to structural system capacity, floor-to-ceiling height, floor-to-floor height, and duct shaft locations and available volume. The locations and sizes of mechanical rooms, outside air intakes, and exhaust air outlets also need to be reviewed to ascertain whether they will be serious obstacles to realizing a benefit from the renovation. Even when an individual laboratory is under consideration for renovation, these items need to be evaluated by engineers who specialize in laboratory building renovations. For example, height restrictions limit the kinds of mechanical systems that can be installed. When vertical shafts are at a distance, long duct runs from renovated laboratories adds cost and their installation and may affect adjacent occupied spaces.

The location of outside air intakes is important when new air supply units must be installed to serve renovated laboratories. In old buildings, existing air supply systems may not have appropriate levels of air filtration. A higher level of air cleaning than is needed should be avoided because it adds resistance to the supply air system, resulting in higher operating and maintenance costs. However, a higher than normal level of supply air cleaning may be required when the existing air intakes are in an undesirable location. Generally, it is better to avoid exhaust air cleaning systems unless called for to retain radioisotopes or because of some other regulatory requirement because of initial high cost and heavy maintenance requirements.

3.2 BUILDING LAYOUT

3.2.1 The Building Program

Programming for a renovation is the same process as programming for new construction and is explained in Chapter 1, Section 1.1. When construction must be phased, programs for renovation projects must also prioritize scope requirements. Code-compliance or facilities condition analysis (Chapter 1, Section 1.2.1.2.1), occupancy analysis (Chapter 1, Section 1.2.1.2.1), current chemical inventory process (Chapter 1, Section 1.2.1.2.1),

and other functional analyses contribute important information on whether a renovation is needed and/or to what extent. Analyses should be completed and coordinated with the program before the building renovation program is approved.

3.2.1.1 Existing Functional Analysis. Before a renovation is planned, an existing functional analysis should be made of the building to identify and evaluate all existing unsafe and unsatisfactory conditions, above and beyond those of building code compliance. Typical conditions that lead to laboratory renovations can be derived from a system evaluation, as illustrated in Table 3-1. Table 3-2 lists the hazards that poor conditions in laboratories cause. The table rates the relative risks of injury or other harm those hazards can cause if not addressed in a renovation.

A relatively simple solution to overcrowded conditions in a laboratory to gain more functional space is by expansion into adjacent areas or by relocation to a larger laboratory. Another, seemingly simple, solution to facility overcrowding is to clean up and clear out unused equipment, supplies, old chemicals, files, and journals. Researchers are often acquisitive, and their work styles are geared to keeping "tools of the trade" readily accessible. Collections of rarely used and old chemicals can be purged. When necessary, scientists can reduce the stock of chemicals kept within their laboratories by limiting storage to a week's supply; they can rely on well-managed chemical stock rooms plus "just-in-time" deliveries by vendors to meet their research and process needs. Given careful thought and planning, reduction of chemical stores is usually feasible and highly desirable. Furthermore, the onerous cost of disposal of hazardous chemicals is a great incentive to establish an institutional policy to get rid of old chemicals prior to renovating laboratories.

Old equipment often has tremendous sentimental value to researchers, but when space is short, storing it in laboratories is inappropriate and inefficient. Therefore, when evaluating the need for a laboratory renovation to increase functional space, it is important to estimate the amount of work and storage space that is unproductive or unsafe because of unused equipment storage. If the laboratories under review for renovation are dysfunctional simply because of poor housekeeping and congestion, a renovation might not even be required. A spring-cleaning effort may suffice to achieve required facility improvements. Research organizations should consider leasing accessible and secure long-term storage not only for unused equipment, but also for inactive files and old reference materials.

TABLE 3-1. Laboratory Diagnostic Issues

	Conditions Commonly Observed in Labs to Be Renovated	Possible Causes to Investigate
1	Crowded lab aisles, collisions	Equipment, supplies stored in aisles and/or too many occupants
2	Overloaded reagent shelves	Too many chemical containers hoarded, not removed for proper disposal
3	Stains on suspended ceilings	Leaky pipes above lab or roof degraded
4	Stains on floors, benchtops	Chemical spills not quickly or adequately cleaned
5	No clear space in chemical hood	Too many chemical containers and waste containers horded, too much equipment inside
6	No clear space on benchtops	Too much equipment or supplies not stored properly
7	Storage cabinets overloaded	Inadequate bulk storage provided in building
8	No free outlets; plug strips and extension cords common	Too much equipment hoarded, not stored, or removed because it might be useful "someday"
9	Roof leaks	Inadequate air supply because pressure in building is less than outside, roof degraded
10	Soot on sills and moisture around closed windows	Inadequate air supply because pressure in building is less than outside, sealants degraded
11	Lab door hard to open or close	Imbalance of air pressure between lab and corridor
12	Rusting metal casework	Inadequate fresh air exchange, or chemical spills not quickly or adequately cleaned
13	Rusty hinges, hardware, faucets	Inadequate fresh air supply to prevent corrosion
14	Bad odors generated within lab	Inadequate fresh air supply, inadequate local exhaust to trap odors, sink or floor drain traps not primed regularly
15	Bad odors migrate into lab	Supply intake entrains contaminants from loading dock or other exhaust source
16	Loud noise at fume hood	Poor installation of exhaust system, hood controls, duct leak, imbalanced or broken exhaust fan

TABLE 3-2. Potential Hazards from Conditions Commonly Found in Labs to Be Renovated

	Observed in Labs	Level of Risk	Potential Hazard
1	Equipment, supplies stored in aisles and/or too many occupants	Moderate to High	Injury from collisions or hazardous materials dropped
2	Too many chemical containers not removed from shelves	Moderate to High	Exposure to and contact with hazardous chemicals from spills or injury from broken glass
3	Leaky pipes above lab or roof degraded	Low to Moderate	Injury from slip and fall or damage to equipment
4	Chemical spills not quickly or adequately cleaned	Moderate to High	Exposure to and contact with hazardous chemicals on lab benchtops and surfaces
5	Too many chemical containers and waste containers horded, too much equipment inside	Moderate to High	Chemical hood not available for lab occupants′ use, compromise to chemical hood containment performance
6, 7	Too much equipment or supplies not stored properly and inadequate bulk storage	Low to Moderate	Injury from shelves failure, dumping materials stored upon them, and damage to materials
8	Electrical circuits overloaded by excess equipment, use of power strips and extension cords	Moderate to High	Painful or injurious electrical shock, fire or explosion potential from sparks and short circuits, risks from equipment failures
9	Roof degraded and leaks caused by low air supply, pressure inside is less than outside	Low to Moderate	Water damage to ceilings and walls, growth of mold and subsequent poor indoor air quality
10	Sealants for window and other penetrations degraded from low air supply because pressure inside is less than outside,	Low to Moderate	Water damage to walls around penetrations, accumulation of soot, growth of mold and subsequent poor indoor air quality
11	Imbalance of air pressure between lab and corridor	Low to Moderate	Hazards to disabled persons unable to exit lab or cross-contamination between labs and into halls
12, 13	Casework corrodes or degrades from chemical spills not quickly or adequately cleaned or poor fresh air exchange to prevent corrosion	Low to Moderate	Unsightly lab furnishings and fixtures from rust, or injuries caused by materials falling from shelves, fire or accident from corroded utility fixtures that cannot be turned off
14	Odors in lab from poor fresh air supply, inadequate local exhaust to trap odors, sink or floor drain traps not primed regularly	Low to Moderate	Unpleasant environment in lab, poor indoor air quality
15	Supply intake entrains contaminants from loading dock or other exhaust source	Low to Moderate	Unpleasant environment in lab, poor indoor air quality, possible risk of air toxicity
16	Poor installation of chemical hood exhaust system, faulty hood controls, duct leak, imbalanced or broken exhaust fan	Moderate to High	Impaired chemical hoof performance raises risk of exposure to hazardous chemicals, long-term loss of hearing capability and increased stress

After building condition, existing occupancy, functional analyses, and program of requirements reports have been completed and the administration has made a decision on the basis of these findings that a renovation is in order, the renovation or retrofit project proceeds to the planning phase.

3.2.2 Planning

Planning for renovations differs significantly from planning for new construction. All existing building conditions must be accommodated in renovations, unless those conditions will be altered or replaced. In new construction, constraints are generally only limited to existing site conditions. Renovation planning must include evaluations of the capacity of all existing utility systems. When utilities are inadequate for the new use, area needed for new equipment and distribution systems must also be planned. Section 3.3 provides additional information on utilities. Chapter 1, Section 1.2.2 contains more information on the general aspects of the planning process, applicable to renovation planning.

3.2.2.1 Building Spatial Organization. The major difference from original construction conditions encountered in renovations is that some spatial factors listed in

Chapter 1, Section 1.2.2.1 are fixed conditions that may not be possible to change. For example, a building's overall structure is difficult to modify; hence, it is expensive to do so. Design of modular laboratories may have to adapt to irregular, inefficient, or less than desirable column spacing to achieve safe, functional, and efficient layouts.

3.2.2.2 Circulation of People and Materials. One of the primary goals in a renovation is to improve circulation so as to be certain that the facility will meet current codes, as well as safely accommodate future functions to be housed in the building. Building code requirements for egress change. Many buildings constructed before 1990 often do not comply with the Americans with Disabilities Act (ADA) of 1991, and those buildings constructed in the mid-20th century and earlier no longer fully comply with basic life safety requirements for egress. In addition, up-to-date laboratory buildings have a need for improved materials-handling systems to function safely and efficiently. In older buildings, elevator shafts may not allow enlargement and upgrade to accommodate passenger elevator cabs that meet ADA standards or freight elevators that meet current laboratory demands. When existing interior space is unavailable or unfeasible to construct, new fire-rated stairways, elevators, and utility shafts may be constructed and attached to the exterior of an existing building. Those exterior additions can provide safe egress and materials' transport in non-code-compliant or otherwise dysfunctional laboratory buildings.

3.2.2.3 Planning a Modular Layout. Planning a safe, effective, and efficient modular layout is a challenge in some old buildings, even for the renovation of a single laboratory, because of the rigidities inherent in existing building structures that are described in Chapter 1, Section 1.2.4.

Existing building structural systems can lead to difficulties in providing adequate laboratory module width. The recommended range of laboratory module width (Chapter 1, Section 1.2.2.1) may not be compatible with an old laboratory building's structural grid dimensions. Retrofit of buildings that were designed for nonlaboratory use, such as parking garages, offices, or hospitals, often pose even greater difficulties because columns and other major structural elements, including shear walls and seismic bracing, can constrain or block laboratory aisles and egress pathways.

3.2.2.4 Distribution of Mechanical Equipment and Utilities. The keys to efficient laboratory performance are building systems that work well, yet today's requirements for supply and exhaust air, piped utilities, electric power, and data/telecommunications networks are likely to be greater than when old laboratory buildings now under consideration for renovations were constructed. Buildings designed for other uses have great difficulty meeting the requirements for laboratory-intensive HVAC and other utilities without major modifications. Just as in the design of new laboratory buildings, utility distributions systems have to take into account all of the obstructions and limitations of existing buildings' structure. Project designers must find areas vertically aligned from floor-to-floor through which vertical shafts can be cut to install mechanical risers. Finding straight shafts for ducts, without offsets, may be a very difficult challenge, especially when a building is to be renovated in phases and some floors will be occupied during renovations. Chapter 1, Section 1.2.5 contains descriptions of the most commonly used methods for mechanical and utility distribution with a review of their advantages and disadvantages. Unless the building being renovated is already a laboratory, few options may be feasible.

3.2.2.5 Structural System. Two primary concerns for a building's structure during renovations are design floor loads and clearance beneath the structure for horizontal distribution of ventilation air and utilities. General-use buildings constructed for commercial and institutional use are unlikely to have floor load capacity adequate for many laboratory operations and will require structural reinforcement to qualify for conversion to laboratory use. Even when floor load capacities are adequate, roof load capacity may be too weak to support rooftop equipment for laboratory HVAC. In these situations, it may be possible to construct separate equipment support platforms with extensions of existing column above the roof. When buildings to be renovated for laboratory occupancy have clear floor-to-floor heights less than 12 ft (3.66 m), there will be limited options for the installation of horizontal utility runs and economical installation of ductwork. Very low flow-to-floor heights, for example, 11 ft (3.3 m) or less, make conversion to unrestricted laboratory use difficult and costly to construct.

3.2.2.6 Site Regulations. When existing buildings are renovated, their sites have fixed characteristics that may restrict the design unless additional land can be acquired. Even when utilities, such as ducts and gas piping, need to be supported outside of the building envelope, the minimum clearance between neighboring structures must still meet zoning and building code requirements. Site restrictions regarding height may limit laboratory exhaust stack heights. A survey of and careful consider-

ation of safety hazards must be completed. Particular attention should be paid to possible hazardous contamination within the site or in soil beneath existing buildings from prior uses. Renovations also involve bringing site features into code compliance. This can range from removing underground fuel tanks to constructing a number of new parking spaces and making building entry accessible for disabled persons. Chapter 38, Sustainable Laboratory Design, describes site considerations and opportunities that are complementary to sustainable design.

3.2.2.7 Building Enclosure. Significant deterioration of the building enclosure is a frequent feature of old laboratory buildings. Over time, increments of exhaust equipment may be added without commensurate increase in supply air capacity. When there has been a lack of sufficient makeup air into laboratory buildings, pressure decreases within the buildings draw water- and dirt-laden air in through every opening and crevice, slowly destroying sealants, mortar, and brick, year by year. Seals on windows can fail from increasing pressure differentials, and seemingly intact roofs will be found to leak, even when no obvious damage is visible. Interior construction elements and finishes can be damaged when water infiltrates through building enclosures that are compromised by lack of maintenance. Renovations must address these building enclosure deficiencies, not only to preserve laboratory buildings from additional deterioration, but because infiltration of exterior contaminants negatively affects the conduct of research and instrument performance.

When a building enclosure undergoes major renovation to improve aesthetics as well as restore the exterior integrity, the project design team may propose to replace and/or enlarge windows to increase natural light in the interior of the building. On the other hand, designers may propose to block windows, reducing daylight reaching the building interior. They may propose to install entirely new materials on the façade. These design changes also change thermal performance factors, such as R-values, as well as change daylight performance. Engineers and designers need to investigate consequences of these proposals and evaluate the true benefits to the building renovation.

When a building exterior cannot be sealed adequately, improvements can be made from the interior. For example, storm windows can be installed inside old windows to reduce water and air infiltration. Insulation and waterproofing can be added on the interior side of the building enclosure to improve comfort conditions. These additions will help improve indoor air quality and water tightness, but the best solution is to pressurize the building positively relative to the atmosphere by increasing supply air. Chapter 1, Section 1.3.1 contains information on pressure relationships for laboratory buildings.

3.3 HEATING, VENTILATING, AND AIR-CONDITIONING SYSTEMS

3.3.1 Engineering Perspective

Careful inspection and evaluation of existing equipment and systems is critical during the planning stages for estimating what can be reused and what must be supplemented or replaced in the renovated building. It is generally necessary to provide a complete and comprehensive evaluation of an entire existing building even when only part of the building is being converted to laboratory use. The inspection and evaluation is best done simultaneously by a team of professionals, each with responsibility for a specialty. It is prudent to engage a team of professionals for this activity that has experience in space conversion and a thorough understanding of the needs of laboratories. The full team should include architects, HVAC engineers, electrical engineers, plumbing engineers, structural engineers, and environmental health and safety specialists. An outline and checklist of the elements of a comprehensive survey of all the mechanical equipment and systems of a building being considered for renovation and subsequent use to house laboratories are given in Table 3-3. This list is generic; the specific equipment items and systems that will be included in a systems evaluation chart will be unique to the structure undergoing inspection and the requirements of the new laboratory. In Table 3-4, the third and fourth column entries are based on an assessment of current conditions. The fifth column entries are based on desired activities. Provided is a refinement and extension of the information that would be entered in Table 3-3. It considers all shortfalls and omissions of mechanical items and systems that will be needed in the new laboratories, characterizes the magnitude and nature of the remedial effort, and gives a method for making preliminary estimates of cost. As with Table 3-3, the specific items that will be entered in such a chart will be site and laboratory use specific.

3.3.2 Mechanical Systems

The survey of in-place HVAC systems includes general ventilation systems that provide comfort control as well as all systems that provide contaminant control. A decision can be made as to whether the existing systems will satisfy all requirements for the new laboratory in as much as new laboratories may require more ventilation services than older ones. In this event, both supply and

TABLE 3-3. Systems Evaluation Chart

No.	Existing Equipment	Information	Condition	Capacity	Requirement	Deficiency	Est. Cost to Remediate Deficiency
1	HVAC System Type						
		All air		CFM	CFM		
		Constant volume		CFM	CFM		
		Variable volume		CFM	CFM		
		Fan coil		CFM	CFM		
		Induction unit		CFM	CFM		
		Chilled beam		CFM	CFM		
2	Heating & Ventilation (HV)			CFM	CFM		
		Air cleaners					
		Motor size		HP	HP		
2A	Heating Coil			BTU/hr	BTU/hr		
3	Air Conditioning (AC)			CFM	CFM		
3A	Air Cooled Condensing			Tons	Tons		
	Unit Chiller			Tons	Tons		
		Chilled water		GPM	GPM		
		Cooling tower		GPM	GPM		
4	Temperature Controller						
		Electric					
		Pneumatic					
		Direct digital					
5	Exhaust Fan						
		Air cleaners					
		Motor size		HP	HP		
6	Electrical Service			KW	KW		
		Number subpanels					
		Emergency power		KW	KW		
7	Plumbing						
		Water piping					
7A	Hot Water Pump			GPM	GPM		
8	Fume Hood			CFM	CFM		
		Duct work condition					
		Supply size					
		Return size					
9	Waste Treatment						
		Acid resistant piping					
		Treatment systems					
		Sanitary systems					
10	Floor to Ceiling Height			FT	FT		
11	Space Pressure Control			DP	DP		

exhaust air will likely have to be increased to serve an increased number of exhaust points and maintain pressure balances. The building construction and renovation documents can provide valuable information and assist in the evaluation. The maintenance records of equipment that is scheduled to be retained and upgraded can also provide valuable information about the current condition and give an indication of the remaining useful life of the equipment. Exploratory openings may be needed in walls and ceilings to fully evaluate many of the systems.

3.3.2.1 Heating, Ventilating, and Air-Conditioning Systems Checklist. HVAC systems servicing the building will provide some amount of comfort ventilation and will likely provide contaminant control ventilation if the building was used for laboratories. The type of air distribution system (constant or variable air volume),

TABLE 3-4. Solutions for Deficiencies

No.	Problem	Minor Renovation (Note #)	Moderate Renovation (Note #)	Major Renovation (Note #)
1	When supply air is limited	1A	1B	1C
2	When exhaust air is limited	2A	2B	2C
3	Supply air filtration needs vs. fan capacity	3A	3B	3C
4	When cooling capacity is limited	4A	4B	4C
5	When reheat capacity is limited	5A	5B	5C
6	Structural limitations HVAC	6A	6B	6C
	(a) Loading limits			
	(b) Space limits			
7	Relative location of supply and exhaust	7A	7B	7C
8	Humidification capacity	8A	8B	8C
9	When sprinkler system is inappropriate	9A	9B	9C
	(a) Water supply	9D	9E	9F
	(b) Sprinkler water supply	9G	9H	9I
10	Emergency power	10A	10B	10C
11	Egress	11A	11B	11C
12	When hazardous substances are present for which no provision has or will be made	12A	12B	12C
13	Excess chemical storage: When excessive hazardous chemicals are present.	13A	13B	13C
14	Differential pressure control	14A	14B	14C
15	Inadequate electrical branch circuits	15A	15B	15C
16	Fire protection inadequate	16A	16B	16C
17	Temperature control zones	17A	17B	17C

1A. When supply air is limited in minor renovations, attempts should be made to increase supply air by rebalancing the existing air handling systems. Examine what the existing air handling system should be and determine whether additional air capacity can be obtained by doing simple things like improving the duct distribution system, the removal of unnecessary high pressure drop, risers and fittings, worn-out fans, etc.
1B. All items mentioned in Note 1A apply. In addition, local makeup air systems may need to be installed to heat, cool, and filter additional incoming air.
1C. Under a major renovation, all items of Notes 1A and 2A apply. Replacement of some or all supply air systems may be needed. This may involve new ductwork and new air handling units. Supply air ducts should be examined, cleaned, or repaired as needed. Most likely new supply air handling systems will be needed.
2A. When exhaust air appears to be limited in minor renovations, rebalancing may be all that is necessary to get the required air quantity. Alternatives for reducing exhaust air volumes should be sought by exploring strategies described in Chapter 35, Energy Conservation.
2B. For moderate renovations, all conditions in Note 2A apply. In addition, fan replacement may be required.
2C. All items in Notes 2A and 2B apply for major renovations. Most likely new exhaust systems will be needed.
3A. When filtration requirements for the new system increase, a system's pressure drop increases to a level greater than the existing fan can handle. In minor renovation, an inline axial flow booster fan to overcome the resistance of a local high efficiency filter may be sufficient.
3B. Same as Note 3A.
3C. A comprehensive supply air system revision may be needed when fan capacity is inadequate to provide air filtration needs.
4A. When cooling capacity is limited in a minor renovation, usually air balancing with resulting higher supply air quantities is sufficient. For a fan coil system, the operation of fan coils from a low to high position may be needed.
4B. Lowering the supply air temperature of the cooling systems may be needed. Lowering of temperature increases the cooling capacity for the same volume of supply air.
4C. All items in Notes 4A and 4B apply. In addition, a comprehensive review of the existing cooling system capacity may be needed. New cooling sources and piping may be required to boost capacity.
5A. When reheat capacity is limited in minor renovations, occupants should be prepared to accept temperature variations.
5B. A Small electric reheat coil may be an accepted remedy. Explore extending existing reheat systems to a laboratory location.
5C. A comprehensive review of the existing reheat system is required. New capacity may be needed in the form of a dual duct system with electric, hot water, or steam reheat.
6A. Structural issues usually do not occur in minor renovations.
6B. Same as Note 6A. Space limitation may be the most critical contributing factor when deciding on installation of new HVAC capacity system. For example, insufficient clear space above suspended ceiling and underside of a slab or steel structure may not allow a certain size of supply air duct run and may require a local cooling system such as chilled beams or fan coils.
6C. A very careful review of structural capacity of the building may be required.
7A. Location of supply air intake relative to exhaust is usually not an issue in minor renovations. The assumption is that if there was a reentry problem because of the proximity of exhaust and intake , it would have been noticed beforehand, and the renovations or changes are no longer to be considered minor.

(*Continued*)

TABLE 3-4. (*Continued*)

7B. Same as Note 7A.
7C. An air-quality survey including taking air samples may be required. Detailed calculations based on CFD technology and on wind tunnel testing, may be required to ensure that appropriate spacing exists between supply and exhaust points when location of supply and exhaust cause recirculation.
8A. Humidification capacity modifications for a minor renovation are usually not cost effective. A check of existing humidification systems should be made to ensure that they are operating at maximum efficiency.
8B. Same as Note 8A with the possibility that additional branch humidifiers might be installed.
8C. If the existing laboratory is not humidified, it is difficult to add humidity in a space. On the other hand, there may be some dehumidification controls required that can only be obtained by subcooling the air going to the space and then reheating it to maintain temperature condition. These conditions are difficult to achieve. Local humidifiers can be installed, but they are expensive to operate and require continuing maintenance. If a space has high humidity, lowering the supply air temperature, or increasing the air volume, could be considered as long as local reheat system with adequate capacity is available. A careful review of all systems is required to ensure the appropriate system capacity exists. The appropriate distribution of humidity into the air is required. An existing single humidifier manifold may need to be replaced with multiple manifold discharge points. Local humidifier installations should be reviewed carefully because usually there is not sufficient space for mixing of vapor with air prior to discharge into the space.
9A. If existing laboratory is not sprinklered, and no sprinkling system is available in the building, it is almost impossible to sprinkle a laboratory in minor renovation. If existing sprinkler piping exists in the building, and the laboratory is not sprinkled, it should be sprinklered.
9B. An infrastructure upgrade is called for to improve the sprinkler system and risers.
9C. When the existing laboratory is not equipped with a sprinkler system, it should be part of the renovation scope.
9D. When adequate water supply, quantity, and pressure is not available, questions should be raised whether the space is adequate to be used for laboratories at all. If adequate quantity is available, but there is low pressure, local booster pumping stations may be needed.
9E. Same as Note 9D.
9F. Same as Note 9E.
9G. The sprinkler water supply is not adequate, which usually means adequate volume but lack of pressure, booster pumps are necessary. However, in a small renovation, it is not cost effective to do so.
9H. Same as Note 9G.
9I. Tank storage should be considered when the sprinkler water supply must be provided but the local water supply is not adequate.
10A. Providing emergency power for a minor renovation can mean redistribution of existing emergency power circuits in the laboratory. Additional circuits could be brought into the laboratory from a floor branch panel. No upgrade in emergency power distribution or capacity can be cost effective for this type of renovation.
10B. Same as Note 10A.
10C. An extensive emergency power system must be incorporated into laboratories undergoing major renovations to ensure that all critical requirements are met. Egress lighting and other safety light services can be provided by battery-operated systems when emergency power is inadequate.
11A. Egress issues are usually not included as part of the scope of a minor or moderate renovation. It is assumed that the laboratory already has compliant facilities egress and this is not an issue. The location of an existing fume hood in the path of the egress pathway can be problematic, but it is usually not cost effective to be changed as part of a minor or moderate renovation.
11B. Same as Note 11A.
11C. Egress issues should be evaluated and changes made as needed when additional egress opportunities are needed.
12A. Inappropriate chemicals should never be used or stored in laboratories because, by definition, the laboratory and its systems are not designed to handle these chemicals in a safe manner. The scope of minor and moderate renovations and funding usually do not permit basic changes required to handle inappropriate chemicals.
12B. Same as Note 12A.
12C. The upgrades required to handle more hazardous chemicals can be included in the budget and the scope for major renovation.
13A. Excessive chemicals should never be stored in a laboratory. A minor renovation should be treated as an opportunity to "clean house."
13B. Note 13A applies. The addition of local approved chemical storage cabinets can be part of the renovation scope.
13C. The whole issue of chemical storage and chemical waste disposal should be addressed in a major renovation. Storage rooms may be needed.
14A. Differential room pressure can be controlled by volume adjustments and air balancing of laboratory supply and exhaust air.
14B. Same as Note 14A.
14C. Differential pressure control in a major renovation can be achieved by adjusting static pressure at exhaust fans, at specified duct locations, and in the spaces. Differential pressure controllers can be used. The volumetric method described in Note 14A is a viable method.
15A. Inadequate electrical branch circuits cannot be upgraded. The relocation of receptacles in the laboratory and rewiring of new circuits from the laboratory electrical panel can be part of the scope. Inadequate laboratory panels can be fixed.
15B. Same as Note 15A.
15C. All electrical deficiencies can be removed in a major renovation.
16A. A fire protection system usually cannot be upgraded. The cost is too high to be included in the budget of a minor or moderate renovation. Relocation of existing sprinkler heads is possible.
16B. Same as 16A.
16C. The fire protection system should be upgraded to code requirements in a major renovation.
17A. The temperature control zones usually cannot be changed within the budget of a minor renovation. Relocation of thermostats from less representative locations to better ones is possible.
17B. The temperature control zones can usually be changed within the budget of a moderate renovation.
17C. Temperature control zones in a major renovation can be changed and additional zones can be added.

heating capacity, cooling capacity, outside air volume, location of air intakes, location of equipment (in basement, roof, or mechanical room, within the building), and adequacy of equipment housing space should be verified and recorded with the condition and age of the materials of construction as well as make and model of fans, motors, etc. All existing heating and cooling coils should be cleaned if soiled. Air flow in all supply, return, and takeup air main ducts should be verified by test. The capacity of the heating and cooling coils should be confirmed and the condition of the casing and insulation checked to determine whether the units can provide a longer period of sustained operation. On the basis of the analysis of the inspection data, including air flow measurements, a decision can be made as to whether additional equipment will be required for the new laboratories. Humidifier capacity should be recorded and checks made to determine condition of pans, floats, and controls.

3.3.2.2 Ducts. It will always be necessary to thoroughly inspect all supply and exhaust ductwork internally and externally; openings may need to be made at intervals so that adequate inspections can be performed. Among items that need checking are the condition of the interior and exterior insulation, its adhesion, and whether it has become a breeding ground for dust mites and other undesirable insects. Significant deposits of solids should be noted. Verification of the good condition of interior insulation is especially important. A thorough inspection of the ductwork will determine whether ducts (1) can be reused as is, or (2) require duct cleaning, removal of blockages, or leak repair. It will also determine whether insulation, if present, is firmly adherent, and whether vapor barriers are still intact. Flexible duct connections should be inspected for constrictions and excessive lengths. Poorly designed and installed duct systems that have small radius bends, abrupt transitions, and absence of turning vanes should be corrected.

3.4. LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

3.4.1 Introduction

The information in this section focuses on overcoming difficulties sometimes experienced during renovations that impact the safety of the renovated facilities. Experience has demonstrated a number of solutions. One should always be alert to alternative solutions because each renovation has its unique aspects.

3.4.2 Emergency Electrical Considerations

The need for adequate emergency electrical power to life support systems such as fire alarms, emergency lighting, and other code requirements must always be met. In this regard, additional space, equipment, and fuel storage for emergency electrical generators may be necessary. When additional space is unavailable, larger and less-efficient older equipment may be replaced with more compact new equipment. In cases in which adequate emergency electrical power cannot be established in a renovated building, a review of the equipment and operations supported by the emergency system can lead, by management decree, to a priority listing and shared applications. For example, transfer switches can be programmed to operate second- and third-tier equipment when selected tier-one equipment is not in operation, thereby utilizing all available emergency electricity. A different fuel or power source may also be used to generate emergency electricity.

3.4.3 Construction Materials

Establishing the flame spread and smoke generation rate for existing building components can be difficult; it is easier when the components are comprised of standard materials. Testing laboratories such as Underwriters Laboratories and Factory Mutual can provide information and services to assist with the task. To meet required building codes, a licensed fire protection engineer should be retained to assist in determining the fire risk, especially when the renovated building will have laboratories with moderate or high fire risk.

3.4.4 Safety Control Systems for Laboratory Experiments

It may be problematic to cut holes through concrete floors and circumvent other obstacles to run control lines; nevertheless, safety control systems must be hard wired. Wireless systems that depend on transmitted signals through the air or power lines are subject to interference and malfunction and should not be used for the control of operations that could lead to fire, explosion, toxic release, or other hazards. Alternatively, it may be possible to utilize wiring routes that are no longer needed when intermediate signal boosters are added. This would likely be the case with some computer monitored and controlled systems. Equipment manufacturers should be contacted for assistance with this issue.

3.4.5 Fire Detection, Alarm, and Suppression Systems

The greater the amount of demolition of walls and floors during renovation, the easier it will be to obtain

full access to pipes, wires, boxes, and control hardware. With this open exposure, replacing components will be easier and cheaper. An ideal time to consider the use of water sprinklers for the basic fire control system is during major renovations. See Chapter 1, Section 1.4.4 and Chapter 2, Sections 2.4.1.1 and 2.4.1.2 for more specific information on smoke and fire detection and suppression systems.

3.4.5.1 Fire Suppression. When water supply is insufficient to support a complete building sprinkler system, the use of local sprinklers in high-hazard areas can provide important coverage. When building codes or building owners call for a fire suppression system greater than partial sprinklers, other types of fixed fire suppression systems can be installed, e.g., vaporizing liquid, dry powder, and carbon dioxide. Selection will be dependent on the nature of the building hazards. For example, a fire system pump to support an existing sprinkler system may be needed to meet code requirements. In cases of insufficient water supply for a sprinkler system, a building roof-top holding tank may serve as an alternative. These are mandated in some locations. A qualified fire protection engineer should be consulted for help in sizing and selecting equipment.

3.4.6 Hazardous Waste Management

When a renovated building is intended to provide laboratory and nonlaboratory use, the location of a hazardous waste facility needs special consideration because it will be considered a high-hazard area and must be designed as such. Therefore, it should be located near or adjoining the laboratory unit it supports. Additional fire and hazard separation between laboratory and hazardous waste areas may be required by local authorities, fire departments, and environmental agencies. Chapter 27, Hazardous Chemical, Radioactive, and Biological Waste Handling Rooms, contains information on the design of hazardous waste handling and storage rooms.

3.4.7 Chemical Storage

When hazardous chemicals will be stored in locations other than laboratories, a storage area close to the supported laboratories should be considered. Factors similar to those used for a hazardous waste facility will also apply to a chemical storage facility (see Chapter 28, Laboratory Storerooms). Chemical storage areas within laboratory units should not function as long-term storage facilities.

3.4.8 Fuel Gas and Compressed Gas Storage and Piping

Planning for a major renovation is an opportune time to consider installing compressed gas piping from an external gas cylinder facility to each laboratory, thereby eliminating the transport of these items through the interior of the building. Special consideration should be given to the routes of delivery within a renovated building for highly toxic and flammable compressed gases, especially when the building will have mixed use. Separate elevators, or nonpublic corridors and stairs for the delivery of highly hazardous materials, should be considered for the safety of the building occupants. Restricting delivery to the night hours usually fails because laboratory personnel seldom honor such rules when a need arises during the daytime. Adequate storage space for compressed gas cylinders must be provided to reduce the temptation to store cylinders in egress corridors. When hydrogen and highly toxic gases are delivered to the laboratory units via a fixed piped system, there is a need for double-walled gas transmission lines. Additional information may be found in Chapter 1, Section 1.4.8 and Chapter 23, Section 23.4.2. All fuel gas pipes or combustible compressed gas lines from storage cylinders to laboratories should be capable of being turned off outside the building or at some ground floor location remote from any hazard or entrapment. All gas systems that transport flammable, highly reactive, or highly toxic materials should include automatic shutoff equipment (excess flow check valves) that is activated when the gas flow exceeds a preset value.

3.5 MISCELLANEOUS SERVICES

3.5.1 Electrical

Evaluation of the installed electrical services should include the following:

- A check with the utility company to determine whether there will be additional capacity from existing services if more power is required
- The number of electrical outlets is frequently inadequate and should be evaluated.
- A check of installed transformers, switch gear, distribution panels, wire sizes, etc., to ascertain whether they conform with current National Electric Code guidelines for acceptable carrying capacity and to determine whether there is adequate fault protection
- An evaluation of emergency power capacity to determine whether it will be able to handle emer-

gency lighting within 10 seconds and carry the additional load of essential incubators, freezers, cold rooms, warm rooms, critical experiments, etc.

There is additional information on electrical service needs in Chapter 1, Section 1.5.

3.5.2 Plumbing

When new laboratories will be located on the upper floors of high-rise buildings, it is important to determine whether pumping will be required to supply hot and cold water. Backflow prevention systems should be checked for compliance with current codes.

3.5.3 Pure Water Systems

The pure water system being considered for use in the renovated laboratories (distilled, deionized, reverse osmosis, etc.) may use, supplement, or replace an existing system. A discussion of chemically pure water systems is contained in Chapter 1, Section 1.5.7. The condition of pure-water pipes in old systems may have degraded to the point where water quality cannot be maintained and may require partial or total replacement. If the existing pure-water system has "dead legs," consideration should be given to installing a pumped return looping system with filtration and a local repurification or polishing system.

3.5.4 Laboratory Waste System

As mentioned in Chapter 1, Section 1.5.3.2, most local plumbing codes now require certain types of acid-resistant waste piping for many kinds of laboratory drains. In renovations, the existing piping system may not be appropriate for acid waste handling, and new piping, including vent risers, will be required. When the types and quantities of chemicals used can be documented to be compatible with existing piping, local authorities may grant an exemption.

The need for end-of-pipe waste treatment systems depends on the type of research wastes produced (see Chapter 1, Section 1.5.3.2. for details on building waste water treatment systems). A central pH control system may not be present in many older facilities. When it is not possible to install a central pH control system, local devices such as chip tanks for low-pH wastes may be substituted. Another alternative is collection and containment of only the most hazardous fraction of the liquid waste to lighten purification requirements for the bulk of the liquid waste stream.

4

RENOVATIONS: LABORATORY CONSIDERATIONS

4.1 GUIDING CONCEPTS

4.1.1 Introduction

Laboratories tend to undergo renovations at intervals of 10 to 25 years because research objectives change, new technologies are introduced, and new instruments become available. Currently, biomedical and pharmaceutical laboratories tend to undergo renovations more frequently and more thoroughly than other types. Laboratory renovations are difficult and costly: They require an ever-increasing level of utility services and environmental control. Common reasons for laboratory space renovation include:

- Existing layout or stationary equipment is deficient.
- Existing space is too small because of personnel increases.
- Aisle widths are too narrow for safe movement and do not meet the requirements of the Americans with Disabilities Act of 1990.
- Aisle widths are too wide, leading to inefficient use of the area.
- There is no remaining free floor or bench area to install additional equipment.
- Safety equipment is inadequate or inappropriate for changing operations.
- Heating, ventilating, and air-conditioning systems are outdated, operate poorly, fail to maintain pressure balance, or are not operating within safe limits.
- Electric power and data communication facilities are inadequate for new instruments and computers (the amount of electrical power required per laboratory has increased by approximately 100% over the past couple of decades)
- There is neither reliable power nor back-up emergency power to prevent loss of research data and materials.
- Water fixtures and drains are beyond their useful life, leak, and need to be replaced.
- Room finishes, casework, and countertops need major repair or replacement.
- Lighting fixtures are energy inefficient and do not provide enough light.

4.1.2 Diagnostics

To determine whether a renovation is needed, start with a diagnostic review of conditions in the laboratory. Equipment hoarding, clutter, and inefficient use of laboratory space are not compelling reasons for undertaking a laboratory renovation, but genuine overcrowding—more full-time occupants than the area can safely accommodate—is a compelling reason. Chapter 1, Section 1.2.1.2.1 and Tables 1-4, 1-5, and 1-6 explain and provide area occupancy guidelines, respectively. The need for more routinely used equipment than can be

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accommodated on existing benches or floor space to house it are legitimate reasons to consider renovating a laboratory. It is the responsibility of the laboratory managers and supervisors, principal investigators, and bench scientists to document unsatisfactory and unsafe conditions in the laboratory. This may be supplemented with statements from health and safety professionals on past emergency or hazardous events that occurred in this laboratory. Laboratory personnel must also describe new factors, such as increases in staff and duties, or changes in materials and processes that require additional space and equipment, to justify a request for funding approval for renovation. Chapter 1, Section 1.1 explains the program process.

4.2 LABORATORY LAYOUT

Laboratories are renovated when the existing layout is deficient for all of the reasons cited in Section 4.1, and when they can be improved and corrected by renovation. As a general rule, all of the guidelines for new construction, contained in Chapter 2, Section 2.2 and Chapter 3, Section 3.2, should be applied to renovated laboratories.

4.2.1 Entry and Egress

When a laboratory will be renovated and made larger, or is scheduled to make use of new hazardous chemicals, materials, or processes, egress conditions should be reviewed. The guidelines for entry and egress in Chapter 2, Section 2.2.2 should be followed. When local and regional codes or corporate and institutional policy have other, more stringent, requirements, they should be followed. Older laboratory buildings may have been provided with seldom-used narrow doors or knockout panels for secondary egress from laboratories, but after renovation, primary and secondary exits and exit doors must meet the current building code, as well as the Occupational Health and Safety Administration (OSHA 1910.37, 2012) requirements, plus any special institutional requirements.

4.2.2 Furniture Locations

Most old laboratories have fixed casework. Base cabinet units, bolted to the floor, support countertops. Wall cabinets are permanently attached. A construction crew will be needed to detach, relocate, and reinstall fixed casework and equipment. The functional condition of old benches needs to be assessed for lost and broken hardware, missing doors and drawers, deteriorated, hard-to-clean and unsightly surfaces, and loss of structural capacity. Good-quality solid-wood laboratory furniture that has been well cared for can sometimes be refinished, repaired, and reinstalled cost effectively, even after 50 years of service. However, it will not be cost effective to repair and relocate most used metal, wood veneer, and plastic laminate fixed casework. Under hard wear conditions, service life is shorter for these materials.

4.2.2.1 Benches. The concept of hazard zoning should guide the redesign of the laboratory and positions in which laboratory benches are installed. Chapter 2, Section 2.2.1 describes the hazard zoning principle. All of the bench layouts depicted in the figures in Chapter 2, Section 2.2 are candidates for installation in laboratories undergoing major renovations, but some may prove to be impractical because of irremediable structural limitations. For example, if existing columns will consistently land in the middle of laboratory aisles, given the normal range of aisle spacing in modules, 90-degree realignment of laboratory benches may be considered to avoid aisle obstructions.

4.2.2.2 Aisles. The renovation process offers an opportunity to improve workflow in the laboratory and to improve safety by a change of laboratory layout. Whenever possible, one of the recommended laboratory layouts illustrated in Section 2.2 should be selected and adapted to the structural and dimensional conditions of the existing structure. Chapter 3, Section 3.2.2.3 describes modular layout options for renovations. Ideally, the laboratory module should be reconfigured to utilize the recommended centerline-to-centerline distance of 10 ft 6 in. to 12 ft (3.2 m to 3.65 m), maintaining a minimum 5-ft (1.5 m) clear aisle width. If this is not possible, a 90° reorientation of bench aisles that lead to the main laboratory aisle(s) is an option that retains the concept of hazard zoning and clear direction toward the egress door.

4.2.2.3 Desks. When planning a laboratory renovation, carefully consider providing computer workstations outside the laboratory for the entire laboratory staff, including students, technicians, and researchers. An outside area for computational work, near the laboratory, releases valuable area for equipment and research. Locating desks and computer stations outside the laboratory reduces occupants' long-term exposure to chemicals and other potential health hazards while in the laboratory environment, and minimizes exposure liability. In addition there can be significant energy savings because office areas are ventilated at significantly lower air exchange rates than laboratories. There is ample evidence that laboratory users spend increasing time on computers, generating and processing data in addition to e-mailing and researching. A high proportion of scientists' and engineers' normal workday is spent on data processing, data analysis, and communications at computer workstations.

4.2.2.4 Work Surfaces. When a renovation involves moving benches and cutting, drilling, and repairing laboratory countertops, determine whether hazardous materials are present. Some old countertops contain asbestos products and should not be drilled or cut without installing all the safeguards required by the Environmental Protection Agency (EPA, 40CFR parts 61 and 763) and OSHA 29CFR1926.1001 and 1101 regulations. The introduction to Section IB has additional information on laboratory decontamination and decommissioning.

4.2.3 Location of Chemical Hoods

Early laboratory designers placed fume hoods near vertical riser locations that were sometimes at an exterior wall and sometimes at an interior corridor wall. They did this to reduce horizontal exhaust ductwork runs. Many older laboratories have fume hoods located next to exits. Often there is no way to enter or leave without passing by a fume hood. Fume hood locations at laboratory entrances and exits are not recommended for two reasons: (1) the fume hood is the most likely source of fires and explosions and should not be located in the evacuation pathway, and (2) traffic past the open face of the fume hood has a tendency to disrupt smooth inflow air streamlines and degrade the hood containment function. Therefore, as a general rule, hoods should be located at the far end of a laboratory aisle in accordance with recommendations contained in Chapter 2, Sections 2.2.4 and 2.2.5.

4.3 HEATING, VENTILATING, AND AIR-CONDITIONING SYSTEMS

4.3.1 Introduction

The conversion of a previously used space to a new laboratory requires careful analysis of the heating, ventilating, and air-conditioning (HVAC) systems in the existing facility to determine the modifications and additions that will be needed in the updated laboratory. Laboratory procedures have changed, as have the analytical equipment employed, and the changes have affected the number and types of hoods and other exhaust air facilities that will be needed. Services and equipment of special importance in renovation planning for HVAC include floor-to-ceiling height and shaft space, makeup air, and ventilation for environmental, glass washing, and instrument rooms. See Chapter 3, Tables 3-3 and 3-4 for checklists of the most important items that will require investigation to make it possible to decide what existing structures and facilities will be retained and what will need to be replaced.

4.3.2 Engineering Perspective

Attention is required during the initial planning phase to identify the building areas and services that need to be upgraded or replaced. The condition of existing systems and a determination of whether the systems are capable of delivering whatever additional capacity will be needed is critical at this stage to reach decisions on whether it will be more cost-effective to upgrade existing equipment or replace it with new equipment. This decision will be based on the age of the equipment, its condition, the adequacy of the maintenance records, and a consideration of cost that includes the benefits that can be expected from new, more efficient, and more reliable equipment.

4.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

4.4.1 Introduction

This section looks at the same issues covered in Chapter 2, but with a focus on renovations and the difficulties sometimes encountered in applying the recommendations of Chapter 2 to renovations. All options should always be evaluated because each renovation has its own idiosyncrasies and solutions; what works in one situation may not work in another. Information on renovation-associated hazards is contained in Part I, Section B, Common Elements of Renovation.

4.4.2 Emergency Considerations

4.4.2.1 Emergency Fuel Gas Shutoff. Emergency fuel gas shutoffs are discussed in Chapter 2, Section 2.4.1.3 from an overall building standpoint. The need for local shutoffs is important in a building that has been renovated, especially when it is used for mixed occupancy because personnel not associated with, or knowledgeable about, the laboratory hazards and their control will be at higher risk. Therefore, it is prudent to install and clearly label a local shutoff as close to each laboratory unit as possible. The shutoff should conform to the recommendations in Chapter 1, Section 1.4 and Chapter 2, Section 2.4.

4.4.2.2 Ground Fault Interrupters. When new wiring will be installed in a renovated building, the recommendations for installation of ground fault interrupters in Chapter 2, Section 2.4.1.4 should be followed. When existing local wiring will remain substantially in place, ground fault interrupters can be installed at local receptacle duplex outlets. This is usually a better application than centrally located circuit breaker box mounted ground fault interrupters.

4.4.2.3 Master Electrical Disconnect Switch. The recommendations in Chapter 2, Section 2.4.1.5 should be followed. In the case of some renovations, the placement of a master electric disconnect switch should not be overlooked, nor should it necessarily be located at or close to the electrical control panel for the laboratory. When the control panel is located in a closet, near the back of the laboratory, or in some other place where rapid operation of the master disconnect switch is hindered, the switch becomes less helpful in emergency situations. The use of transfer switches with low-voltage remote activation switches operating through relays can allow for the location of the activation switches almost anywhere. In some organizations, the emergency disconnect system is tested on a semiannual basis, and it is the laboratory users' responsibility to perform the test. The need is to locate the switch where it is clearly visible and easily accessible in times of emergency yet not easy to operate accidentally. Unprotected switches located close to door frames and near coat racks give poor results because these are areas where personnel stand and may inadvertently lean against the switches.

4.4.2.4 Emergency Showers. Old buildings being renovated, modernized, or undergoing a use change to house laboratories frequently have wide corridors that provide an opportunity to use some of the space for recessed emergency deluge showers. The full use of an emergency shower after a chemical incident depends on a reasonable level of privacy, and a recessed shower with a curtain closure provides an adequate facility. When the availability of potable water is an issue, shower systems can be developed that include a storage reservoir located in a space elevated from the point of use. These systems provide room-temperature water, a plus factor, but require some method of periodic flushing. Chapter 2, Section 2.4.1.6 contains additional information. Renovations are a convenient time to upgrade emergency showers to meet the most recent standard, ANSI 358.1 (ANSI, 2009). Appendix A contains additional information.

4.4.2.5 Emergency Eyewash. Even in cases of limited portable water supply, the use of portable eyewash systems should be resisted because these units cannot provide the copious supply of water needed for the recommended irrigation time of 15 minutes. All buildings under consideration for laboratory use should be able to deliver the recommended flow rate of 3 gallons per minute. ANSI Z358.1 standard for Emergency Eyewash and Shower Equipment (ANSI, 2009) requires 0.4 gallons per minute (1.5 L). The reason for the difference is that the ANSI standard does not require the recommended full face wash capability. Appendix B, Emergency Eyewash Units, contains additional information.

4.4.2.6 Chemical Spill Control. When a laboratory is a part of a mixed-use building, locating a chemical spill control storage area becomes more difficult than when a building is entirely devoted to laboratory use. In this situation, it may be necessary to store all the materials in or near the laboratory unit rather than in a central building location. Provision of adequate space for chemical spill control storage cabinets or carts is a planning requirement. In addition to storing chemical cleanup materials, it may be necessary to maintain decontamination materials for radionuclides and biohazardous materials.

4.4.2.7 Control Systems. Control systems require wiring to a central control point within the laboratory building. However, when nonlaboratory buildings are being renovated for partial laboratory use, it is unlikely that a central control station will be a part of the finished renovation. Even when there will be a security station, it may not be manned by personnel technically competent to respond to laboratory emergencies. Therefore, a solution might be to establish a joint monitoring station with operators competent to handle both responsibilities. When a building central station is incorporated into the design, provisions must be made for installation of signal and control cables.

4.4.2.8 Storage of Hazardous Waste. Hazardous waste regulations limit the amount and length of time waste materials can be kept in the laboratory satellite accumulation area before being moved to a main accumulation holding area for pick-up or processing. When renovated mixed-use buildings with hazardous waste-generating laboratories cannot include a hazardous waste holding area, arrangements must be made with a hazardous waste disposal company to remove materials directly from the laboratories on short notice. This is likely to be a very costly way of handling hazardous waste.

4.4.2.9 Chemical Storage and Handling. Providing a chemical storage room to support the laboratories may be difficult in renovated space, but it is necessary when a laboratory is to be constructed in a nonlaboratory building. The temptation to resolve the difficulty by providing storage within the laboratory for quantities in excess of those needed for a week or two should be avoided, particularly when very hazardous, flammable, reactive, and toxic materials are in use (see Chapter 28, Laboratory Storerooms).

PART II

DESIGN GUIDELINES FOR A NUMBER OF COMMONLY USED LABORATORIES

The following chapters address environmental, safety, and health issues for a number of well-defined laboratory types. Laboratory type is determined largely by the hazardous properties and quantities of the materials and equipment normally used, the work activities performed, and any special requirements of the laboratory that may affect the environment or personnel's safety and health adversely inside or outside the laboratory. It is of extreme importance that a specific laboratory type be selected in collaboration with laboratory users and safety and industrial hygiene advisors. After the laboratory type has been selected, all of the issues discussed in the chapter of this manual dealing with that specific laboratory type should be evaluated and implemented in the design stages. Therefore, the trend in research is to have more interdisciplinary collaboration. Quite frequently, the desired laboratory will be a combination of several types of laboratories and the applicable requirements of each should be adopted.

The items discussed under "Common Elements of Laboratory Design" (Part I, Section A) apply to all laboratories except when we exclude elements in specific laboratory chapters and provide alternatives. In each of the specific laboratory types, special requirements unique to that laboratory are addressed. They may supplement or supersede the requirements of the Common Elements section. Chapters 1 and 2 should be read before final discussions about the specific laboratory design. For renovation projects (Part I, Section B), it may not be possible to comply with all requirements because of constraints imposed by the existing facility. However, if any safety and health recommendations must be compromised, safety and industrial hygiene personnel or consultants should be approached for professional advice.

A matrix showing the major safety and health considerations that should be addressed for each laboratory type is provided in Appendix E. It is intended as a design refresher and as a quick overview of the detailed information given in the text.

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5

GENERAL OR ANALYTICAL CHEMISTRY LABORATORY

5.1 DESCRIPTION

5.1.1 Introduction

General and analytical chemistry laboratories are designed, constructed, and operated to provide a safe and healthy work area for the analysis, experimentation, and quality control of a wide variety of chemicals ranging from nanograms to kilograms, although not in the same laboratory. Many analytical procedures call for handling moderate amounts of hazardous chemicals, including petroleum solvents, explosive gases, and toxic substances. Usually this type of laboratory will be located in a building containing other laboratory units; they should not be housed in office buildings.

5.1.2 Work Activities

General chemistry laboratory activities include mixing, heating, cooling, distilling, evaporating, diluting, and reacting chemicals for testing and experimentation. The activities performed in analytical chemistry laboratories are more specific, with the primary activity being sample analysis involving the mixing, blending, ashing, and digesting of various chemicals, or the preparation of materials for further manipulation. These functions require a number of analytical instruments, some of which contain, utilize, or produce hazardous radiation from lasers or microwaves. Most of this work is conducted on an open bench or in a laboratory chemical fume hood. Today's instrumentation can measure at ppb levels; therefore, it may be very sensitive to ambient conditions. These conditions must be identified early in the design stage.

5.1.3 Equipment and Materials

Spectrophotometers, gas and liquid chromatographs, magnetic resonance spectroscopy and imaging instruments, scintillation counters, mass spectrometers, balances, microscopes, stills, extraction apparatus, ovens, and furnaces may be used in analytical chemistry laboratories. General chemistry laboratories may also have reactor vessels, evaporators, and crystallizers. Heavy use of some of this equipment will generate a significant heat load in the laboratory.

Hazardous materials used in analytical chemistry laboratories include small quantities of chemicals of high toxicity, volatile liquids, dusts, compressed gases, and flammables. Toxic materials may be reacted or decomposed into nontoxic compounds during the analytical procedures, but usually they remain in a toxic state during manipulation. Occasionally, nontoxic components may react to produce hazardous reaction products, but this is not usual.

If work with nanoparticles is to be conducted in this laboratory the additional requirements of Chapter 7 (Nanotechnology Laboratories) should be reviewed for applicability.

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5.1.4 Exclusions

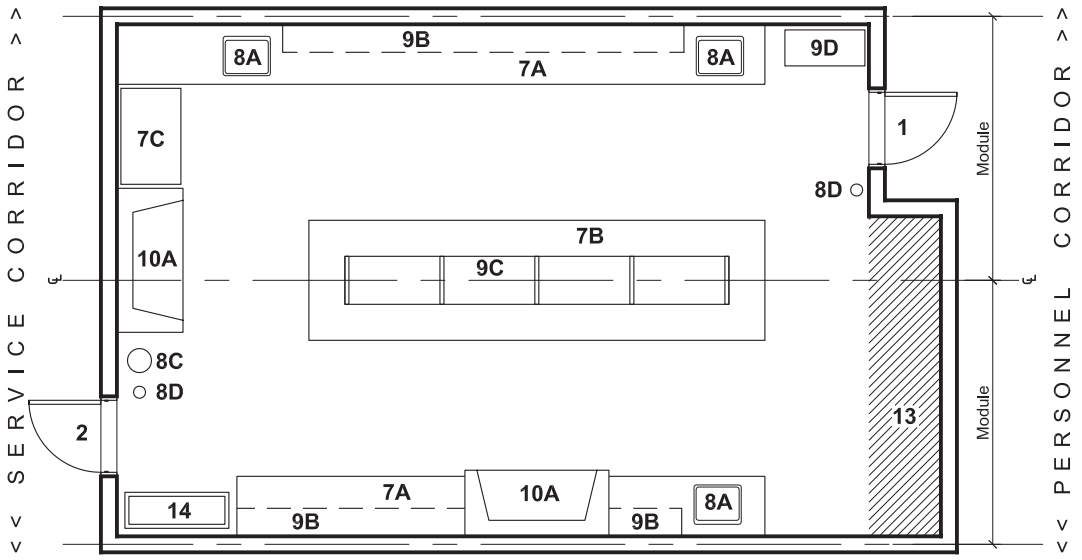
These chemistry laboratories are not designed (1) for handling extremely hazardous chemicals, (2) for using chemicals with unknown toxicity and/or hazardous properties, (3) or performing especially hazardous operations. Hazardous operations not recommended for general and analytical chemistry laboratories include, but are not limited to, the use of

- Carcinogenic, mutagenic, or teratogenic chemicals
- Highly explosive materials in greater than milligram quantities
- High-voltage and high-current electrical services
- Radiofrequency generators and all electrical operations with a high potential for fire, explosion, or electrocution
- Lasers of over 3-mw output power with unshielded beams
- Gas pressures exceeding 2,500 psig
- Liquid pressures exceeding 500 psig
- Radioactive materials in greater than 1-μci amounts

These operations are addressed in other laboratory types. General and analytic chemistry laboratories usually need no special access restrictions except when specialized or highly sensitive instruments are to be used, or when a normal building environment may contain contaminants in quantities that equal or exceed those measured in trace analysis laboratories. This type of laboratory is an exclusion laboratory.

5.2 LABORATORY LAYOUT

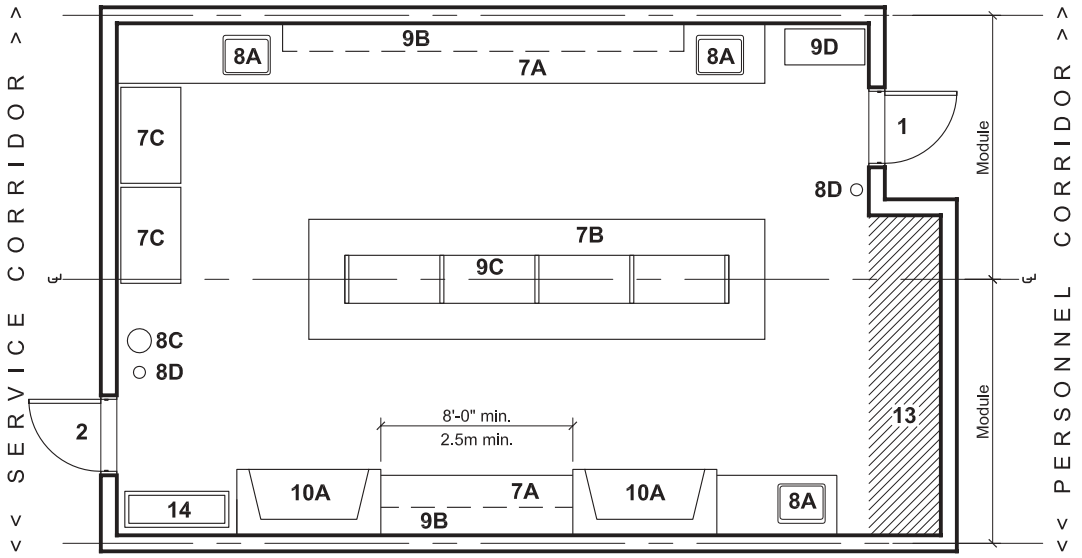
The layouts of an analytical chemistry laboratory and a general chemistry laboratory are similar (see Figures 5-1A and 1B). Each item addressed in Chapter 1, Section



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 5-1A. General or analytical chemistry laboratory layout with two fume hoods on intersecting walls.



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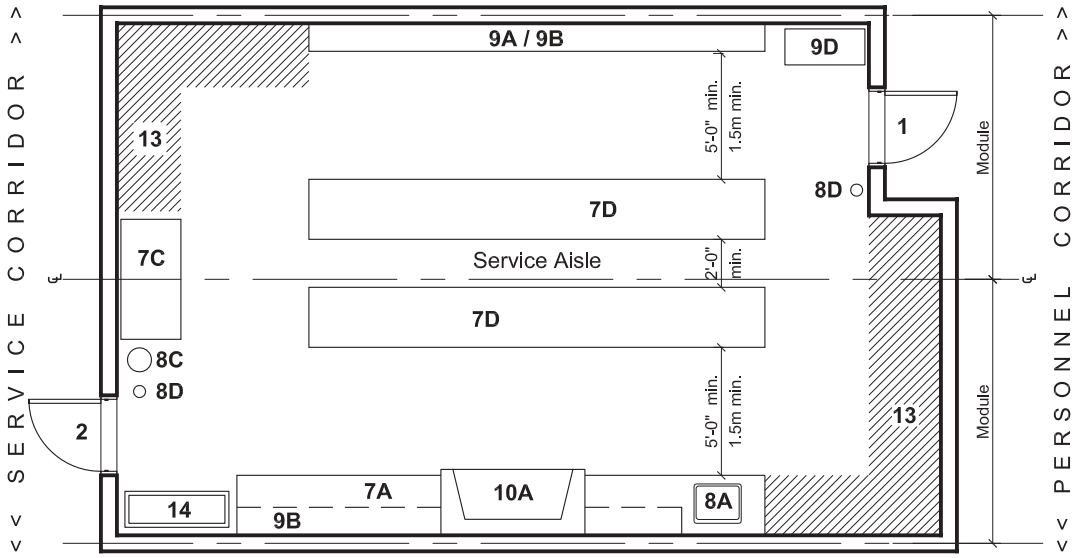
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 5-1B. General or analytical chemistry laboratory layout with two fume hoods along same wall.

1.2 and Chapter 2, Section 2.2 should be evaluated for its applicability to the specific needs of those who will use this facility, and items that are relevant should be implemented. The most important consideration in the layout is safely locating the number and sizes of chemical fume hoods required. In laboratories where multiple fume hoods are needed, a minimum of 4 ft (1.2 m) should be provided between fume hoods on the same wall. If only two fume hoods are needed, one hood on each side wall toward the rear of the laboratory is acceptable when the face-to-face distance is more than 10 ft (2.9 m).

Because it is likely that many pieces of analytical equipment of substantial size will be present in an analytical chemistry laboratory at all times, special care should be given to their location relative to egress routes, ventilation patterns, and the interactions of laboratory personnel with chemical handling operations. Access to the rear of bench-mounted analytical instruments is very important for gas, fluid, and vacuum lines, as well as for data transmission and power connections. Benches and countertops can be split and separated by a safe distance, minimum 2 ft (60 cm), to allow one person at a time access to the back of the instruments (Figure 5-2). Overhead service carriers for split lab benches can provide safety and flexibility because they bring cables and gas lines overhead instead of on the bench and floor. Additional bench space beside each instrument may be needed for sample preparation and loading to each piece of equipment. For bench top equipment, clearance for lifting covers or lids must be provided by carefully locating the equipment or removing shelving that may interfere with the ability to lift the covers. Services should be cleanable and easily wiped down. Alternatively, instrument racks (mobile or fixed) can be separated for access. When compressed gas cylinders are mounted in the service aisles, separation must increase between benches to allow safe access around cylinders.



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5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
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7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 5-2. General or analytical chemistry laboratory layout with split benches.

Because most analytical instruments have interfaces with computers and printers, adequate areas should be provided for these devices. Fixed and mobile instrument racks can be designed for safe and efficient arrangement of peripheral devices as well as chemical supply and waste containers. Racks allow vertical storage of these components and afford greater floor area efficiency.

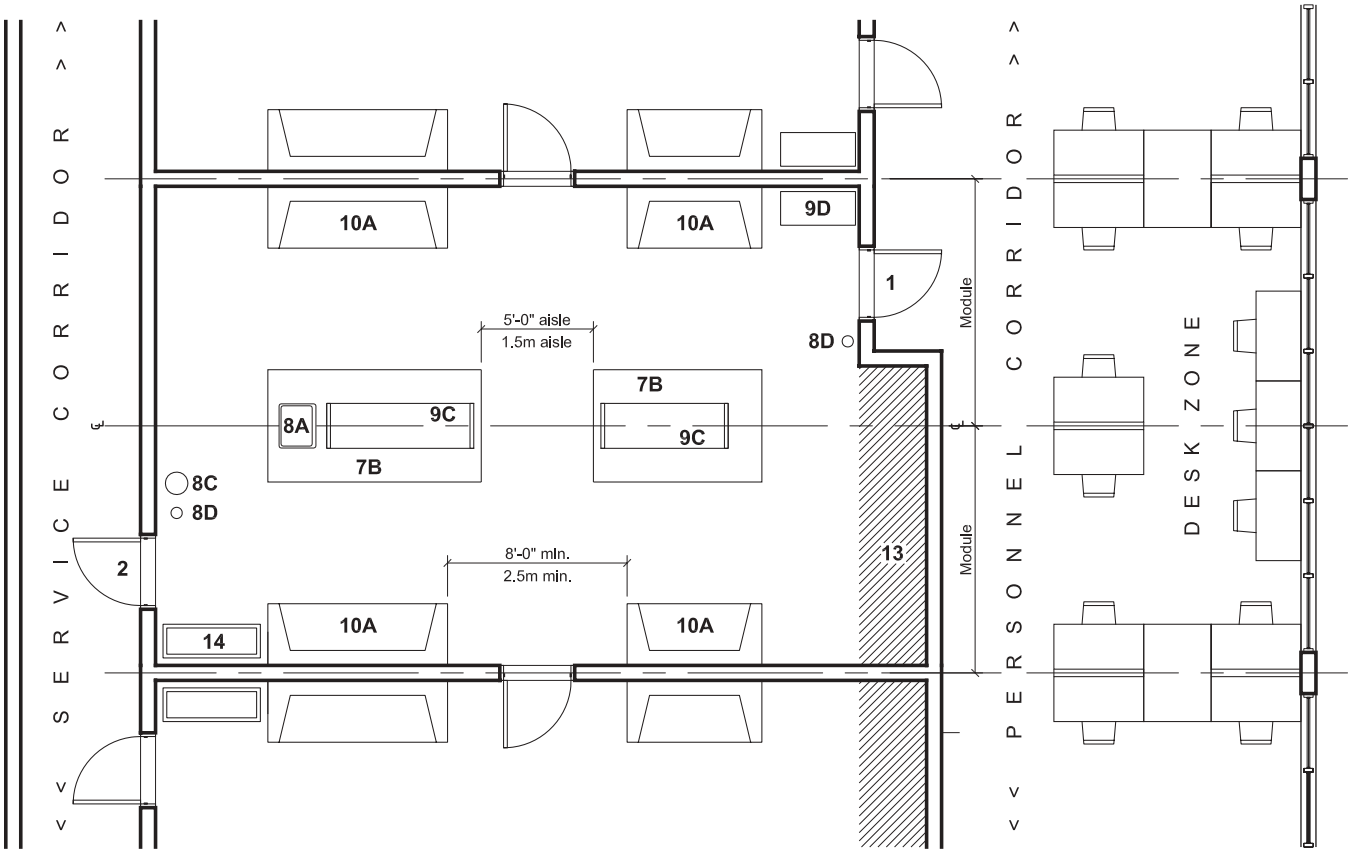
Floor-mounted instruments also need adequate clearances for connections to ancillary equipment and controls, and for servicing. Required clearances are shown in installation and service manuals that manufacturers provide with their instruments. Safety and industrial hygiene personnel should be consulted for assistance with special problems of hazardous chemical handling, magnetic fields, and laboratory ventilation. A suggested layout for a general or analytical chemistry laboratory is provided in Figures 5-1A and 1B. Figure 5-3 shows a chemistry facility where the desk stations for computer work are located outside the laboratories. Other layout options are shown in Figure 5-4. All items described in Sections 1.2 and 2.2 should be reviewed, and those that are relevant should be implemented.

Underfloor distribution of utilities by either a raised floor or utility trenches is not recommended because of the potential for spills of hazardous materials and the resultant collection of materials in these hard-to-access areas.

5.3 HEATING, VENTILATING, AND AIR-CONDITIONING

5.3.1 Introduction

All the items described in Chapter 1, Section 1.3 and Chapter 2, Section 2.3 should be reviewed, and those that are relevant should be implemented.



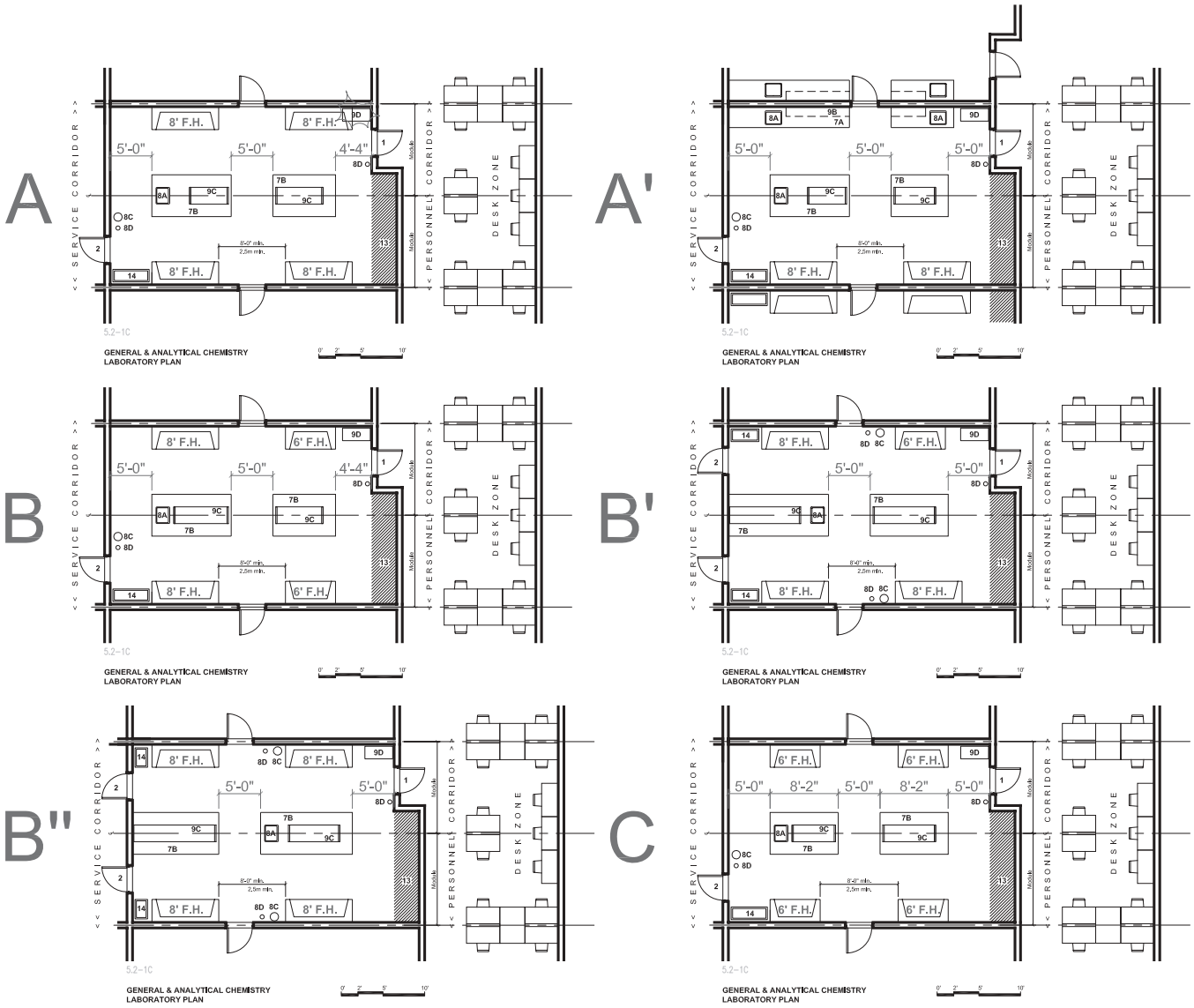
KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 5-3. General or analytical chemistry laboratory layout with office zone outside lab.

5.3.2 Additional HVAC Needs

Special consideration should be given to providing good coverage of the laboratory with local exhaust systems. The effluent gases from some analytical devices, such as gas chromatographs and atomic absorption spectrometers, often contain toxic chemicals that need to be controlled at the source of generation by being vented to the outdoors. In some cases, instrument manufacturers provide recommendations specific to their instruments. Otherwise, the *Industrial Ventilation Manual* (American Conference of Governmental Industrial Hygienists [ACGIH], 2010a) or a qualified industrial hygienist should be consulted for advice. Chapter 31, Air Cleaning, provides some examples of local exhaust ventilation that may be used for some equipment. If perchloric acid use is anticipated, the safety measures described in Chapter 2, Section 2.3.4.4.3 should be implemented.



KEY

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7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 5-4. Variety of layouts for general or analytical chemistry use.

Because of the density of heat-producing sources in analytical chemistry laboratories each of the analytical instruments and auxiliary equipment should be evaluated when estimating heating and air-conditioning requirements.

5.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

5.4.1 Introduction

All of the items described in Chapter 1, Section 1.4 and Chapter 2, Section 2.4 should be evaluated for their applicability to the specific analytical laboratory under consideration; particular attention should be given to the location of analytical equipment in relation to egress routes and interaction with other equipment or chemical handling operations. Safety and industrial hygiene personnel should be consulted when additional advice is needed.

5.4.2 Electrical

Because high-voltage equipment is often installed in analytical chemistry laboratories, individual breaker boxes and emergency shut-off switches to equipment should be located beside and near equipment, but within reach of all workers. Adequate space should be planned between equipment for staff to gain access to breakers for equipment service and cleaning. Breakers should not be located behind equipment because they are then too difficult to reach.

5.5 SPECIAL REQUIREMENTS

5.5.1 Security

The use of high-value instruments or materials in the general chemistry or analytical laboratory may require the material or equipment be secured and the laboratory provided with access control. See security considerations discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1.

5.5.2 Hazardous Materials

Should it become necessary to introduce highly toxic or reactive materials in more than trace quantities, laboratory modifications to accommodate them will be needed. See for example, Chapter 6, High-Toxicity Laboratory, and Chapter 9, Pilot Plant: Chemical, Engineering, and Biological, for additional information on design features that will enhance handling this material.

5.5.3 Renovations

When renovating these laboratories, all requirements in Chapters 3 and 4 should be reviewed for applicability. In particular, special procedures may be needed for decontaminating analytical equipment before they are moved.

6

HIGH-TOXICITY LABORATORY

6.1 DESCRIPTION

6.1.1 Introduction

A high-toxicity laboratory is designed and operated to provide safe use of highly toxic chemicals, including carcinogens, mutagens, and teratogens and chemicals of unknown toxicity. Because quantity and handling procedures are important in determining the characterization of the lab, select agents (toxins) below specified quantities may also be used in the laboratory (U.S. Department of Health and Human Services [HHS], 2009). Industrial hygiene and safety personnel should be consulted for assistance in determining whether the nature and quantity of chemicals that will be used in a proposed laboratory fall into this category. In January 1990, the Occupational Safety and Health Administration (OSHA) promulgated 29 CFR 1910.1450, a standard regulating exposure to chemicals in laboratories (OSHA, 2012). "Particularly hazardous chemicals," defined in this standard, may require special handling procedures or design features, although not all chemicals that meet the definition of particularly hazardous must always be used in a high-toxicity laboratory. The decision depends on amounts and manner of use. Many chemicals used in a high-toxicity laboratory will meet the OSHA definition of particularly hazardous. Sources of assistance to determine whether the quantity of hazardous materials used will require a laboratory designation of high toxicity include local OSHA and NIOSH offices and state departments of occupational health and industrial hygiene. The National Institutes of Health (NIH) periodically publishes a "suspected carcinogens" listing and an internal guideline document entitled "Guideline for the Laboratory Use of Chemical Carcinogens" (NIH, 1981) that provides specific information on carcinogens. Prudent Practices (National Research Council [NRC], 2011) can also provide assistance in determining requirements for highly toxic materials. Another source is the Business & Legal Resources' (BLR's) *Book of Lists* (BLR, 2012), which provides lists of chemicals that are covered by a variety of regulations including those that meet the OSHA definition of "particularly hazardous chemicals." Not all of the design considerations included in this chapter may be needed in every high-toxicity laboratory. Close communication between all involved in the planning process will be necessary to determine specific requirements.

6.1.2 Work Activities

The basic experimental procedures used in high-toxicity laboratories are similar to those conducted in general chemistry and analytical chemistry laboratories, but provisions should be made for the additional safety procedures that will be required when highly toxic chemicals are handled in significant (more than microgram) quantities. Although this section describes a laboratory

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that is similar to a general chemistry laboratory (Chapter 5), the design and operation of the safety provisions will be much more critical. The safety guidelines outlined here can be applied to other laboratory types, such as chemical engineering and physics laboratories, whenever they use highly toxic materials in quantities that do not exclude their use in such laboratories.

6.1.3 Equipment and Materials Used

The equipment used in a high-toxicity laboratory will vary depending on the nature of the work; in general, the equipment will be similar to that found in a general chemistry, organic chemistry, or analytical chemistry laboratory. Many of the chemicals used in this laboratory will fall into the category of "particularly hazardous" as defined by OSHA (2012) in 29 CFR 1910.1450 (e)(3)(viii). They include "select carcinogens, reproductive toxins, and substances having a high degree of toxicity." Select carcinogens include (1) chemicals regulated by OSHA as carcinogens, (2) chemicals listed as "known carcinogens" by the National Toxicology Program of the NIH (latest edition of the "Annual Report on Carcinogens"), (3) Group 1 chemicals (carcinogenic to humans) listed by the International Agency for Research on Cancer (IARC), and (4) chemicals causing a statistically significant tumor incidence in experimental animals as defined in 29 CFR 1910.1450 (b). There is considerable overlap of chemicals in the four lists, but they are not identical.

6.1.4 Exclusions

Excluded from this chapter are the use of ionizing radiation, biological agents, and animals. Their use with high-toxicity chemicals requires additional design features that are addressed in Chapters 13, 14, and 22, respectively.

6.1.5 Special Requirements

The nature of the materials used makes it necessary for the high-toxicity laboratory to have special access restrictions. OSHA (2012) has stringent requirements that must be followed for specific chemicals. More recent OSHA regulations must be consulted to determine whether important changes have been promulgated since the cited edition (www.osha.gov). In some cases, provisions must be made for change rooms and showers. Industrial hygiene and safety personnel should be consulted for advice when high-toxicity laboratories are to be built or when existing laboratories are to be converted to this use.

6.2 LABORATORY LAYOUT

6.2.1 Introduction

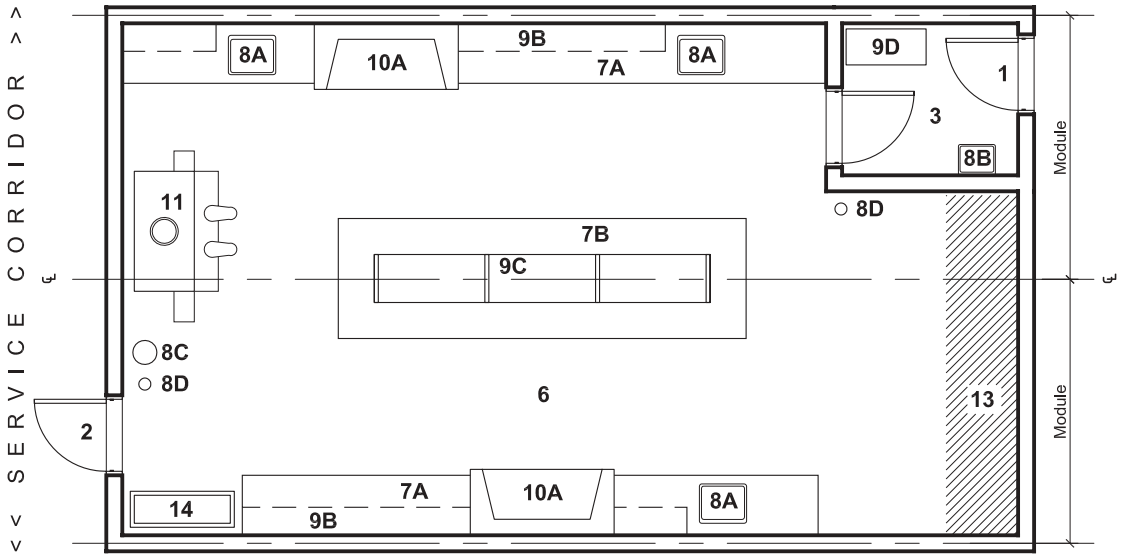
Many types of laboratory layouts are possible, depending on the specific nature of the work to be performed and the space available. A layout similar to that of a general or analytical chemistry laboratory (Chapter 5, Figure 5-1) is often adequate. A simple anteroom can be added, as shown in Figure 6-1A, if additional security and/or differential airflows are required upon entry into a high toxicity laboratory. Specific work space utilization layouts are described in *Safe Handling of Chemical Carcinogens, Mutagens, Teratogens, and Highly Toxic Substances* (Walters, 1980). Using the NIH, Walters, or OSHA reference source as a starting point, all the recommendations for safety and health contained in Part I should be reviewed, and those that are relevant should be implemented. In addition, the following items should be considered for their applicability to the laboratory work to be performed. Industrial hygiene and safety personnel, as well as appropriate state and federal agencies, may have to be consulted early in the planning phase because adoption of some of the recommendations contained in Part I may depend on the specific nature and quantity of the chemicals to be used in relation to applicable regulations for their use and safe disposal.

6.2.2 Change, Decontamination, and Shower Rooms

Adequate facilities must be provided for laboratory workers to change and shower when procedural requirements for working with highly toxic materials necessitate the use of frequent changes of protective clothing. Some OSHA requirements specify that a shower must be included as an essential part of a high-toxicity laboratory when certain toxic materials are used. Use of other toxic materials requires merely the availability of a shower in the building. Traffic flow into change and shower rooms should be designed so that there are separate clean and dirty pathways to and from the facility and there is no way to bypass the shower on the way out of the high-toxicity laboratory, as shown in Figure 6-1B. (See Anterooms in Chapters 1 and 2, Section 2, and Chapter 14, Biosafety Laboratory, for more information on this topic.)

6.2.3 Work Surfaces

Work surfaces should be constructed from impervious and easily cleanable materials such as stainless steel that contain a minimum of joints in the surface. Strippable,



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 6-1A. High-toxicity laboratory layout with anteroom or airlock entry.

epoxy-type paint is acceptable on walls and ceilings when the material on which it is applied is sufficiently solid that it experiences little to no deflection in use and protects the epoxy from cracking. Use of disposable bench coverings during work should be considered an added safety practice.

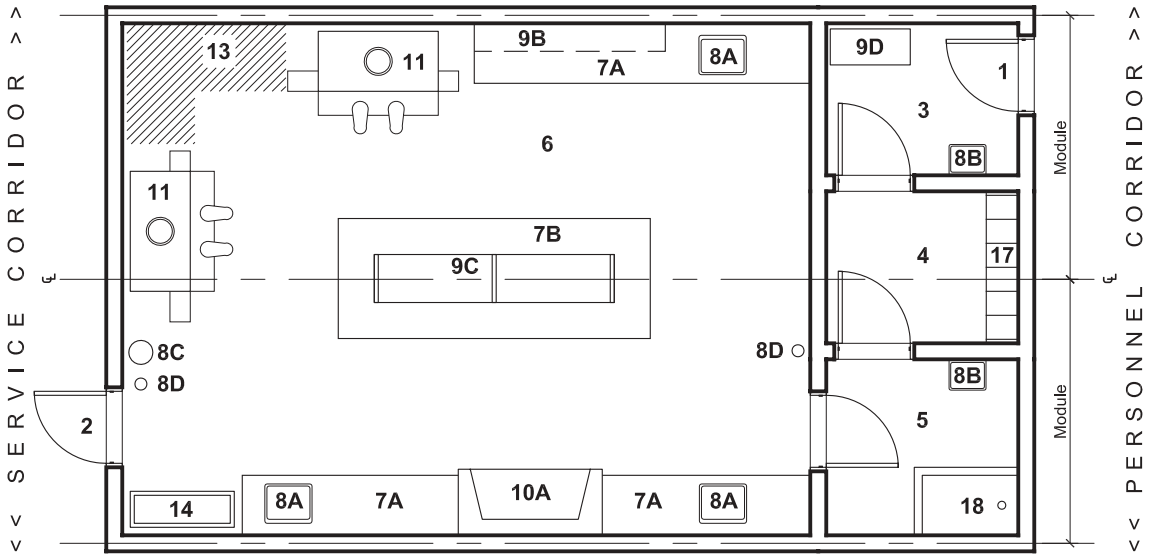
6.2.4 Floors, Walls, and Ceilings

Floor coverings should be of monolithic (seamless) construction and utilize materials such as solid vinyl or troweled epoxy, both of which are impervious to most chemicals and easily formed into seamless sheets that can be extended up the wall to form an integral cove base. All cracks and construction seams in floors, walls, and ceilings should be sealed with epoxy or another chemically resistant, long-lived sealant. Utility conduits should be epoxy sealed wherever they penetrate floors, ceilings, and walls. All laboratory lighting should be sealed with similar materials to be vapor- and water-proof. Ceiling surfaces should be solid and imperious, not suspended tiles or panels. Walls should be extended and sealed to the underside of the structure. Access may be needed to this space for utility control valves or other equipment. Access requirements should be kept to the minimum possible by locating these devices outside the laboratory.

Manufactured panels with baked enamel surfaces with sealed and gasketed joints may be considered for use in high-toxicity labs. See discussion of laboratory materials in Chapter 2, Section 2.

6.2.5 Hand-Washing Facilities

Readily accessible hand-washing facilities should be located within the high-toxicity laboratory, as well as in



KEY

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7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 6-1B. High-toxicity laboratory layout with change room and shower-out.

change and shower rooms. Foot-operated or automatic infrared controls should be considered.

6.2.6 Access Restrictions

All entrances to a high-toxicity laboratory should be posted with permanent signs indicating restricted access due to the use of specific classes of chemicals (e.g., carcinogens, mutagens). The use of special key access should also be considered when a security breach is liable to result in serious illness or dispersal of high-toxicity materials outside of the laboratory.

The tightly closed doors used to isolate the laboratory should have viewing windows. Consider designing these laboratories with a ventilated anteroom entry to contain airborne toxins and provide additional security device and detection equipment.

6.3 HEATING, VENTILATING, AND AIR-CONDITIONING

6.3.1 Introduction

All of the items described in Chapter 2, Section 2.3 should be reviewed, and those that are relevant should be implemented. Additional recommendations are given below. Industrial hygiene personnel should be consulted for assistance when safety and health situations not covered in this book are encountered.

6.3.2 Laboratory Fume Hood

An average face velocity of 80 to 100 fpm is recommended. We do not recommend that it be increased to 150 fpm as an added safety feature for work with highly

toxic materials. Several investigators have indicated that higher face velocity (above 125 fpm) does not necessarily provide added protection, but might produce disruptive turbulence effects (Chamberlin, 1978; DiBerardinis, 1991; Maupins, 1998; Ivany, 1989; Smith, 2009). However, in some cases the American Conference of Governmental Industrial Hygienists (ACGIH), the U.S. Department of Energy, and National Institute for Occupational Safety and Health (NIOSH) recommend a higher exhaust velocity; hence, all current and applicable local, state, and federal codes and regulations should be followed regardless of our recommendation.

6.3.3 Glovebox

Some highly toxic materials require the use of a completely enclosed, exhaust-ventilated work space rather than a conventional laboratory fume hood. In these instances, a glovebox is required. It should meet the specifications defined by the ACGIH (2010), as outlined in Chapter 31, Air Cleaning. Additional guidance on glovebox selection can be found in ANSI Z9.5 (ANSI/AIHA, 2012) and in the American Glovebox Society Standard, "Guidelines for Gloveboxes" (AGS, 2007). Gloveboxes should be maintained as a closed system at all times and kept under a negative pressure of 0.25 in. W (60 Pa). It is recommended that properties filtration (e.g., HEPA or charcoal) be provided on the air inlet and outlet. They should be thoroughly decontaminated or encased before exhaust airflow is shut down, to avoid loss of toxic contents into the laboratory.

6.3.4 Spot Exhaust for Instruments

Instruments used to weigh, manipulate, and analyze highly toxic chemicals should have spot exhaust ventilation at each potential source of contaminant release or be completely and permanently enclosed in an exhaust-ventilated enclosure. Specific design requirements will vary with each type of equipment and chemical used. Consultation with the manufacturer of the equipment and an industrial hygiene engineer is recommended when the design and application of exhaust ventilation facilities is not built into the equipment or obvious. See Chapter 32, Section 32.10 for more details.

6.3.5 Ventilation for Storage Facilities

All facilities used for storage of highly toxic materials, such as cabinets and refrigerators, should be provided with exhaust ventilation to maintain inward air flow and prevent buildup of a toxic contaminant concentration within the storage space. Slot ventilation around refrigerator doors can be very effective. Storage cabinets can be provided with exhaust ventilation to maintain negative pressure within the cabinet. These can be used for small quantities of volatile materials.

6.3.6 Filtration of Exhaust Air

The air exhausted from fume hoods, gloveboxes, and spot exhaust hoses should be decontaminated before release to the environment. The first cleaning stage should be a HEPA filter with a minimum efficiency of 99.97% for 0.3-μm particles when toxic aerosols are present. The second stage should be an activated charcoal adsorber when toxic vapors are present. The size will depend on the total quantity of air flow. All replaceable components should be capable of being changed without exposure of maintenance personnel (e.g., bag-in, bag-out procedures). For some chemicals, an adsorbent other than activated charcoal may be necessary or more desirable. In case of doubt, an industrial hygienist should be consulted. Note that filtration of selected agents should be carefully analyzed. HEPA filters and carbon absorbers have different efficiencies and capacities for different materials. Air cleaning is the subject of Chapter 31.

6.3.7 Directional Airflow

A high-toxicity laboratory is a containment laboratory, and air infiltration should always flow from uncontaminated to contaminated areas, that is, from corridors to change and decontamination rooms and, finally, to the high-toxicity laboratory itself. Flow direction should be monitored by differential pressure sensors equipped with audible and visual alarms to warn of upset conditions.

6.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

6.4.1 Introduction

All the recommendations described in Chapter 2, Section 2.4 should be reviewed, and those that are relevant should be implemented.

6.4.2 Protection of Laboratory Vacuum Systems

Laboratory vacuum systems should be protected from contamination by installation of traps containing disposable HEPA filters and activated charcoal or chemical-specific adsorbent systems as needed.

6.4.3 Security

It is recommended that chemical storage areas for high toxicity laboratories have restricted access and locks. Security is discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1. For select agents (toxins) above the threshold quantities defined (HHS, 2009) additional security requirements will be required. This includes street access control and security of the agents. Operational requirements are very specific. The HHS regulation should be reviewed carefully for both design and operations requirements.

6.5 SPECIAL REQUIREMENTS

6.5.1 Renovations

All the recommendations in Chapters 3 and 4 should be reviewed for their applicability and implementation when appropriate. In particular, careful attention should be devoted to decontaminating all potentially contaminated surfaces because it will be necessary to remove all residual, acutely toxic materials that may have been used in the laboratory.

7

NANOTECHNOLOGY LABORATORIES

7.1 DESCRIPTION

Nanostructures are being used worldwide to create countless new technologies. They are being incorporated in transistors, solar cells, biomaterials, hydride advanced composites, cosmetics, and pharmacological delivery methods. Nanoscale materials are of great interest because some of the toxicological properties of the parent materials change as the particle size decreases from centimeters and micrometers to nanometers.

The ASTM Committee on Nanotechnology (ASTM, 2006) has defined a nanoparticle as a particle with lengths in two or three dimensions between 1 and 100 nanometers (nm) that may or may not have size-related intensive properties. Nanoparticles can be composed of many different base materials (carbon, silicon, and metals, such as gold, cadmium, and selenium). Nanoparticles can also have different shapes: They can be nanotubes, nanowires, nanofibers, nanospheres, and nanopowders. They can also be crystalline structures such as quantum dots and fullerenes. Table 7-1 lists some of the more common nanoparticles and their uses.

Nanoparticles often exhibit very different physical properties from their respective larger micron-sized materials: greater strength, conductivity, and fluorescence, among other properties. Many more of the atoms in nanoparticles are on the surface, resulting in greater chemical reactivity than bulk materials. Table 7-2 shows how the number of particles and surface area of the particles dramatically increases for the same mass as the particle diameters decrease from the micro to the nano scale.

Their health effects are also in question relative to what is known about them at larger particle sizes. Carbon nanotubes in particular are showing early signs of being much more toxic than the parent bulk material. Some others show unusually high reactivity and create a concern for fire and explosion hazards. Many biological materials (infectious agents, bacteria, etc.) may also be in the nanoscale size. The considerations in provided in Chapter 14, Biosafety Laboratory, should be followed to provide for safe design.

7.1.1 Work Activities

The type of work performed in nanotechnology laboratories is dependent on the basic type of research which varies greatly. These laboratory types may be similar to high toxicity, biology, engineering, team research, pilot plant, microelectronics, or general and analytical chemistry laboratories. Materials of nanoparticle size also may be used in animal studies. The major distinction is the types of systems and matrices in which the nanoparticles are used. Typical equipment and processes used in nanoparticle research are listed in Table 7-3.

7.2 LABORATORY LAYOUT

There are no special requirements beyond those already identified in the type laboratory noted above, e.g., a biology laboratory working with nanoparticles will have a laboratory layout similar to a biology-type laboratory.

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TABLE 7-1. Types of Nanoparticles and Their Uses

Name	Components	Use
Quantum dots	Cadmium, selenium	Immunostaining as alternatives to fluorescent dyes; sunscreens, cosmetics
	Metals; metal oxides such as titanium dioxide	
Carbon nanotubes – Single wall – Multiwall	Carbon	Great tensile strength and are potentially the strongest, smallest fibers known. Used in materials science studies; protective clothing
Fullerenes	Carbon	Medical applications
Graphene	Carbon	Industrial coatings; fuel cells

TABLE 7-2. Particle Number and Particle Surface Area for 10 μg/m³ Airborne Particles

Particle Diameter (μm)	Particles/mL of Air	Particle Surface Area (μm²/mL of Air
2	2	30
0.5	153	120
0.02	2,390,000	3000

TABLE 7-3. Types of Equipment or Processes Used in Nanoparticle (NP) Research

Equipment	Engineering Control
Weighing station	Use in specially designed enclosures or gloveboxes
Furnaces growing NP	Use in fume hood or other enclosure
Manipulation or transfer of dry NP	Gloveboxes or fume hoods
Reactors for synthesis	Specially designed enclosures, gloveboxes, or use of local exhaust at points of potential release
Vapor deposition equipment	Specially designed enclosures, gloveboxes or use of local exhaust at points of potential release
Electrospinning	

Some of the analytical equipment or tools may be unique and have some special HVAC and structural requirements.

Easily cleanable nonporous surfaces should be specified.

7.3 HEATING, VENTILATING, AND AIR-CONDITIONING

Operations involving easily dispersed "dry" nanoparticles require more stringent controls than those embedded in solid or liquid matrices. Many nanoparticles are synthesized in enclosed reactors or gloveboxes. These enclosures are maintained under vacuum or exhaust ventilation.

Processing of materials removed from reactors should be done in fume hoods, Class I hoods, gloveboxes, or Class II Type A and Type B biosafety cabinets. The choice of enclosure will depend on the need to minimize the velocity of air within the workspace. Air velocities within the standard chemical fume hood or biological safety cabinet may disrupt the handling of fine powders. In this situation, full enclosures with low airflow might be needed. Note that preliminary research has shown that particles can escape from conventional fume hoods (Tsai, 2010). The need for HEPA filtration should be determined on a case by case basis. Note some health and safety agencies are recommending HEPA filtration be used for all processes generating engineered nanoparticles (HSE, 2009). For trivial amounts of materials, filtration may not be required. A risk assessment should be performed and local regulations reviewed to determine requirements.

For equipment or processes too large to be used in a fume hood, local exhaust ventilation or capture hoods should be used to capture particles at potential emission points. Examples of this are weighing stations (See Chapter 32) and furnaces (see Figure 7-1) used to grow carbon nanotubes. Figure 7-2 shows a photo of nanotubes. Specially designed enclosures can also be designed for specific operations, see Figures 7-3 and 7-4. Canopy hoods and other types of exterior hoods are not usually as effective as enclosures and should only be selected when use of enclosures is not possible. The exhaust air from equipment or processes that aerosolize nanoparticles should be HEPA filtered. Examples of this include weighing stations, furnaces, and gloveboxes. Do not use horizontal laminar flow hoods (clean benches) that direct flow of HEPA-filtered air through the enclosure

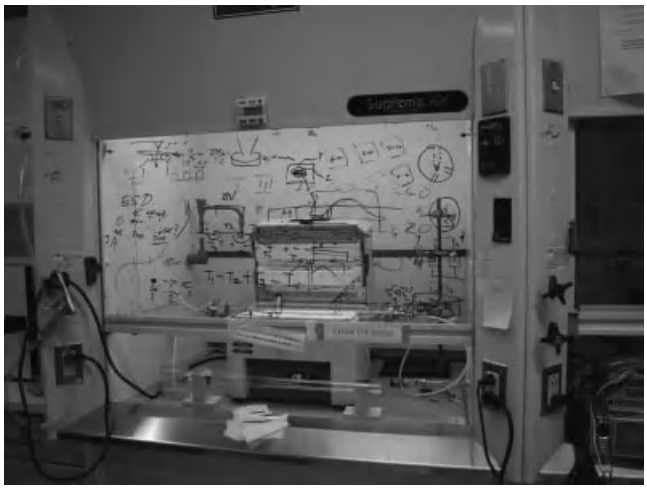


FIGURE 7-1. View of furnace used to grow carbon nanotubes in chemical hood.

FIGURE 7-2. Carbon nanotubes grown on a substrate.

into the user's face. For additional information, refer to Chapter 31, Air Cleaning, and Section 3 in Chapters 1 and 2 are also applicable.

7.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

Because nanoparticles have a very large surface area relative to their mass, they have much higher reactivity. Some nanomaterials may initiate catalytic reactions that would not otherwise be anticipated from their chemical composition. Fires and explosions are potential hazards when large quantities of dust are generated during reactions or production. This is more of a concern when reactions are scaled up to pilot plant or production

FIGURE 7-3. Example of a standard-sized enclosure hood used to control nanoparticles.

FIGURE 7-4. Example of a large enclosure hood used to control nanoparticles.

levels and there is a potential for aerosolizing or release of the nanoparticles. Nanodusts can be anticipated to have greater potential for explosivity than larger particles because of the larger surface area to mass ratio (see Table 7-2). The ability of nanoparticles to become electrostatically charged presents a unique hazard because they potentially can become their own ignition source when dispersed into the air. In situations with this

potential, the following safety considerations should be given special attention:

1. Grounding and bonding of equipment
2. Fire suppression inside process equipment or enclosures where nanoparticles may be aerosolized in large quantities

Best practices calls for use in closed systems where practicable or handling of nanoparticles in solution, thereby minimizing the potential for aerosolization. Section 4 in Chapters 1 and 2 are applicable.

7.5.1 Environmental Considerations

Nanoparticles are treated as hazardous waste when they are ready for discard. Solidifying the nanoparticles as hazardous waste might trigger EPA regulations as a transport, storage, and disposal facility and they should be reviewed carefully.

There may be potential air emissions. The need for air cleaning has been discussed in the HVAC Section 7.3 above.

Waste water disposal should be evaluated. Waste water containing nanoparticles cannot go into drains that lead to sewers. They must either be collected as hazardous waste or filtered before discharge.

7.5.2 Decommissioning

All of the recommendations on decommissioning in Part 1, Section B should be reviewed for applicability. Because nanoparticles may accumulate in equipment or exhaust systems upstream of any filtration, the need for decontamination before any renovation or demolition must be carefully evaluated.

8

ENGINEERING LABORATORIES

8.1 DESCRIPTION

8.1.1 Introduction

This chapter deals with the safe design of a group of laboratories classified as engineering laboratories. An engineering laboratory may refer to a part of an educational institution where engineering principles are taught, demonstrated, and researched, or to industrial facilities focused on a wide range of engineering activities—from research or design—to implementation or construction.

8.1.2 Exceptions

However, engineering laboratories associated with industry, such as manufacturing, quality control, or product testing are not included in this chapter. Some of these laboratory types have their health and safety design needs discussed in other chapters—some in more than one chapter. Only those laboratories associated with teaching or research in academic settings are discussed here, although design principles found in industrial laboratories may apply and be useful.

Hazards associated with laboratories are generally perceived and managed on a more advanced level by experienced researchers than by undergraduate engineering students, who are generally younger and less experienced. Hence, it is important to design diligently to reduce or eliminate, where possible, hazards in academic engineering laboratories.

The types of laboratories that are discussed here are generally associated with one or more of the engineering disciplines. Students of one engineering discipline are frequently required to use laboratories of more than one type. However, this is not often the case with university-level laboratories doing research in engineering. In this chapter, the laboratory type is grouped under the most appropriate engineering discipline first.

8.2 ENGINEERING DISCIPLINES AND SOME OF THEIR MOST COMMON LABORATORY TYPES

Engineering disciplines and their corresponding laboratory types are

Aeronautical Engineering

A. Wind Tunnel Laboratory
B. Jet and Rocket Propulsion Laboratory

Civil Engineering

C. Hydraulics Laboratory
D. Material Analysis and Testing Laboratory

Electrical Engineering

E. Electrical Circuits, Motors, and Generator Laboratory

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

Mechanical Engineering

F. Foundry Laboratory
G. Internal Combustion and Gas Turbine Engine Laboratory

Chemical engineering, though not discussed in this chapter, is also an important engineering discipline with laboratories whose safe design considerations are covered in Chapter 9, Pilot Plant: Chemical, Engineering, and Biological, and in several other chapters.

Engineering laboratories are found in vocational high schools, engineering and technical colleges and universities, commercial and industrial manufacturing facilities, government and private research and development institutions and organizations, and national testing laboratories.

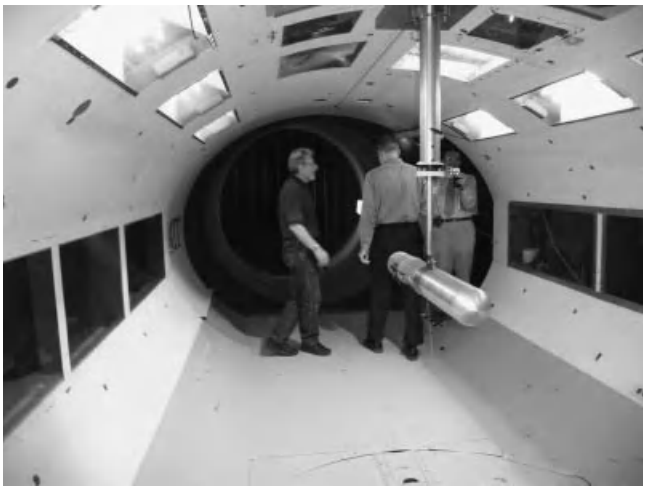


FIGURE 8-1. View of wind tunnel during set-up process.

8.3 WIND TUNNEL LABORATORY

8.3.1 Introduction

The design considerations for safe wind tunnels include laboratories that are small, compact, and placed in a mixed use area along with larger, even stand-alone facilities that are unique to their purpose. Size can vary from small bench-top experimentation to large-scale research.

For additional information relevant to these laboratories, see also Section 4 of Chapters 1, 2, 9, 10, and 26.

8.3.1.1. Work Activities. Wind tunnels are typically used to observe the effects of gases or air at varying velocities on objects placed in the test areas of the tunnels. Some tunnels used for relatively low-velocity testing may range in diameter or width and height of up to 10 or more feet (3.05 m); however, some multi-Mach high-velocity tunnels may be only a few inches in diameter or cross section. The term "Mach" is defined as the speed of an object divided by the speed of sound in the fluid through which the object is passing. Another type of tunnel is the recirculating gas tunnel, where the gas is collected and reused for reasons of economy and ecology. Many, if not most tunnels require substantial space with additional space for control rooms. Some tunnels are capable of sustained velocities, whereas others are only capable of short bursts of high-velocity gases. Some high Mach-velocity tunnels operate by having air or other gas rush past the test target and into a large vacuum chamber.

In-use test observation techniques may include direct visualization through windows into the wind tunnel or the use of closed-circuit TV cameras, as well as electronic and thermal instrumentation and other pressure and sound measuring equipment within the tunnel or tunnel enclosure area.

Personnel usually set up tests by entering the tunnel test area of large wind tunnels; in the case of smaller tunnels, by placing the test object in its proper test zone (Figure 8-1). They then attach instrumentation, secure the test area and run the test, followed by any necessary cleanup. Collected test data is then analyzed.

The hazards of operating these devices include accidental startup, catastrophic release of the sample or destruction of the model being tested, accidental release to the atmosphere of toxic or reactive test gasses, high noise levels, and catastrophic loss of air or gas pressurizing equipment that results in flying debris and unanticipated ignition of the test sample. Control rooms and observation areas should therefore be physically remote or otherwise protected from operating hazards. Risks can be reduced through consideration at the time of design.

8.3.1.2 Access Restrictions. Wind tunnels, high-velocity or high-volume low velocity, need to have perimeter control to keep unauthorized persons away during times of operation or risk. Thus, it is necessary to provide access system interlocks to ensure that no persons are in a test area at the time of startup or test initiation.

Larger tunnels that permit personnel entry into the tunnel must have entrance walkways and stairs, doors of standard proportions and size, and operational interlocks. High-velocity tunnels frequently require physical safety barriers between the sample or target zone and the tunnel operators to preclude errant flying missiles from causing personnel injuries.

8.3.1.3 Equipment and Materials Used. Equipment to supply the test air or gases can involve large fan systems, high-pressure–high-volume compressors, large vacuum pumps, and large storage tanks. In other experiment setups, banks of compressed gases may be employed. Some of these gas supply systems will consume large amounts of electrical energy.

High-velocity tunnel systems need to be fabricated from high-pressure tunnel material, usually in the form of thick steel or stainless steel piping or tubing. Target or test areas may become extremely hot during test runs. Test materials vary according to the research being done and could include a wide variety of materials including solid and liquid chemicals. Some test materials could spontaneously ignite due to frictional heat depending on the amount and makeup of the material being tested.

Some chemicals and solvents may be used for the experiment's setup and post-experiment cleanup. Space for the safe storage of these chemicals should be provided.

8.3.2 Layout

For large, low-velocity, walk-in wind tunnel laboratories, give careful consideration to the facility location relative to adjacent buildings or spaces because these laboratories can be very noisy, and the discharge air or gas may be of such volume as to create problems for other building ventilation systems. Determine the need for sound abatement of noisy exhaust discharge. The wind tunnels, where practical, should be located adjacent to rooms where the operational controls are placed. Doors leading into the tunnel, or tunnel area, directly from the control room would provide the additional safety feature of observation by others in the room. Large, low-velocity tunnels may be installed exterior to the building. In this case the control room is protected by exterior wall construction. Small bore, high-velocity tunnels may be very long, up to 50 ft. Large compressors, vacuum pumps, and gas containers are best placed indoors or outdoors in warm climates, but not placed in the room where the experimentation takes place. Where large recirculating gas tunnels are to be used, both the delivery gas- and receiver gas-holding containers should be housed in rooms outside the control room and the test target room.

Carefully plan the path of egress pathways from the laboratory around each tunnel. Two exits are required from laboratories over 500 ft^2 (46.5 m^2); laboratory personnel must be able to move from any part of the lab toward both exits. In addition to wind tunnels, it is prudent to carefully plan the locations of overhead cranes and hoists, so that laboratory exits cannot be inadvertently blocked. A personal protective equipment storage and dispensing area should be located in the laboratory entry zone.

8.3.3 Heating, Ventilating, and Air-Conditioning

Normal building occupant air quality, air quantity, and comfort conditions should be provided. Local exhaust for some high-velocity target area tests may be needed to remove heat and toxic or noxious gases from the opened test chamber. Discharge air or gas may be of such high volume that it could create problems for adjacent building ventilation systems.

If an accidental release of a large quantity of highly flammable or toxic gas into the test room or control room may occur, an emergency ventilation system should be designed. The design calculations should consider the relative weight of the gas and the highest possible rate of release into the room.

In addition to the above HVAC information, all the items described in Chapters 1 and 2, Sections 3, and Chapter 9, Section 9.3.2 should be evaluated and implemented where applicable.

8.3.4 Loss Prevention and Personnel Safety

In addition to the issues mentioned above, all of the items described in Chapters 1 and 2, Sections 4; and Chapter 9, Sections 9.4.1 and 9.4.2, should be evaluated for relevance, and all that apply to wind tunnels should be implemented.

8.3.5 Special Requirements

Wind tunnels that are large enough for personnel entry may be considered "confined space" areas under OSHA regulations. In that case, special access requirements are necessary. Design to avoid the restrictions of the OSHA regulation where possible to ensure the tunnel is not a "confined space." Chapter 9, Sections 9.5.1 and 9.5.2 should be reviewed for applicability and implemented where necessary.

8.4 JET AND ROCKET PROPULSION LABORATORY

8.4.1 Introduction

Although few universities and research organizations perform experimentation with jet and rocket propulsion systems, those that do, face safety issues with more severe consequences resulting from any accident. This engineering laboratory is included to provide guidance to those organizations.

For additional information relevant to these laboratories, see also Section 4 of Chapters 1, 2, 9–12, and 26.

8.4.1.1 Work Activities. Activities in the jet and rocket propulsion laboratory include setup and testing of prototype propulsion systems. This can include the use of a static firing test stand or a test bench where the test device is coupled with equipment to measure thrust force, specific impulse, and exhaust gas composition. In most cases, tests would be started and run from a safe, remote location. Post test cleanup and equipment removal is a normal activity that may present risks associated with toxic byproducts of spent fuels and unconsumed explosive or flammable liquid or gaseous fuels.

8.4.1.2 Equipment and Materials Used. Materials used in this type of laboratory may include propulsion fuels such as aviation jet fuel and rocket fuels. Rocket fuels can include solid and liquid nitrates and a host of other highly reactive solids, liquids, and liquefied gases including rubber-based solids, petroleum-based liquids, and liquefied hydrogen.

Each of these materials and fuels has the potential for mishaps in the laboratory. Including plans for the handling and storage of these materials in the building design phase can reduce these risks. Fire protection and protection from flying debris are an important consideration in these laboratories and should not be overlooked.

Other materials used in propulsion laboratories include various classes of liquid and solid chemicals such as reagent acids, conventional flammable liquids, and air or water reactive metals and materials. These chemicals need well thought-out storage that allows for isolation from each other and protection from initiating sources, activities, or incompatible chemicals.

In addition to the chemicals discussed above will be the need for test benches, cradles, or harnesses to contain the devices as they are being tested or fired. Test data will be collected through data wiring and other electrical/electronic equipment along with tubing for pneumatic sampling and temperature recording.

8.4.2 Layout

The layout of the propulsion laboratory will vary according to the activities carried out within the laboratory and the sizes of experimental setups. For example, a laboratory that is used to test the specific impulse of a jet or rocket engine would be better located outside a normal laboratory building due to exhaust gases, flame, heat, noise, and potential for explosion or engine or rocket break-away. Design a separate building to withstand and contain these specific explosion and ballistic hazards, sufficiently away from other structures and with earth berms or other barriers to protect persons and property. Test engines or rockets need structurally secure test stands for vertical and horizontal testing. Locate test control rooms isolated from and protected from the normal hazards of the test, as well as any anticipated test accident.

Provide storage for chemicals and highly reactive materials in a safe and secure location. According to quantities of these materials required, this storage facility may also require some isolation from surrounding buildings and in a fire- and explosion-resistant structure, such as a bunker. Any high-explosive material storage must be in compliance with OSHA 29 CFR 1910.109, DOT 49 CFR Chapter 1 Parts 100 to 185 (CFR, 2012) and the U.S. Bureau of Alcohol, Tobacco and Firearms (ATF) 27 CFR Part 55 (CFR, 2012).

8.4.2.1 Access Restrictions. The propulsion test site needs to have perimeter control to keep unauthorized persons away during times of risk. System interlocks to ensure that no persons are in the test area at the time of start-up or test firing are helpful in accomplishing this requirement. Access cards with their associated fixed equipment may be helpful to maintain control of in-the-area personnel.

8.4.3 Heating, Ventilating, and Air-Conditioning

Ventilation in engine test areas would be applicable only if the tests are performed inside a walled building and an exhaust of toxic or noxious gas is generated. In such a case, local exhaust, if practical, would eliminate the problem. *The Industrial Ventilation: A Manual of Recommended Practice, 27th Edition* (American Conference of Governmental Industrial Hygienists [ACGIH], 2010) should be consulted for design guidelines for specific processes noted above.

For certain test exhausts, filtration of the exhaust gases may be necessary. To build an engine test facility that has not defined all the different fuels that it might use, it is recommended that the facility be designed to accommodate control of the most severe out-gassing. This includes both particulate and chemical filtration.

The HVAC recommendations contained in Chapters 1 and 2, Sections 3 and Chapter 9, Section 9.3.2 should be reviewed. Those found applicable should be implemented.

Ventilation for the control room areas would follow normal office requirements.

8.4.4 Loss Prevention and Personal Safety

All the requirements of Chapters 1 and 2, Section 4 should be reviewed and where relevant, should be implemented.

Due to the nature of testing of jet fuels and rocket fuels, special attention to fire protection should be addressed. Consider high-volume water or dry chemical deluge systems for the test areas. For storage areas, normal chemical storage protection as discussed in Chapter 2, Section 2.4 should be used.

8.4.5 Special Requirements

The use of highly reactive and explosive materials may require special building, use, and storage permits. Early communications with the local authority having jurisdiction is highly recommended. Consideration should also be given to Chapter 9, Sections 9.5.1 and 9.5.2.

8.5 HYDRAULICS LABORATORY

8.5.1 Introduction

Hydraulic laboratories are common in engineering schools, technical high schools, naval architectural and marine engineering schools, and other research and development organizations. The design considerations of these laboratories center on structural integrity and multifunctional use to produce a safe facility.

For additional information relevant to hydraulics laboratories, see also Section 4 below and Section 4 of Chapters 1, 2, and 9.

8.5.1.1 Work Activities. Work activities in the hydraulics laboratory may include hydraulic pressure experimentation, fluid flow measurement, fluid flow circuitry development, and model testing in water tanks.

8.5.1.2 Equipment and Materials Used. Water in large quantities, both static and flowing, is generally used for many types of experimentation in the hydraulics laboratory. Large water pipes, pumps, and turbines will be used in this laboratory. There may also be some chemicals used for testing water attributes, adding color, cleaning samples, and other general purposes.

8.5.2 Layout

(See Chapter 9, Section 9.2 for additional information.) The layout of the hydraulics laboratory will vary according to the activities conducted in the lab and size of equipment arrays required, including high-bay space for an overhead crane or hoists. School and university teaching laboratories will be more generalized and have a greater variety of activities and subsequent materials and equipment than those used for research only. Water tanks used for weir and flow experimentation require very long, yet narrow floor space, so be careful to plan egress pathways to laboratory exits so there will be no dead-end aisles or obstructions to egress. Structural engineers must design the floor structure to accommodate very heavy floor and wall loads in this laboratory. Floor drains are recommended to accommodate minor spills. Consider designing methods and controls for channeling water to a holding pond or tank inside the laboratory or outside the building in case there is a catastrophic failure of a tank or valves in the hydraulics lab. Consider how to protect adjacent labs and any rooms below hydraulic laboratories from flooding. A location for the proper storage of chemicals used in water testing should be provided.

8.5.3 Heating Ventilating, and Air-Conditioning

Normal heating, ventilating, and air-conditioning requirements are satisfactory when there are no unusual temperature or human consumption requirements. The typical hydraulics laboratory can be large, and humidity control may be necessary depending on the number and size of open water tanks. For additional information, see Sections 3 of Chapters 1 and 2.

High humidity conditions in hydraulic labs should be avoided as it may lead to condensation resulting in mold and mildew on building surfaces.

ASHRAE (*2011 Handbook; HVAC Application*, Chapter 4: Natatoriums) provides a method for calculating water evaporation rates for pools. The same equations can be used to calculate evaporation rates from large tanks.

8.5.4 Loss Prevention and Personal Safety

All the requirements of Sections 4 in Chapters 1 and 2 should be reviewed and where relevant, should be implemented. In addition, Sections 4 of Chapter 9, Pilot Plant: Chemical, Engineering, and Biological, Chapter 10, Physics Laboratory, and Chapter 16, Teaching Laboratory, should be reviewed for applicable information.

In areas of frequent wet flooring, high friction, nonslip flooring should be provided.

8.5.5 Special Requirements

Floor drains for normal or accidental release from water tanks and systems may need to be sized larger than normal. Such sizing should come from calculations made at the time of determining the quantities of water that the building or laboratory will have at maximum times. There has been at least one case where a hydraulics laboratory design failed to consider the weight of water in the laboratory pipes resulting in costly post-

construction structural changes to fix the problem. Structural strength of walls and ceilings to which pipes are attached should be calculated to withstand maximum loads. Consider Chapter 9, Sections 9.5.1 and 9.5.2 for applicability.

8.6 MATERIAL ANALYSIS AND TESTING LABORATORY

8.6.1 Introduction

The material analysis and testing laboratory discussed here can be found in mechanical engineering research and teaching as well as in chemistry and chemical engineering facilities. The use of very forceful test equipment and strong analytical chemicals calls for detailed planning to accomplish a safe laboratory environment.

For additional information relevant to these laboratories, see also Section 4 of Chapters 1, 2, 9, 10, and 16.

8.6.1.1 Work Activities. Activities in large-scale material analysis and testing laboratories include setting up and testing test specimens that can be quite large, such as a concrete beam to be tested for tensile or compressive strength. Other activities include the testing of smaller samples of materials for various characteristics such as hardness, friction coefficient, viscosity, combustibility, and tensile or compressive strength. Soil testing and analysis may also be carried out in the materials and testing laboratory. Activities in small-scale material analysis and testing laboratories are similar, but samples may be very small and tests highly varied.

8.6.1.2 Equipment and Materials Used. Large pieces of equipment used for compression / tension testing and beam deflection testing can be present and will require optical and electronic test equipment, some of which is large enough that electronic cabinets are needed. There may also be some chemicals used for soil testing, cleaning samples, and other general purposes. In small-scale sample material analysis, testing equipment and instruments are of standard laboratory sizes, and can often be bench mounted.

8.6.2 Layout

(See Figure 8-2 and Chapter 9, Section 9.2 for additional information.) The layout of the materials analysis and testing laboratory will vary according to the use of the laboratory and whether the lab is designed for analyzing large-scale or small samples. In a large-scale testing laboratory, the floor area will be required to accommodate equipment for testing the strength and hardness of materials and to provide clearances required for setting up test materials such as concrete structural components, metals and other materials that are very large and heavy. High bay space for overhead hoisting equipment and tall columnar test setups should be provided. The high bay space will most likely be necessary to move equipment and put test materials into position for testing. A small chemical storage facility convenient to large-scale testing laboratories will be needed.

For small-scale testing laboratories, equipment and samples are generally sufficiently small to be used on normal laboratory benches. However, it is prudent to plan for an open floor area to accommodate some floor-mounted testing equipment.

8.6.3 Heating, Ventilating, and Air-Conditioning

Normal heating, ventilating, and air-conditioning requirements are satisfactory when there are no unusual temperature or human consumption requirements. See Chapters 1, 2, and 9, Sections 3 for additional HVAC considerations. The design plates 35-40 and 99-03 of Table 2-7 in Chapter 2 provide ventilation design guidelines that should be reviewed for applicability.

8.6.4 Loss Prevention and Personal Safety

All the requirements of Chapter 1 and 2, Sections 4, and Chapter 9, Sections 9.4.1 and 9.4.2 should be reviewed and where relevant, should be implemented. In addition, the Sections 4 of Chapter 9, Pilot Plant: Chemical, Engineering, and Biological; Chapter 10, Physics Laboratory; and Chapter 16, Teaching Laboratory, should be reviewed for applicable information. Fire protection for the laboratory should be provided by a standard water sprinkler system.

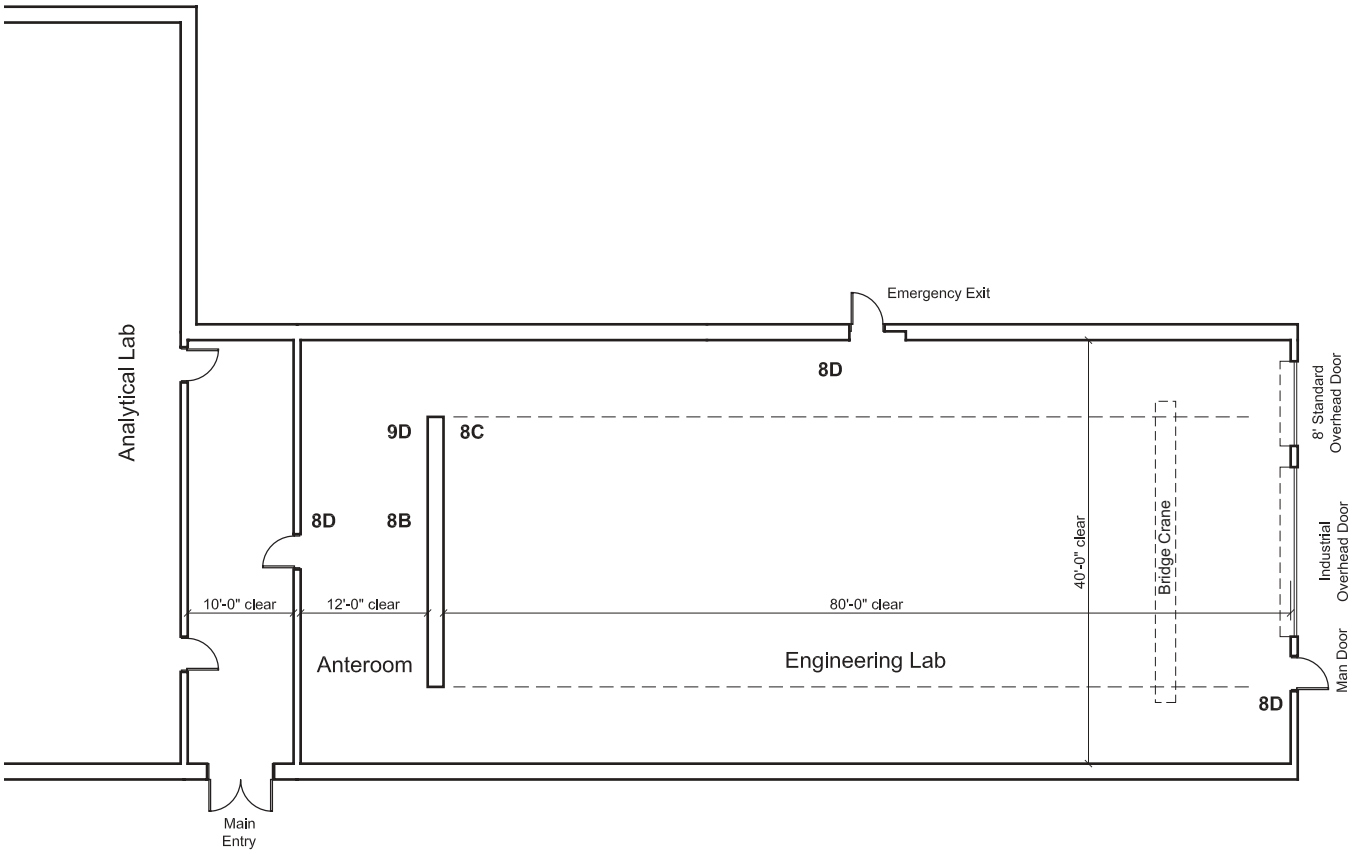
Testing operations in this laboratory can occasionally result in flying debris, collapse of a test assembly, or a component failure. Provide a barrier for the safety of testing operators and observing personnel.

8.7 ELECTRICAL CIRCUITS, MOTORS, AND GENERATORS LABORATORY

8.7.1 Introduction

This laboratory will continue to grow in importance as the world becomes more and more dependent on electronics and electrically oriented equipment and devices. The inherent dangers of fire, electrocution, and equipment damage can be reduced through good laboratory design.

For additional information relevant to these laboratories, see also Section 4 of Chapters 1, 2, and 10.



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 8-2. Materials' testing and engineering laboratory layout.

8.7.1.1 Work Activities. Work activities in the electrical laboratory may include measuring the characteristics of both large and small motors, generators, machines, and electrical devices. Activities will also include working with test equipment; experimentation with and observation of the effects of high, moderate, and low electrical voltages and currents; and bench development of "breadboard" electrical and electronic circuits.

8.7.1.2 Equipment and Materials Used. Large and small electrical motors and machines will be in the electrical laboratory. Structural engineers must design the floor structure to accommodate heavy floor loads in this laboratory. Work benches will be necessary for testing and experimentation. In large current applications, electrical cabinets may be necessary within the laboratory unit.

8.7.2 Layout

(See and Chapters 10 and 16, Section 2 for additional information.) If the laboratory is used for instruction,

plan for an additional open floor area for students to safely observe the machine / motor area. Test control areas and control rooms are preferred to be isolated from kinetic, noise, and electrical hazards. An adequate bench work area should be planned and consideration should be given to using movable benches that can be reconfigured as required for a variety of experimental arrays and functions. Secure storage facilities or an area for secure cabinets to hold high-value equipment may be required. This laboratory also requires an area for the safe storage of small amounts of chemicals.

8.7.3 Heating, Ventilating, and Air-Conditioning

Consideration should be given to the possible build-up of heat in areas of the laboratory where large amounts of electrical current are being consumed. Local ventilation may be an easy and economic solution. No other special requirements are necessary. Refer to Sections 3 of Chapters 1, 2, and 10 for general heating, ventilating, and air-conditioning considerations. The design plates 95-01 and 95-02 of Table 2.7 in Chapter 2 provide ventilation design guidelines that should be reviewed for applicability.

Very low humidity levels should be avoided as low humidity (less than 20% relative humidity [RH]) could create static electricity and may affect testing results.

8.7.4 Loss Prevention and Personal Safety All the requirements of Chapters 1 and 2, Section 4, and Chapter 9, Sections 9.4.1 and 9.4.2, should be reviewed and where relevant, should be implemented. Chapter 10, Physics Laboratory, should be consulted and the principles of the chapter applied where appropriate. Fire suppression may be in the form of a pre-action sprinkler system, but a non-water system would be preferable.

8.8 FOUNDRY LABORATORY

8.8.1 Introduction

Foundries, large and small, deal with very high-temperature materials, proportionally large amounts of electrical current, toxic materials and byproducts, and noisy operations. The foundry laboratory is discussed here because to develop a safe one requires much forethought and planning.

For additional information relevant to foundry laboratories, see also Chapters 1, 2, 10, and 26.

8.8.1.1 Work Activities. Foundry laboratory activities involve making mold patterns, making molds and mold cores, melting casting materials, pouring molten cast material into molds, and removing molded parts from molds. Following removal of the molded part from the mold and any core material, the molded part is cleaned and prepared for use, usually by some form of machining or chipping and grinding.

Although some foundry laboratories are used for research and development, most are teaching laboratories found in colleges, universities, and trade schools. As such, Section 4 of Chapter 16, Teaching Laboratories, should be reviewed for pertinent health and safety considerations.

8.8.1.2 Equipment and Materials Used. Foundry laboratories will have some sort of furnace, usually electrical or gas fired. Depending on the furnace size, a large rate of fuel or electricity may need to be anticipated and designed for.

Casting materials usually found in foundry laboratories include ferrous and nonferrous metals such as aluminum, iron, steel, zinc, copper, tin, magnesium, silver, and gold. Serious burn and fire hazards are common to all of these materials in their molten form.

Mold-making materials often include large amounts of "green sand," a sand/clay mixture that can be made semirigid with precise amounts of bentonite and of moisture. Green sand is mixed in a Muller, a large piece of equipment that requires open floor space and clearances for users. The sand may be high in silica; therefore, its dust needs to be controlled. Nonsilica sand may be used to minimize exposures and special ventilation needs. Additional chemicals used in the metals foundry include phenol formaldehyde and urea formaldehyde resins that are used to make mold cores. Exhaust devices will need to be provided to remove toxic formaldehyde gas from cores as they undergo casting.

8.8.2 Layout

(See Figures 8-3A and 8-3B and Chapter 9, Section 2 for additional information.) Provide adequate space at entries to foundry laboratories for storing and distributing personnel protective equipment including hard hats, face shields, welder's gloves, welder's masks, high-temperature reflective suits, and fireproof long aprons. One or two persons working together perform most foundry operations, and this is true of the foundry laboratory as well. Therefore, in most, but not all student foundries, faculty and staff members perform the operations that students observe. Design and provide adequate protected area for the students. In addition, students working in small groups of 2–4 may perform the operations under supervision of the faculty and staff.

Furnaces are best located on or near an outside wall for ventilation purposes. Plan for additional storage space for raw materials in the form of scrap metal and

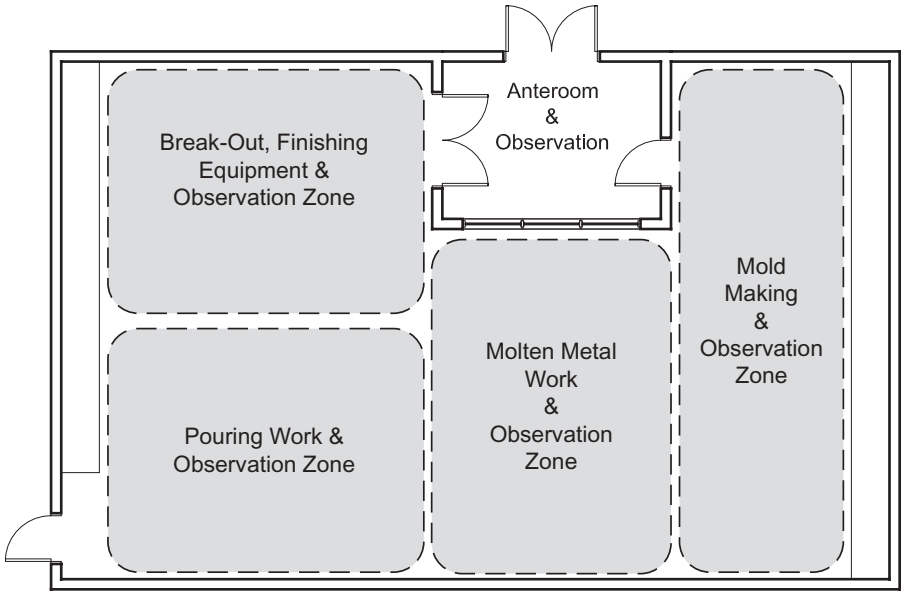


FIGURE 8-3A. Foundry laboratory activity zoning diagram.

pigs, and for open floor space for the other materials and equipment used in the laboratory. This open area should include a place for the Muller and unused green sand. Provide an area with a bench for assembling and filling mold boxes with patterns and green sand.

Design a separate area for pouring liquid metal into the mold with safe clearance for a pouring ladle and any observers. If large molds are made and used, it may be necessary to provide a high-bay space for overhead hoists used to assist in pouring, a ladle, a crucible, and furnace-loading operations. Plan a storage area for unused mold boxes and a facility or storage cabinets for the limited amount of chemicals used in the foundry laboratory.

Casting materials include many metals. These must be stored in a dry location that is not exposed to rain or other source of moisture. Raw material metals being placed into a hot crucible or furnace must be free of moisture or explosions can occur and/or molten metal erupt. Persons performing this task as well as those pouring melted metal into molds must be protected with appropriate PPE not only from high heat, but also the possibility of an explosion or eruption.

Specify and use only noncombustible and heat-resistant construction materials in building a foundry laboratory unit. Protect floors against the extreme heat from a spill of molten steel or iron in areas of the laboratory where pouring ladles or crucibles are used. Unprotected concrete can fracture explosively, sending shrapnel flying. Many foundries protect floors by laying down 2 or 3 inches of sand in areas where spills can occur.

8.8.3 Heating, Ventilating, and Air-Conditioning

Heating, ventilating, and air-conditioning requirements for the foundry laboratory will address the issues of high heat load in the laboratory, local exhaust for specific high heat areas, and exhaust of toxic byproducts of the casting process.

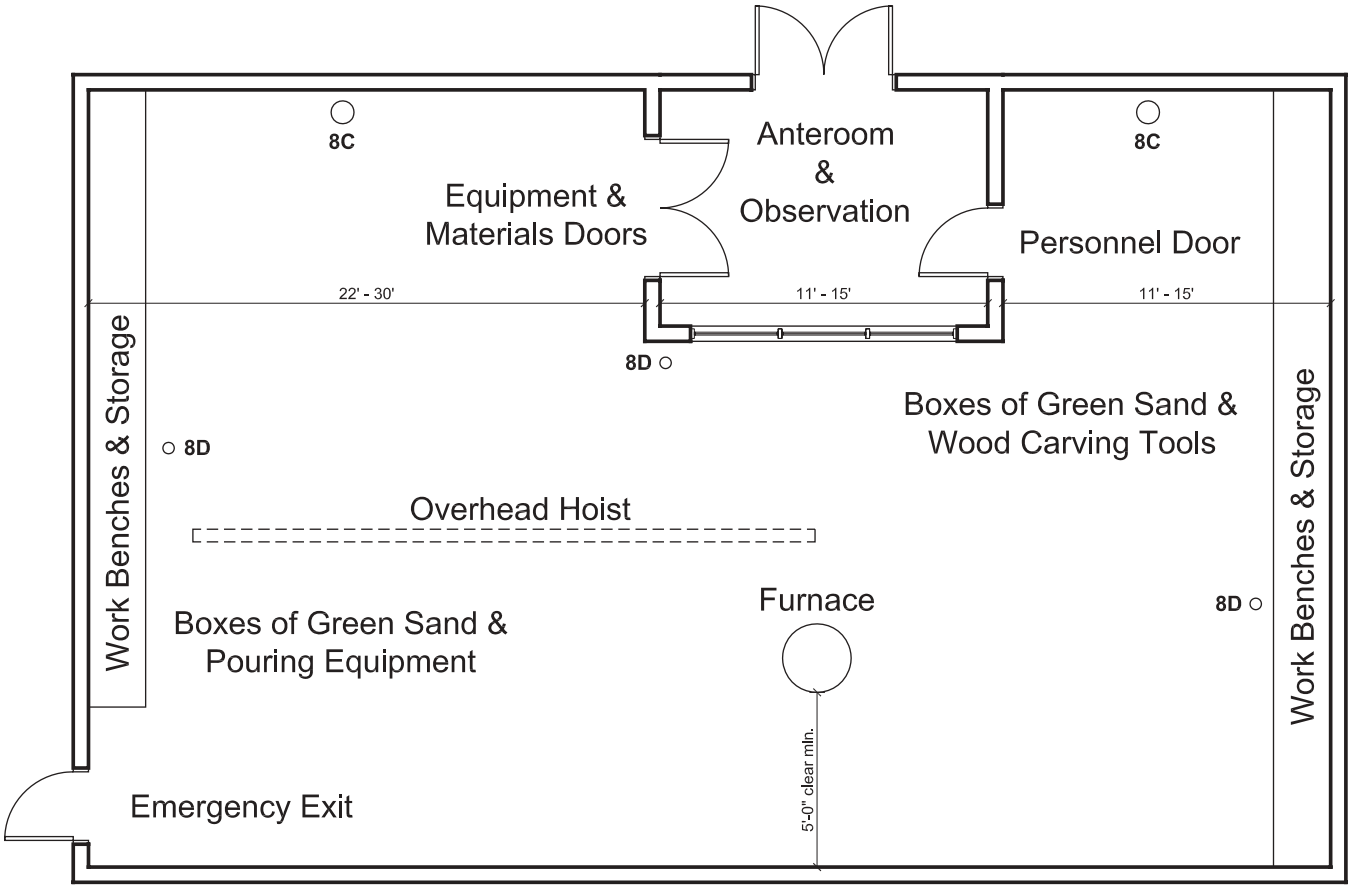
Traditional temperature and humidity levels need not be maintained and can be allowed to vary. To maintain comfort, conditioned air should be supplied near the space where laboratory occupants will be present. The air movement itself can create a comfort level.

All of the considerations in Sections 3 of Chapters 1 and 2, as well as Chapter 9, Section 9.3.2, should be reviewed for applicability. The design plates 80-10 to 80-13, 80-18, 95-02, 99-03, 20-01 to 20-03, 55-01 to 55-07, and 55-10 of Table 2-7 in Chapter 2 provide ventilation design guidelines that should be reviewed for applicability.

Appendix D, Stack Design, provides information on exhaust design that should be reviewed.

8.8.4 Loss Prevention and Personal Safety

All the requirements of Sections 4 of Chapter 1 and 2, as well as Chapter 9, Sections 9.4.1 and 9.4.2 should be reviewed and where relevant, should be implemented. Fire suppression systems for the foundry laboratory should not include water sprinklers, but rely on a dry chemical or gas system. Large-capacity fire extinguishers using dry chemicals for Class A, B, C, and D fires should have a prominent place in the laboratory.



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 8-3B. Foundry laboratory layout.

8.9 INTERNAL COMBUSTION AND GAS TURBINE ENGINE LABORATORY

8.9.1 Introduction

The hazards associated with handling, fueling, running, and exhausting gas turbines and reciprocating, rotating, and other internal combustion engines can be safely dealt with through good facility design. Laboratories involved in this work can be found in universities, technical schools, and fuel and gas analysis research and development.

For additional information relevant to these laboratories, see also Chapters 1, 2, 8, and 23.

8.9.1.1 Work Activities. Internal combustion and gas turbine engines can be used in both teaching and research laboratories. These engines may be piston- or

combustion gas-driven engines that are typically installed semi-permanently on a fixed bench or cradle. Operation of these engines develops heat, toxic exhaust gases, and output-motion, usually in the form of rotating parts or shafts attached to dynamometers, water brakes, or other output testing devices.

Activities in the engine lab include engine installation, instrumentation, fueling, and testing. Running a test may be done for demonstration purposes for groups of students or for data collection for research purposes.

8.9.1.2 Equipment and Materials Used. Typically, the laboratory will have a supply of mechanical tools for installation purposes and wiring and tubing supplies and tools for electronic, pneumatic, and thermal data-collecting equipment. Gasoline, diesel fuel, propane, and other gaseous and liquid fuels will be used to fuel the engines. These fuels may be in batch containers located within the laboratory, requiring special fire protection, or may be piped into the laboratory from an exterior remote source.

Piston and rotating lobe automobile type engines, along with small turbine engines are typically found in these laboratories (see Figure 8-4). Both large engines in the range of several hundred output horsepower and smaller engines of one or a few horsepower may be brought into these laboratories for teaching or research purposes. These engines may be coupled with dynamometers or water breaks for testing the output of the engine (see Figure 8-5). Lasers are sometimes used for various measurements.

8.9.2 Layout

(See Figure 8-6 and Chapter 9, Section 2 for additional information.) Internal combustion engines and turbines have several possible hazards that need special design considerations. They are (1) noisy, (2) use flammable or highly combustible fuel, (3) emit toxic exhaust, and (4) they frequently have unguarded moving parts. In the early stages of planning this laboratory determine the source and types of fuel that will be used and method(s) of distribution, i.e., liquid fuel containers, gas cylinders, or fuel piped in from an exterior source. Carefully consult current building codes and regulations of the jurisdiction in which the combustion laboratory will be built to understand any restrictions on the volume of fuels, types of fuels, and design of piping that is required to supply the equipment.

Restricted access to these laboratories is required when lasers are in use. Noise and moving parts in these laboratories also pose hazards. Unauthorized persons must be kept out of the test area during times of risk. Provide signage, signals, and electronic door interlocks to high-power lasers, for example, to prevent entry while hazardous equipment is operating. Provide separate areas, rooms or enclosed stalls to contain these hazards. Cover the walls and ceilings with a noncombustible and sound-absorbing material. Consider designing high-bay space for this laboratory, due to the size of the engines and the volume of supporting equipment and instruments required, and the use of cranes and hoists to move them.

Design this laboratory with instrument control stations directly outside the experiment chambers, rooms,

FIGURE 8-4. View of large internal combustion laboratory and central equipment area.

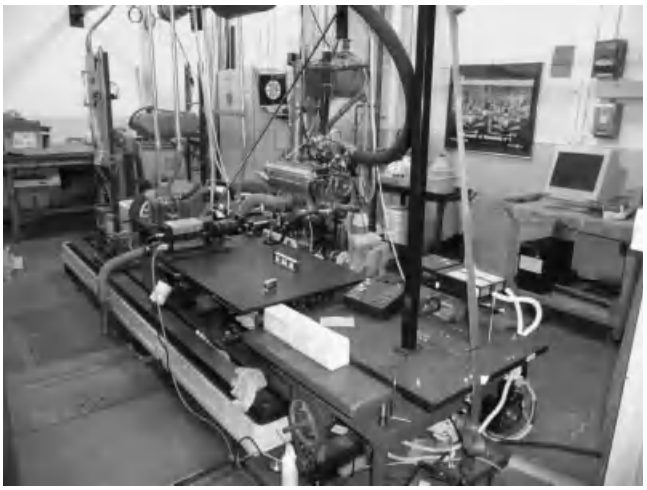


FIGURE 8-5. View of small internal combustion testing laboratory.

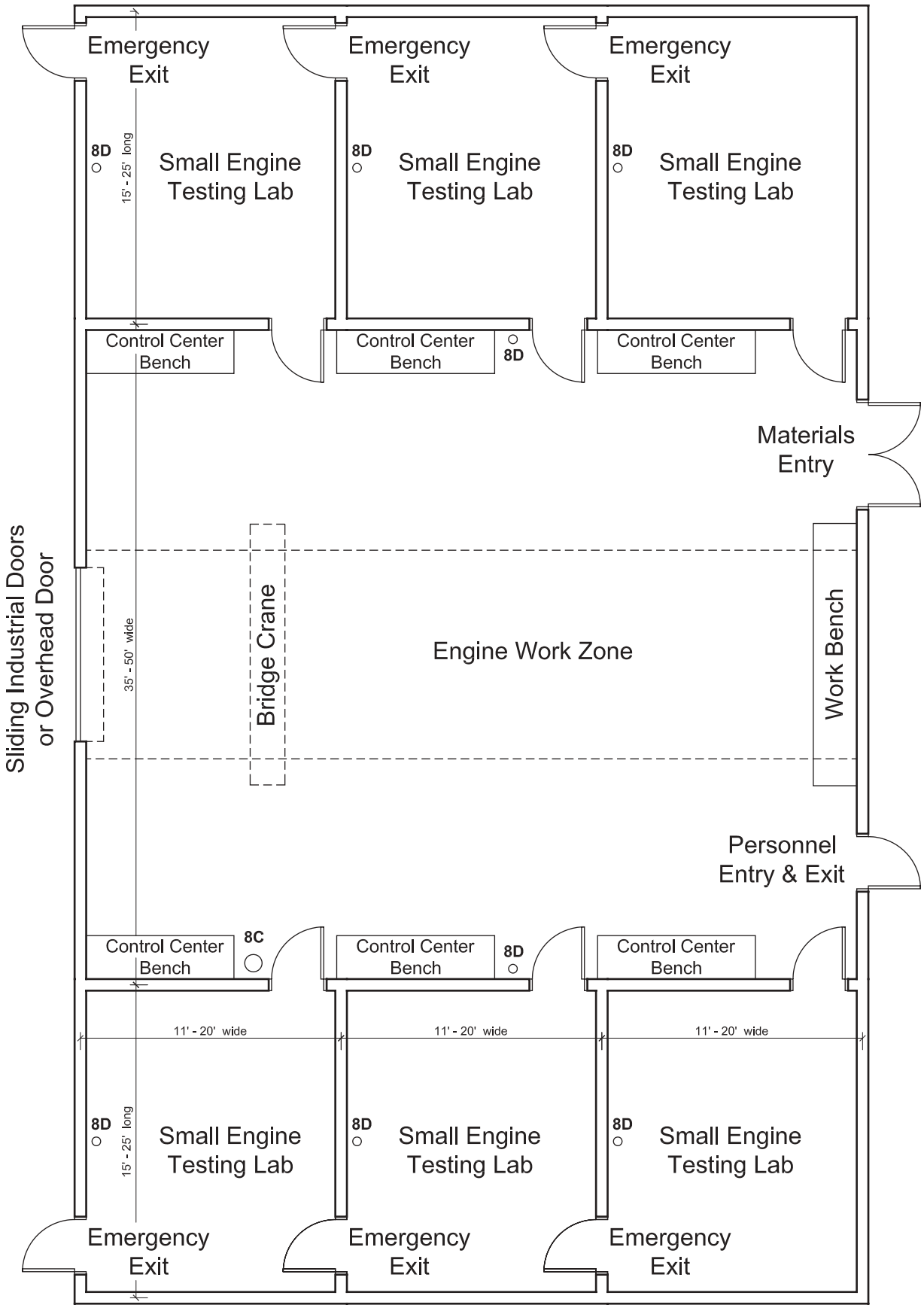


FIGURE 8-6. Internal combustion engineering laboratory layout.

or alcoves to protect researchers and students from noise and hazards. Construct solid walls with large windows, double-glazed with safety glass, through which researchers can safely observe the experiment in progress. Provide another area outside the experiment chamber for an electronics repair bench. Plan for an area close to or adjacent to this laboratory for a machine shop and storage of materials.

8.9.3 Heating, Ventilating, and Air-Conditioning

All of the considerations in Sections 3 of Chapter 1 and 2, as well as Chapter 9, Section 9.3.2 should be reviewed for applicability.

Special forms of local exhaust ventilation will be needed to capture the exhaust gases from engines. These may be a direct connection to an exhaust system or controlled by a canopy or other style of hood. *The Industrial Ventilation: A Manual of Recommended Practice* (ACGIH, 2010) has a design plate for "service garage exhaust ventilation" that may be helpful (VS-85-01) allowing multiple engines to exhaust into the system. Turbines present the largest challenge in this regard as the hot and noisy exhaust gases are not released through a convenient piping system.

Supply air for large engines/turbines will need to be considered along with the exhaust. In some cases, supply air may be required to be conditioned to specific temperature and humidity levels. The design plate 99-03 of Table 2-7 in Chapter 2 provides ventilation design guidelines that should be reviewed for applicability.

Appendix D, Stack Design, provides information on exhaust design that should be reviewed.

8.9.4 Loss Prevention and Personal Safety

All the requirements of Sections 4 of Chapter 1 and 2, as well as Chapter 9, Section 9.4.1 and 9.4.2 should be reviewed and where relevant, should be implemented.

Fixed automatic fire suppression should be considered where flammable fuels are used. Sprinklers, CO_2 gas systems, or total flooding dry chemical systems are all satisfactory.

An external fuel source shutoff valve should be located outside each area where flammable gas or liquid fuels are piped into the test zone. Plan for fuel source locations in the design phase to reduce inappropriate storage and supply.

8.9.5 Special Requirements

Good lighting is critical in this laboratory. Consider ways in which natural light can be introduced. See Chapter 9, Section 9.5.1 for additional information.

9

PILOT PLANT: CHEMICAL, ENGINEERING, AND BIOLOGICAL

9.1 DESCRIPTION

9.1.1 Introduction

A pilot plant, for chemical, engineering, or biological work, is designed, constructed, and operated to provide a safe and healthful work area for activities associated with the handling of substantial quantities of toxic chemicals, petroleum fuels, compressed gases, microbiological agents, and other hazardous materials for chemical or biological processing experimentation. A special characteristic of a pilot plant, in addition to large floor area and multistory height, is that materials are usually handled in large quantities (gallons and pounds) as opposed to the small quantities (milliliters and grams) used in most other types of laboratories. Because of the frequent use of flammable and explosive chemicals, pilot plants should be isolated from public areas, other laboratories, and office spaces by distance, special fire protection, and explosion-resistant construction (Palluzi, 1992). Frequently, special access restrictions must be imposed when inherent hazards are associated with the specialized materials and equipment being used.

9.1.2 Work Activities

The activities performed include mixing, blending, heating, cooling, distilling, filtering, absorbing, crystallizing, evaporating, grinding, size separating, biological fermentation, and chemical reacting as a part of production or purification of a product. In physical engineering pilot plants, hydraulic, mechanical, electrical/electronic, and large experiment construction may take place. Some of the procedures and materials require the special ventilation capabilities that are discussed in Section 3. Some procedures must be kept sterile or extremely clean. Special enclosures and special environmental conditions may be required for this work. A pilot plant usually requires a more- or less-permanent service crew with special training that includes instruction in safety and health protection. Because of the size and uniqueness of the equipment, protective clothing and respirators must be available for all personnel working in the pilot plant. A permanent, well-trained pilot plant crew is especially important when a pilot plant will be used for teaching and academic research because of the magnitude of the equipment and materials and the inexperience of students. Training of all personnel in the processes to be conducted in a pilot plant, including an understanding of first aid, emergency procedures and the use of emergency equipment, and hazardous waste disposal should be mandatory before operations begin.

9.1.3 Equipment and Materials Used

Analytical instruments and a full range of sensors and automatic process controllers will usually be present, in addition to large—possibly multistory—process equipment. Extremely hazardous materials that are sometimes used

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

in pilot plants include chemicals of high toxicity, biological agents, volatile liquids, combustible dusts, and highly reactive or explosive materials. Some radioactive materials may also be used in the pilot plant. Operations often involve the use of high voltages, very high-radiofrequency generators, and other electrical equipment with a high potential for fire, explosion, and electrocution. High-pressure steam, air, and special gases are employed frequently, as are open flames, furnaces, and similar intense heat generators that make the heat load in pilot plants a special ventilation concern.

9.2 PILOT PLANT LAYOUT

Because pilot plant operations involve a large variety of equipment and operations arranged in a constantly changing pattern, it is not possible to illustrate a comprehensive layout. Process engineers should consult with the architects and the engineers, contractors, and the owner's team to determine the present and future requirements of the space. All of the recommendations provided in Chapter 1 and 2, Sections 2 should be evaluated for their applicability, and safety and industrial hygiene personnel should be consulted when unusual requirements are encountered. Additional sources of information include OSHA; NIOSH; state departments of occupational health, safety, and industrial hygiene and pertinent reference materials (Palluzi, 1992).

Materials handling may be done with automated equipment such as fork-lift trucks and overhead cranes. Cargo doors and special ramps may be needed for bringing in large pieces of equipment. A pilot plant circulation layout should take into account the additional clearances needed to move materials safely with this equipment. High bay areas within pilot plants may have mezzanines or catwalks installed to provide easy access to equipment, processes, and controls. These structures must meet local codes for seismic requirements, live loads, railing height and load, stair or ladder access, fall protection, and exit requirements. Below-floor areas required for access to equipment or controls must have safe access and safety railings. Special care is needed with work areas below the normal pilot plant floor level because hazardous liquids and heavier-than-air gases can pool there. These may also be considered confined spaces as regulated by OSHA. In the case where there are higher risks from accidental release of toxic or suffocating gases and liquids, pilot plants may require additional emergency exits or areas of refuge, so lab occupants can very quickly reach a safe location(s) in emergencies.

Utilities provided in pilot plants, usually from a number of well-distributed locations, include high-amperage single- and three-phase electrical current of 120, 240, and 440 V; compressed air to 100 psig (791 kPa); vacuum of 0.5 atm or lower; steam at least up to 15 psig (205 kPa); hot and cold water, purified water; and multiple floor drains leading to waste handling facilities.

9.3 HEATING, VENTILATING, AND AIR-CONDITIONING

9.3.1 Introduction

Pilot plant ventilation is needed to provide an environment that is within acceptable comfort limits and to provide a reasonable capacity for diluting contaminants released into the work environment. Air ventilation rates for chemical processing are typically 5 CFM/ft^2 (0.0132 meters cubed per min per meter square) of floor area. For petroleum processes, 3 CFM/ft^2 (0.00789 meters cubed per min per meter squared) is considered adequate. Ventilation must be provided in a manner that will not contaminate other areas of the building either by infiltration through low-pressure pathways or by contamination of air intakes with pilot plant exhaust air. Sterile chambers and very clean work environments within the pilot plant may require high-efficiency particulate air (HEPA) filtered supply air. As discussed in Section 2.3.4, the exchange rate (room ventilation rate) is not the important design criterion. The design criteria should include adequate exhaust ventilation for each piece of equipment and the activities to be performed. Due to the larger volumes of volatile materials that may be handled or stored here, the consequences of the maximum credible release should be evaluated and appropriate emergency exhaust provided.

9.3.2 Additional Requirements

All of the recommendations given in Chapters 1 and 2, Section 3 should be examined, and all that apply to pilot plants should be implemented. Special provisions for pilot plant local exhaust systems follow.

9.3.2.1 Local Exhaust Systems. Pilot plants should be provided with fixed general laboratory ventilation systems designed to supply air at ceiling level and exhaust it from floor level. In addition, multiple local exhaust outlets should be provided from a perimeter system of main ducts by the use of quick-disconnect types of fittings and flap-type dampers that automatically close the connections when they are not in use. Such a local exhaust system is capable of serving the entire pilot plant area at the same time that it limits the amount of ventilation air exhausted, thereby conserving energy. Care in the design of these systems is necessary

because a static pressure of at least 2.5 in w.g. (6.35 cm) at each exhaust point will be required to assure adequate air flow capacity.

Typical equipment found in the pilot plant that may need some form of local exhaust service includes mixing and reaction vessels, distillation columns, fermentation units, ovens, filtration apparatus, analytical equipment, and centrifuges. The exhaust air quantity and hood configuration will depend on the particular process and equipment as well as generation points of the contaminant emission. The exhaust hoods may range from an enclosure, such as a laboratory chemical hood or glovebox, to a capture or exterior hood, such as a canopy or a slot hood. Some examples are provided in Chapter 32. General design guidelines in Chapters 3 and 5 of *The Industrial Ventilation: A Manual of Recommended Practice, 27th Edition* (American Conference of Governmental Industrial Hygienists [ACGIH], 2010) should be followed.

For large vessels such as reactors and other confined spaces that may need personnel entry, a means to exhaust air to ensure a nonhazardous atmosphere must be provided. A simple example of this is a flexible exhaust duct that can be lowered to the bottom of a vessel to purge the atmosphere (University of Michigan, 1995).

9.3.2.2 Temperature and Humidity Control. When necessary, the pilot plant laboratory must be heated, cooled, humidified, or dehumidified. Low humidity levels that may lead to high static electrical charge are not desirable. Air conditioning of the entire space may not be necessary. Local cooling systems or booths may be adequate for personal comfort.

There may be process equipment that requires close temperature control for operation. For this purpose, a separate system should be provided; usually water-cooled direct expansion (D-X) equipment is used. Water-to-waste condenser cooling systems are wasteful of water; hence, air-cooled D-X systems should be used when appropriate.

9.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

All the recommendations provided in Chapters 1 and 2, Section 4 should be evaluated for relevance, and all that apply to pilot plants should be implemented.

9.4.1 Spill Containment

In operations in this type laboratory, large quantities of chemicals and other materials may be necessary. Storage containers and locations for them should be carefully selected to provide hazard separation and isolation. Spill dikes may be necessary, and large quantities of spill control materials may need to be stored. These materials should be stored outside of the laboratory yet not isolated from it in time of need. Floor drains should have closures that are normally in place to prevent a release of hazardous materials from entering the drain and sewer system.

9.4.2 Electrical Considerations

Consideration should be given to the use of explosion-proof-rated electrical wiring and fixtures for all standard room equipment such as lighting, outlets, and switches. This would facilitate the use of highly flammable material in the pilot plant.

9.4.3 Confined Spaces

Because there may be large vessels or reactors and pits or enclosures below floor areas, special care must be taken to design the space to eliminate or reduce the number of confined spaces and permit required confined spaces. The general principles discussed in the OSHA general industry standard 29 CFR 1910.146 (OSHA, 2012) should be carefully reviewed. Some design features can help to classify the more onerous permit-required confined space to a nonpermit required design space. For large vessels or reactors, where possible easy access and egress should be provided, fixed or movable stairs can be utilized. Provide adequate ventilation to assist in reclassifying a permit confined space to a nonpermit required space.

9.4.4 Fall Protection

OSHA general industry standard 29 CFR 1910 Subpart D (OSHA, 2012) requires fall protection where workers need to perform activities above 4ft (1.2 m) from the floor. In a pilot plant situation, this may become a design consideration requiring attention in the planning stage. Because many vessels and work platforms may be greater than 4 ft (1.2 m) off the floor when access from above is required, some type of catwalk or fixed platform with railings will be needed.

9.5 SPECIAL REQUIREMENTS

9.5.1 Illumination

Unusually high ceilings combined with the use of bulky processing equipment, such as large tanks, in a constantly changing pattern make provision of uniform lighting of good quality and adequate intensity difficult.

Ceiling lighting should be provided by many closely spaced fixtures to avoid the heavy shadows cast by large equipment when only a few widely spaced, high-intensity light sources are used.

9.5.2 Air-Supplied Respirators

Provisions should be made for the installation of an air-supplied respiratory protection system. It should be a dedicated and protected compressed air system supplied by an oilless compressor.

9.5.3 Security

Many of the security considerations discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1 may apply to pilot plant laboratories and should be reviewed for specific applicability.

9.5.4 Renovations

Chemical decontamination will often be necessary for pilot plants and equipment in pilot plants. Vessels will be larger than found in most laboratories. Some old reaction vessels may be insulated with asbestos-containing materials and will require special removal procedures.

When different processes are under consideration for the renovated pilot plant, a careful evaluation of the new utility requirements should be carried out early in the design process to avoid a shortfall in service.

10

PHYSICS LABORATORY

10.1 DESCRIPTION

10.1.1 Introduction

Research carried out in a physics laboratory may include the use of electricity (high current, voltage, and frequency levels), many chemicals (solid, liquid, and gaseous), intense light sources (lasers with >3-mW output power), magnetics, cryogenics, and a variety of high-energy systems, including high-temperature steam, compressed air, and high vacuum. Research may be carried out with radioactive materials to produce ionizing radiation, but consideration of their use is not included in this chapter. Chapter 13, Radiation Laboratory, contains a description of laboratories using more than trivial amounts of radioactive materials.

10.1.2 Work Activities

The basic procedures carried out in physics laboratories include experimental development of mechanical, electrical, hydraulic, and pneumatic systems, and examinations of the properties of matter. Operations involve equipment setups and physical measurements for experiments that involve observation, data collection, and analysis.

10.1.3 Equipment and Materials Used

Equipment used in physics laboratories is varied and dependent on the nature of the work. A partial list of physics laboratory experiments and equipment includes the following:

- Shock tube studies (air compressors, pressure-relief diaphragms, pressure and gas-flow measuring instruments)
- Lasers (electrical circuits, cryogenic liquids)
- Spectroscopy (carbon arc source generators, magnets, photography facilities)
- Cryogenics (refrigeration equipment, liquified gases, low-temperature measuring instruments)
- Electromagnetics (high electrical current services, cryogenic liquids, ion source generators)
- High-frequency noise and electricity research (high-current and high-voltage electrical services)
- Energy storage systems (rotary machines, heat exchangers, electrical condensers, temperature measuring instruments)
- Ionizing radiation systems (x-rays, high-current and high-intensity electrical services, and ionizing radiation measuring instruments)
- High-vacuum systems

Very small quantities of chemicals primarily used for cleaning may be found in a physics lab. If chemical lasers are used, then small quantities of some highly toxic chemicals might be present or generated as waste gas or fumes.

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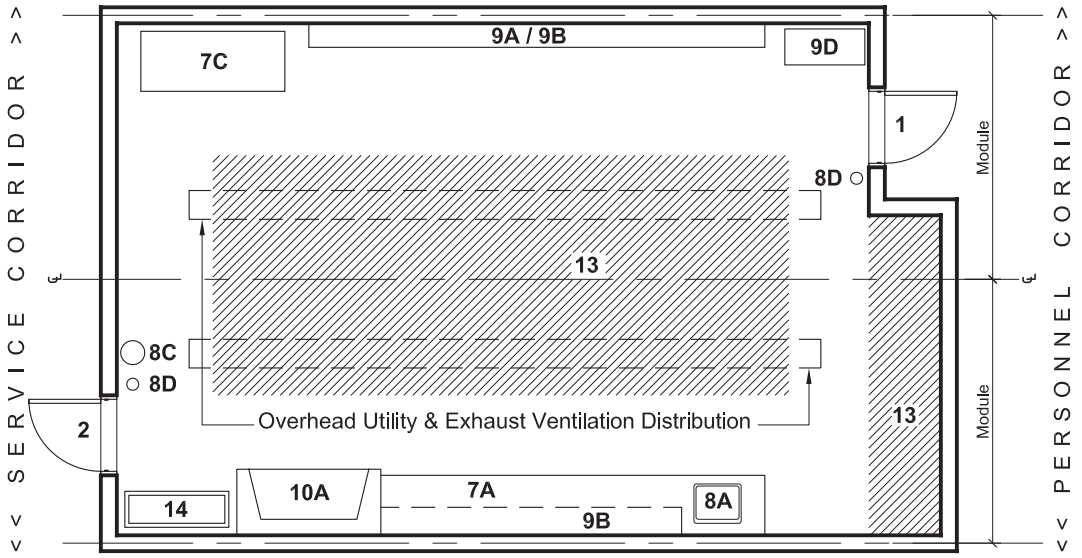


KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 10-1. Physics laboratory layout.

10.1.4 Exclusions

Large quantities of chemicals should not be used in a physics laboratory. If large quantities are needed then features of the type of laboratories reviewed in Chapters 5, 6, and 9 might be needed.

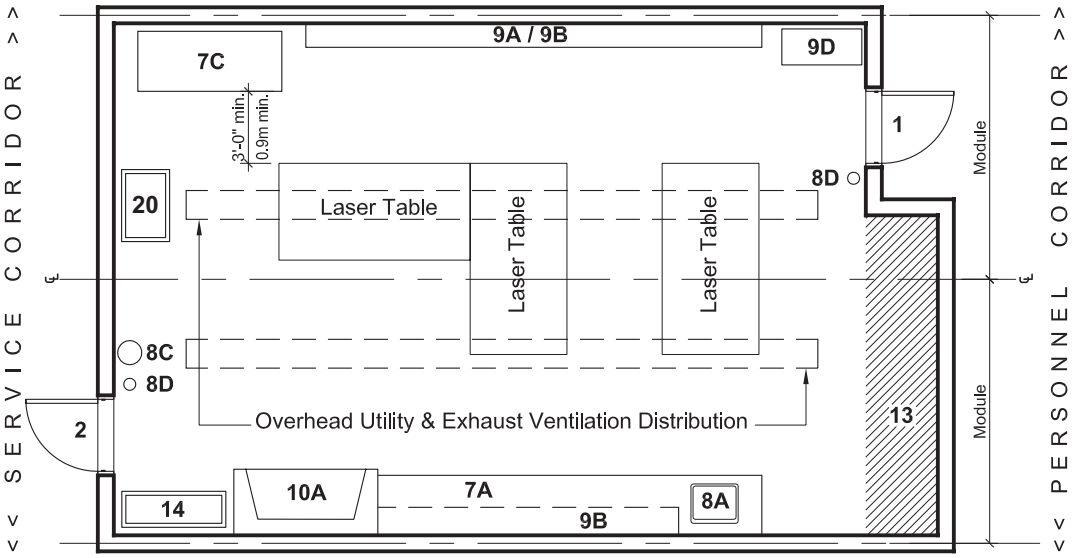
10.2 LABORATORY LAYOUT

A physics laboratory should be laid out to provide easy access to all areas within, and associated with, the laboratory by wheeled trucks, dollies, cranes, and special-handling equipment. Services (electrical panels, gas shutoff valves, water control devices), should have easy access for safe modification of experimental setups and emergency control and shut-down. Because a physics laboratory can be used for so many different types of research, equipment configurations are likely to be different from experiment to experiment. For this reason, all services should be flexible enough and adequately distributed to serve all parts of the laboratory conveniently. A typical layout is shown in Figure 10-1, a two-module area. Physics laboratories are often larger than two modules. Physics laboratories may require higher than normal ceiling height or high bay space. Requirements for high bay areas in laboratories are reviewed in Chapter 9, Pilot Plant: Chemical, Engineering, and Biological. Figure 10-2 shows a layout for a physics laboratory that is equipped with vibration isolation tables for laser equipment.

All the recommendations reviewed in Chapters 1 and 2, Sections 2 that are applicable to physics laboratories should be implemented. An additional recommendation is noted below.

10.2.1 Egress Routes for Physics Laboratories

In the typical physics laboratory layout illustrated in Figure 10-1, two required separate egress routes are shown. Doors should be wide enough and the route width sufficient to accommodate medical stretchers and



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6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 10-2. Physics laboratory layout with laser table array.

other emergency equipment. Door height and width and aisles should also be adequate for materials handling equipment, such as fork-lift trucks, used for transporting heavy and bulky items. Therefore, laboratory aisles may need to be wider than the minimum recommended in Chapter 2.

10.2.2 Furniture Location

In laboratories using unshielded laser beams, desk chairs and seated work surfaces with heights of 30–32 in. (76.2–81.3 cm) are not recommended. Laser beams are often directed and optically transferred at seated eye level. Desks and seated computer stations should be provided in separate rooms, as recommended in Chapter 2, Section 2.4.1.

A sample layout of a physics laboratory with vibration-isolation tables for lasers is illustrated in Figure 10-2.

10.3 HEATING, VENTILATING, AND AIR-CONDITIONING

All the recommendations in Chapters 1 and 2, Section 3 that are applicable to physics laboratories should be implemented.

A small number of fume hoods or other forms of local exhaust ventilation systems as described in Chapter 31, Air Cleaning, may be found to control exposures to the small quantities of cleaning chemicals such as acetone or for the chemical lasers that may be used.

10.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

All the recommendations provided in Chapters 1 and 2, Section 4 that are applicable to physics laboratories

should be implemented. Additional recommendations are noted below.

10.4.1 Emergency Eyewash Stations

When chemicals hazardous to face and eyes, such as strong acids, alkalis, and other corrosive materials, are used in a physics laboratory, one or more eyewash stations should be provided according to recommendations contained in Chapter 2, Section 2.4.1.5. Because of the large amount of electrical equipment contained in most physics laboratories, plumbed eyewash stations should be located in a corridor or some other nearby area outside the physics laboratory proper but within a 10-s walk. Specifications for such a system are in ANSI Z358.1 (ANSI, 2009). Hand-operated package-type eyewash units located close to the hazardous work area may be used to supplement the plumbed eyewash station.

10.4.2 Fire-Detection, Alarm, and Suppression Systems

Fire detection and suppression systems should be carefully planned from the earliest stages of laboratory design because even under the best of conditions, installation costs are very high for this type of laboratory.

10.4.2.1 Fire- and Smoke-Detection and Alarm Systems. Physics laboratories need fire and smoke detectors that respond to products of combustion (e.g., photoelectric and ionization detectors) or thermal effects (either rate of temperature rise or a final fixed temperature). A combination of ionization and photoelectric detectors is useful to sense either visible or invisible combustion products generated in a fire in a physics laboratory. When the laboratory uses substantial amounts of flammable gases or flammable volatile liquids, fixed temperature or fixed rate of temperature rise detectors are acceptable, reliable, and less expensive, although slower to alarm. When a physics laboratory is in a part of a building without windows to the outside and when light research, such as with lasers, is not being carried out, flame-sensing detectors are also appropriate. Flame-sensing detectors can be accidently triggered by pulsating or flickering light from indoor or outdoor sources. All detectors should be UL or FM approved and be connected into a UL- or FM-approved general building alarm system. Chapter 1, Section 1.4.4.1 contains additional information about fire-detection systems.

10.4.2.2 Fire-Suppression Systems. The basic methods of fire suppression in a physics laboratory should be fixed, automatic systems combined with hand-held, easily accessible portable extinguishers. Although sprinklers are considered to be the best fixed automatic fire-control device for most laboratories in a research laboratory building, physics laboratories often contain special electrical hazards that should be protected with fire-suppression systems other than sprinklers. This would be the case unless those electronic/electrical devices can be coupled to the sprinkler system to shut down upon the activation of the sprinkler system. Other acceptable fixed automatic systems include total-flooding CO_2, total-flooding dry chemical systems, and water-mist systems. Whenever water-sensitive equipment is not used and whenever high-voltage electronics or high-current electrical equipment, such as superconducting magnets, are not present, or are not able to be controlled by the automatic sprinkler system physics laboratories can best be protected from fire spread with automatic sprinkler systems.

10.4.2.2.1 Fixed Automatic Extinguishers. Fixed automatic fire extinguisher systems used in physics laboratories should be consistent with the operations anticipated for that laboratory as explained here in Section 10.4.2.2. When operations prohibit the use of a water sprinkler system, fixed automatic inert gas, such as carbon dioxide; or a mixture of carbon dioxide, argon and nitrogen, or chlorine and bromine free halocarbons can be used. A total-flooding dry chemical system that uses ammonium phosphate or sodium or potassium bicarbonate can also be used. But, dry chemical systems leave a powdery residue that may harm equipment. Although a powder residue is not the primary concern when selecting a fire suppression system, when there are alternatives of equal efficacy, it becomes an important criterion in the selection process.

Total-flooding CO_2 systems should be avoided whenever the enclosure to be protected will be occupied unless a one-minute predischarge alarm is installed and occupant training provided.

10.4.2.2.2 Portable Extinguishers. Hand-portable fire extinguishers of adequate size that contain appropriate extinguishing agents for anticipated fires should be located in the laboratory. Appropriate hand-portable units for a physics laboratory are 15-lb (67.5 kg) CO_2 extinguishers and 2A-40 BC multipurpose dry chemical extinguishers. Places for these extinguishers should be provided within the laboratory where they can be picked up to assist personnel in making an exit from the laboratory. Sizes of multipurpose extinguishers should always be in the range of 2A to 4A and 40 BC to 60 BC. Portable extinguishers should also meet all the requirements of "Portable Fire Extinguishers" as per the NFPA (NFPA 10, 2010).

10.4.2.2.3 Special Systems. Wherever a potential for an electrical fire exists within equipment cabinets that can be protected without involving the entire building system, this type of protection should be provided with an inert gas or halocarbon total-flooding system. Such systems should be wired into the building alarm and annunciation system. All of the ventilation shutdown and containment requirements for use of these special systems should be met as outlined by the NFPA 12, "Carbon Dioxide Extinguishing Systems" (NFPA 12, 2011).

10.4.3 Special Equipment Requirements

Careful consideration should be given to the potential contribution of cryogenic and special compressed gases, high electrical energy demands, and strong laser beams to accident, emergency, and stress situations. Design features should be considered to provide adequate barriers against damage from any of these high-intensity energy forms. The use of lasers frequently requires personnel in the laboratory to wear special eye protection or shielding. A location for storing these shielding devices should be established near the laboratory entrance.

10.4.3.1 Equipment Operation with Hazardous Materials and in Hazardous Modes. Equipment that operates on materials that are hazardous (toxic or flammable) should be provided with all of the building design features (such as ventilation and emergency services) that will make it possible to control the hazards in case of unexpected events. The special safety requirements for handling more than trivial quantities of hazardous materials contained in Chapter 9, Pilot Plant: Chemical, Engineering, and Biological, should be reviewed. Potential problems may be discovered in discussions between users of the laboratory and safety professionals.

If lasers that are hazardous to humans will be used in the physics laboratory, special lit signs and door interlocks should considered. These signs and interlocks will provide warning and system shut down to persons attempting to enter the lab when the laser is in operation.

10.4.4 Special Safety Requirements

When screen rooms, such as a Faraday cage, are required to block radiofrequency energy from entering the laboratory area, entrances to these rooms should be interlocked with the electrical power source while always permitting easy egress for personnel in the event of an emergency.

A grounding grid system should be installed in a physics laboratory to enable grounding of all pieces of equipment that are electrical in nature or that come in contact with equipment that is electrical. The grid system should be extensive enough and of sufficient size to result in only a small potential difference between the two farthest points.

Because water supply and drainage requirements may be high for water cooling of magnets or other devices, design for such systems should be evaluated early in the building planning phase. For economy of operation, a closed-loop condenser water-cooling system should be considered for all such facilities. However, drains are still required and of sufficient capacity to capture flow of broken hoses or pipes from closed-loop systems.

10.5 SPECIAL REQUIREMENTS

10.5.1 Security

The use of high-value metals or other materials and radiochemicals in the physics laboratory may require the application of equipment and laboratory lockup. Refer to the security considerations discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1.

11

CONTROLLED ENVIRONMENT ROOM: HOT OR COLD

11.1 DESCRIPTION

11.1.1 Introduction

A controlled-environment room is a laboratory or a laboratory adjunct in which temperature and humidity are maintained within a specified range so that laboratory activities can be conducted and laboratory products maintained under controlled conditions. A controlled-environment room can be maintained to within 1°F or 0.5°C at an elevated temperature up to 120°F (49°C) or at a reduced temperature down to 35°F (2°C). In addition, relative humidity can be controlled to within 0.5% of the full humidity span.

11.1.2 Work Activities

Although controlled-environment rooms are primarily designed and used for storage of sensitive materials that require maintenance within a specified temperature and relative humidity range, they are also frequently used for conducting activities normally performed in a general chemistry laboratory or in biology, bacteriology, or cell culture laboratories.

11.1.3 Equipment and Materials Used

It is expected that few pieces of analytical equipment will be located permanently in controlled environment rooms because they provide an unfavorable storage environment. Specialized storage containers will usually be found there. Controlled-environment rooms usually have no special access restrictions unless sensitive equipment or dangerous materials are being used.

11.1.4 Exclusions

Controlled environment rooms are not designed for handling extremely hazardous chemicals or performing especially hazardous operations. Hazardous operations not recommended for controlled environmental rooms include, but are not limited to, the use of (1) carcinogenic, mutagenic, or teratogenic chemicals; (2) highly explosive materials in greater than milligram quantities; (3) high-tension voltage and high-current electrical services; (4) radiofrequency generators and all electrical operations with a high potential for fire, explosion, or electrocution; (5) lasers of over 3-mW output power with unshielded beams; (6) gas pressures exceeding 2500 psig (17,338 kPa); (7) liquid pressures exceeding 500 psig (3,549 kPa); and (8) radioactive materials in greater than 1-mCi amounts. Controlled environment rooms (hot or cold) usually need no special access restrictions. Very cold rooms (below freezing) such as -4°F (- 20°C) are not included in this chapter.

11.1.5 Special Requirements

Ideally, environmental rooms should be the product of a single manufacturer and completely furnished and

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installed by the same manufacturer to avoid division of responsibility. If possible, rooms should be prebuilt at the manufacturer's plant and pretested before shipment. Pretesting conditions should simulate, or even exaggerate, the environmental conditions that will be found in service. Tests should include a thorough check of the mechanical, electrical, and temperature-control systems. It is advisable to have an owner's representative present during the manufacturer's preinstallation testing program.

11.2 LABORATORY LAYOUT

11.2.1 Introduction

A controlled environment room is a laboratory type that need not always conform to the dimensional guidelines set out in Chapter 2, Section 2.2.1.1. The interior area of manufacturers' standard controlled environment rooms can vary from closet size—20 NSF (1.8 m^2)—to double-laboratory module size—400 NSF (37 m^2), or even larger. The minimum dimension may be less than 7 ft 6 in. (2.3 m) because a controlled environment room is not usually classified as a habitable room. If a controlled environment room larger than double-laboratory size is needed, safety personnel should be consulted for assistance in the preparation of design specifications.

Temperature conditions within controlled environment rooms are usually outside the comfort zone for personnel, so work efficiency must be considered carefully during the layout of work surfaces and storage units. When work surfaces and sinks are present inside the controlled environment room, they should be located close to the door so that the zone of greatest activity will be near the exit. Chromatography separations normally run for many hours and must be visually checked frequently. To increase efficiency, a flexi-frame chromatography support grid should also be located near the exit. Because space is usually limited in this type of laboratory facility, storage units should be placed to the rear so that materials on them will be less likely to get bumped and spilled. Examples of average and small environmental rooms are shown in Figure 11-1.

11.2.2 Egress

11.2.2.1 Doors. Two doors are not practical or required in controlled environment rooms less than 200 NSF (20 m^2) because of limited wall perimeter. However, controlled environment rooms of 400 NSF (37 m^2) and over should have a second egress. For rooms between 200 and 400 NSF, a second egress should be considered based on (1) individual need, and (2) understanding of the materials stored, processed, and the work conducted therein.

11.2.3 Furniture Location

Work surfaces and storage shelving should be designed and located to facilitate ease of egress. Other furnishings should be kept to a minimum so that aisles are not obstructed. In controlled environment rooms having a minimum inside width of 15 ft (4.5 m) an island-type work surface, bench, sink, or storage unit may be located inside the room, provided a minimum egress aisle width of 60 in. (1.5 m) is maintained to the exit. Aisles between parallel rows of work surfaces or storage units, as well as aisles between an interior wall and a work surface or storage unit, should be not less than 36 in. (1 m). Desks should not be placed in controlled environment rooms.

11.2.4 Access for Disabled Persons

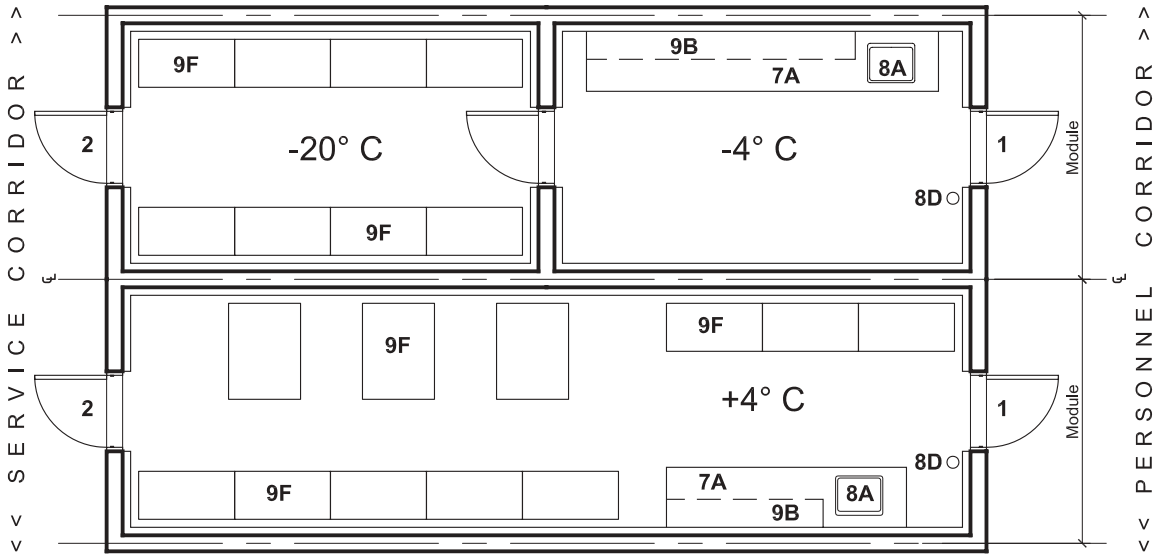
To make controlled environment rooms accessible to persons in wheelchairs, a clear floor area of at least 5×5 ft (1.5×1.5 m) will be required for turning the wheelchair around, and a work surface 32 in. (0.8 m) high should be provided. A ramp is commonly used to roll in laboratory carts. However, ramps with a slope not greater than 1:12 may be used for access by a wheelchair and should be capable of safely supporting that load. The dimension of ramp will depend on the application. The minimum weight standard should be 100 lbs (450 kg).

11.3 HEATING, VENTILATING, AND AIR-CONDITIONING

11.3.1 Introduction

HVAC requirements for a controlled environment room depend on the temperature and humidity conditions to be maintained, as well as on the activities to be performed. Outside air-volume rates should be kept to a minimum, particularly when close humidity control is required. Most cooling systems are of the direct expansion refrigeration type with separate condensing unit and evaporator coil section.

Unless there are special requirements, such as a need for a fume hood or numerous local exhaust points, outside air exchange requirements for controlled environment rooms will be minimal. A minimum of 50 CFM (0.025 m^3/s) of outside conditioned air is recommended when people must work inside the controlled environment room regularly for prolonged periods. To provide



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 11-1. Controlled environment laboratory layout with multiple rooms.

fresh filtered air for the people using the room, a supply air blower with full modulating control should be connected to a ceiling plenum located at the entrance to the work area and the supply air should be discharged directly through the evaporator or heating coil. Air should be exhausted to the building exhaust air system through an adjustable damper. Supply and exhaust air volumes will depend on room size and the activities to be conducted inside the controlled temperature room. When toxic chemicals will be used, spot exhaust points or chemical fume hoods will be needed, and they should conform to the recommendations in Chapter 2, Section 2.3.4.4.

11.3.2 Temperature and Humidity

11.3.2.1 Room Temperature. For low-temperature control, the refrigeration system should contain a direct expansion unit of industrial quality designed to operate continuously with an integral evaporator coil. Room temperature controller and other instrumentation should be designed to control coil temperature over the full temperature range on a precise demand basis. The control mode should be fully modulating, with proportional action from 0–100% of total condensing unit capacity over the full-rated temperature range. The main controller should include a means for direct setting of the control point, input and output meters to display the proportioning action of the control unit, a temperature indicator to permit monitoring room temperature conditions with a set-point accuracy of not less than 0.5% of the full-rated temperature span, and a proportioning band of not less than 1% above or below the control point. The temperature-sensing unit must possess adequate inherent stability, accuracy, and sensitivity to provide the degree of temperature control

required for the operations that will be conducted in the controlled environment room. A recorder with a 12-in. (0.35 m) circular 7-day or 24-h chart should be installed in a central control panel to assist in monitoring the stability of the set conditions.

11.3.2.2 Room Humidity. When humidity control is required in controlled environment rooms, extreme care must be exercised in the selection of the humidifier. For humidification, steam injection remains the most popular choice. However, steam from a central boiler plant or a local boiler in a facility is treated with chemicals that, some studies have shown, though unlikely can create harm to the items stored. (See Chapter 1, Section 1.5.6). A review of effect of the chemicals on items stored in constant temperature rooms should be done.

There are many humidifiers available, such as cold mist types and steam generators that use building steam to evaporate city water or pure water to make clean steam. Self-contained humidifiers make clean, dry, low-pressure steam electrically and collect the minerals in a replaceable cartridge. Control should be in response to a pneumatic or electronic proportioning control system. The controller should be fully calibrated and include an electronic sensing unit, an integrated recorder with a 12-in. (0.35 m) recording chart, and a set-point accuracy of not less than 0.5% for the full humidity span.

11.3.3 Emergency Alarm and Control System

A safety control and alarm system, provided by the manufacturer, should be mounted on an outside wall of the cold or warm room adjacent to the entrance door. It should consist of an independent electrical low- and high-temperature control system that will take over operation in the event of a main control failure and should contain an alarm buzzer to give audible warning in the event of temperature deviations. The safety control and alarm should be equipped with the following components: a main on/off switch for the entire system, a silencing switch for the buzzer, and a reset switch to return the system to normal operation. Terminals should be provided to connect the alarm system into a remote central location. See Section 2.4.4 for more details.

11.4 LOSS PREVENTION

The information provided in Chapters 1 and 2, Sections 4 applies to all controlled environment rooms, and all relevant items should be implemented. In addition, when an experiment could give rise to a hazardous situation, either by depleting oxygen or by releasing toxic contaminants, provisions should be made during the building design phase to install facilities for supplied air or self-contained breathing apparatus and one or more atmospheric monitors to identify the hazardous situation and provide an appropriate alarm.

11.5 SPECIAL REQUIREMENTS

11.5.1 Materials of Construction

Controlled-environment rooms may contain a rapidly degrading environment for some of the services and equipment installed in it. For example, hot rooms can reduce the normal expected life of electrical wiring through deterioration of the insulation. The National Electrical Code (NFPA 70, 2011) should be consulted to determine whether an over-design in wire size and insulation type will be required because of the specific temperatures and current loads that will be encountered.

Frequently, cold rooms become wet with moisture that condenses from building air that enters the room when people go in and out. The moisture affects materials of construction such as steel shelves, electrical conduits and fixtures, and moisture-absorbing materials. The use of a vapor-tight electrical system can help prevent early deterioration and possible shock hazards. A careful selection of materials should result in shelves, structural components, and finishes in the cold room that do not corrode.

When designing for humidity rates above 60%, there is a potential for microbiological growth. In this case, the materials of construction should be easily cleanable and be of a nonorganic nature to the extent possible. If there is to be prolonged human occupancy under these conditions, the use of HEPA filtration of the recirculated air should be considered.

11.5.2 Lighting

Interior lighting should be high-output fluorescent fixtures designed to provide 70 foot-candle (750 lx) evenly distributed when measured at 40 in. (1 m) above the floor. Ballasts should be mounted externally, and fluorescent lamps should have moisture-proof covered socket ends. Lens panels should be the diffuser type made from acrylic plastic. LED lighting can be an attractive alternative.

11.5.3 Renovation

It is critical that the controlled-environment room is decontaminated before renovation starts. Consult

methods described in Part I, Section B. A careful analysis must be made of the new requirements of the room relative to the existing room design. Several electrical and mechanical changes may be required. The integrity of insulation and the vapor barrier in the room must be checked.

11.5.4 Security

The use of proprietary materials and operations in the controlled environment room may require locks. See security considerations discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1.

12

HIGH-PRESSURE LABORATORY

12.1 DESCRIPTION

12.1.1 Introduction

A high-pressure laboratory is designed, constructed, and operated to permit safe experiments at gas pressures over 250 psig (1700 kPa) and liquid pressures over 5000 psig (35,000 kPa).

Because of the high-energy potential of high-pressure fluid systems, special consideration must be given to the location of the laboratory within the building structure and to its materials of construction. For example, a 10-ft^3 (0.28-m^3) volume of dry nitrogen at 6000 psig (41,000 kPa) has the energy equivalent of approximately 300 lbs (136 kgs) of TNT. Designing a laboratory to handle a potential explosion of this magnitude requires great care. Ideally, the laboratory should be a freestanding barricaded building, but when it is located inside a laboratory building, the ultimate in control of the qualities and quantities of materials that will be used in its construction and in the management of laboratory procedures will be required.

12.1.2 Work Activities

The investigative procedures used in a high-pressure laboratory include those used in a general chemistry laboratory except that they are conducted on gases and liquids at higher pressures. Pressure testing of vessels, high-pressure reactions, and some handling of very high-temperature, as well as cryogenic liquids may take place in the high-pressure laboratory. Small quantities of high explosives such as trinitrates may also be used, but quantities of more than 2 oz (57 g) must be banned.

12.1.3 Equipment and Materials Used

High-pressure oil pumps, gas compressors piping, and valves; accumulators; barricades; and compressed gas cylinders are used in high-pressure laboratories. There is likely to be a need for some chemical storage. The location of each of these items should be considered carefully from a safety standpoint to protect one from another in the case of a system malfunction or accident. Because much of the equipment is necessarily heavy, floor loading requirements must be evaluated early in the building planning process. Access restrictions will apply to this laboratory during many operating conditions.

12.1.4 Exclusions

High-pressure energy systems that exceed the design capabilities of the facilities must be carried out in other locations. Before construction, the designer/architect/engineer must determine the maximum size of experiments and pressure conditions that will be allowed in the facility; management controls must be instituted to make certain these limits are never exceeded. High-explosive materials such as trinitrates beyond 2 oz (57 g) are excluded from this laboratory.

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12.2 LABORATORY LAYOUT

12.2.1 Introduction

All provisions of Chapter 2, Section 2 apply to high-pressure laboratories and should be implemented. In addition, wall, floor, and ceiling construction should be designed to contain the explosive violence of a maximum design or accidental energy release. One method of construction is to contain the released energy; an alternative method is to channel the release of energy into safe pathways designed to protect persons and property outside the laboratory.

Full containment of an explosion requires the construction of high-pressure areas or "cells" along outside walls. The walls and ceiling of cells are constructed of 18 in. thick (0.45 m) reinforced concrete or steel, or of combinations of materials of adequate strength to contain the maximum anticipated explosion. All exterior approaches to the cells must be secured. The cell is sealed with a door assembly of required strength and fire rating. See the U. S. Department of Energy publication, *DOE Explosives Safety Manual*, DOE M440.1-1A, for additional information (DOE, 2006; www.directives.doe.gov). This strength should be consistent with that of the walls and ceiling. Personnel conducting experiments in which explosions are anticipated are restricted from the active cell during the actual experiment. An adjacent room, adequately protected from the maximum design energy release, may be needed for remote monitoring and control equipment.

Venting panels may be installed in a wall, or if the high-pressure laboratory is in a single-story building, in the roof to direct the safe release of energy of exploding materials. The panels are designed to open outward by the force of a sudden pressure rise before structural damage occurs. The free area required and release pressure are specified for laboratories in *Venting of Deflagrations* (NFPA 68, 2007) according to the amounts and nature of the explosive or volatile materials used. High-order explosions or detonations have pressure rise rates so rapid that venting panels may not open in time to offer adequate building protection and should not be relied upon for this type of explosion research. Wall construction and door assemblies should be structured to withstand the pressure expected by the type and maximum quantity of explosive material. The area outside the blowout or pressure relief panels should be protected as described in the following paragraph.

Locations for blowout panels and cell walls should be selected in locations that prevent passersby from close approach. Blowout panels should be securely tethered to immovable elements of the building structure with loose ropes of strong steel cable to prevent their release as free projectiles after a forceful explosion. In addition, heavy mesh screening or a similar barrier should be installed to contain the debris that may be ejected through the opening. Earth berms of sufficient height and breadth are the best means for containment, but if there is not enough area outside the high-pressure laboratory for a protective berm, a solid blank wall with the strength to withstand the blast should be constructed. As a minimum, a high, heavy-duty chain-link fence should be erected far enough away to prevent any dangerous approach to the panels or cells.

When the high-pressure laboratory is within a multistory building, it should be located on the ground floor. Windows or other building openings above blowout panels should be protected from possible flame spread and explosion debris by a solid canopy above the blowout panel of sufficient strength and fire rating to withstand the hazards.

All laboratories and storage rooms involving a significant explosion hazard must comply with NFPA 45 (NFPA, 2011), NFPA 30 (NFPA 2012), local building codes, and fire department regulations.

The construction of a fully equipped high-pressure laboratory can be avoided by substituting a specially designed, heavy-walled vessel that is large enough to house the experiment plus auxiliary equipment and strong enough to contain the energy resulting from any foreseeable accident. For specific details on the construction of heavy-walled pressure vessels, the ASME Unfired Pressure Vessel Code, Section VIII (ASME, 2010) should be consulted.

12.3 HEATING, VENTILATING, AND AIR-CONDITIONING

12.3.1 Special HVAC Requirements

A high-pressure laboratory presents a number of unique problems for the designer. High-pressure laboratories are seldom air-conditioned, but when they are, the ducts and fans may have to be specially constructed and mounted to withstand explosions. Also, special venting arrangements must be provided to relieve excessive pressure safely under unexpected circumstances.

When a high-pressure laboratory functions at ordinary pressures, all the provisions of Section 3 in Chapters 1 and 2 that are applicable to its new use should be implemented, plus those that apply to whatever type of laboratory it most closely resembles.

Normal ventilation rates described in Chapter 2, Section 2.3 are considered more than adequate for most high pressure laboratory operations, but the use of more

than trace amounts of highly toxic chemicals will require reevaluation of ventilation rates.

12.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

All the recommendations provided in Chapters 1 and 2, Section 4 apply to high-pressure laboratories and should be implemented. In addition, the following recommendations should be given careful consideration.

12.4.1 Portable Fire Extinguishers

Space should be provided for hand-portable fire extinguishers of larger capacity than those used in other laboratory types. They should be sized and typed in consultation with a safety specialist to make certain they will provide adequate protection for the planned operations. Units of size 6A 60BC are recommended as a minimum.

12.4.2 Compressed Gas Cylinder Racks

Racks similar to those described in Chapter 2, Section 2.4.7 should be located so that an explosive incident within the high-pressure laboratory will not spray the storage area with shrapnel that may puncture other tanks and cause the explosive release of additional toxic or flammable materials.

12.4.3 Fire Suppression Systems

Water sprinklers as discussed in Section 4 of Chapter 1 and 2 should be installed as a first line of suppression. Unique fire potential may require the addition of special rapid response suppression systems.

12.4.4 Chemical Storage

Chemicals used in high-pressure laboratories must be stored as described in Section 4 of Chapters 1 and 2 with the additional consideration of protecting them from explosive release with resultant projectiles. This may require the addition of reinforced separation walls. Any high explosives that will be stored in this laboratory must be stored in magazines and in accordance with Occupational Safety and Health Administration, OSHA 29 CFR 1910.109, "Explosives and Blasting Agents" (OSHA, 2012), Department of Transportation, DOT 49 CFR Chapter 1, Parts 100 to 185, "Hazardous Material Regulations" (DOT, 2010), and U.S. Bureau of Alcohol, Tobacco and Firearms ATF 27 CFR Part 55 "Commerce in Explosives" (ATF, 2002).

12.5 SPECIAL REQUIREMENTS

12.5.1 Security

See security considerations discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1.

13

RADIATION LABORATORY

13.1 DESCRIPTION

13.1.1 Introduction

A radiation laboratory is designed and constructed to provide a safe and efficient workplace for a wide variety of activities associated with materials that emit ionizing radiation that can be harmful either by direct radiation in the electromagnetic spectrum (such as neutron, gamma, or x-ray energy), by ingestion, or by inhalation of particulate materials that emit ionizing radiation (e.g., alpha, beta). Ordinary chemicals labeled with radioactive isotopes may be in liquid, gaseous, or solid form. They retain the same inherent properties to produce toxic chemical exposures as non-radiolabeled forms and have the added hazard of being radioactive. General chemistry activities may also be performed in this laboratory. It is preferable that this type of laboratory be located in a building containing similar laboratory units, but not necessarily all conducting work with radioactive materials. Not all of the design considerations presented here may be needed in every radiation laboratory. Close communication between users and designers will be necessary to determine when certain items can be omitted without degrading safety. Consultation with a health physicist who may be the laboratory's radiation protection officer is recommended.

13.1.2 Work Activities

The basic experimental procedures used in this laboratory will be similar to those conducted in general chemistry and analytical laboratories, but special provisions must be made for the additional safety procedures that will be required when radioactive materials or radiation-producing equipment are handled. Although this chapter describes a facility similar to a general chemistry laboratory, the safety requirements that are outlined can be applied to other laboratory types, such as chemical engineering, physics, or high-toxicity laboratories, in which radioactive materials will be used. As a design guideline, any laboratory that uses radioactive materials with a total activity greater than 1 mCi should be considered a radiation laboratory. See Appendix C in 10 CFR 20 for an overview of radioactive materials (NRC, 2012).

13.1.3 Equipment and Materials Used

The equipment used in a radiation laboratory will depend on the specific nature of the work; however, in general, it will be similar to that found in a general or analytical chemistry laboratory. X-ray-producing equipment and gamma cell irradiators may be included. Counters for beta and gamma radiation may be used, as

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well as small cyclotrons/accelerators. Note that many radioactive materials are also toxic.

3.1.4 Exclusions

This section does not cover the use of ionizing radiation in connection with animal studies or biological agents. It does not cover activities that produce nonionizing radiation such as lasers and ultraviolet (UV) radiation.

13.1.5 Special Requirements

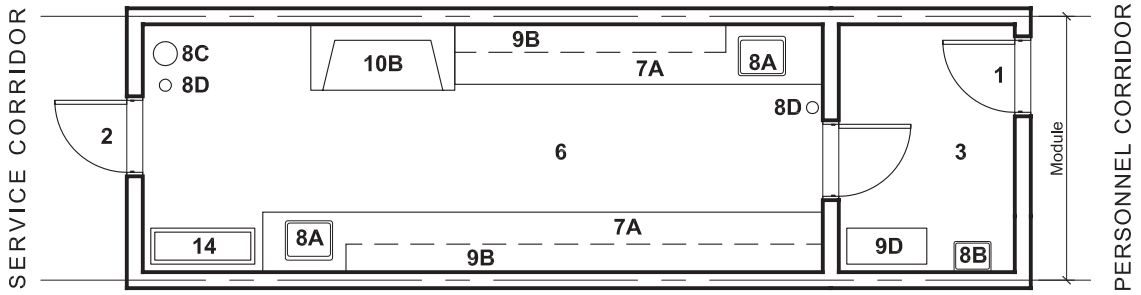
An ionizing radiation laboratory should have special access restrictions. In addition to permits and licenses, there are stringent EPA, OSHA, and Nuclear Regulatory Commission (NRC) requirements pertaining to acquisition, storage, use, release, and disposal of radioactive materials that must be followed. In some cases, provisions must be made for change rooms and showers. Health and safety professionals, including health physics specialists, should be consulted when the total quantities of radioactive materials are likely to equal or exceed a regulatory threshold and whenever estimates of external radiation levels exceed 25% of the maximum allowable human exposure levels. (See 10 CFR 20, Appendix C, 2012.)

13.2 LABORATORY LAYOUT

13.2.1 Introduction

Many laboratory layouts are acceptable. Final choice will depend largely on the type of work to be performed and the available space. In general, energy-emitting devices should be directed away from laboratory entrances and primary egress aisles. A radiation laboratory layout similar to that of a general or analytical chemistry laboratory, as well as a number of specialized work utilization layouts, are described in *Safe Handling of Chemical Carcinogens, Mutagens, Teratogens, and Highly Toxic Substances* (Walters, 1980). Whatever laboratory design is selected, all the provisions of common elements of laboratory design contained in Section 2 of Chapters 1 and 2 apply to the radiation laboratory and should be followed. Some thought should be given to keeping the size of the laboratory to a practical minimum, as shown in Figure 13-1. This will facilitate decontamination should it become necessary. For large radiation-producing equipment, such as is found in an x-ray laboratory or cyclotron, limiting size will reduce the number of potentially exposed individuals.

In addition, the special items that follow should be reviewed for their applicability to the particular laboratory work being planned. Because the need for some of



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 13-1. Example of A one-module radiation laboratory layout.

the special items will depend on the nature of the work and the quantity of radioactive materials that will be used, health and safety professionals should be consulted for assistance.

13.2.2 Change, Decontamination, and Shower Rooms

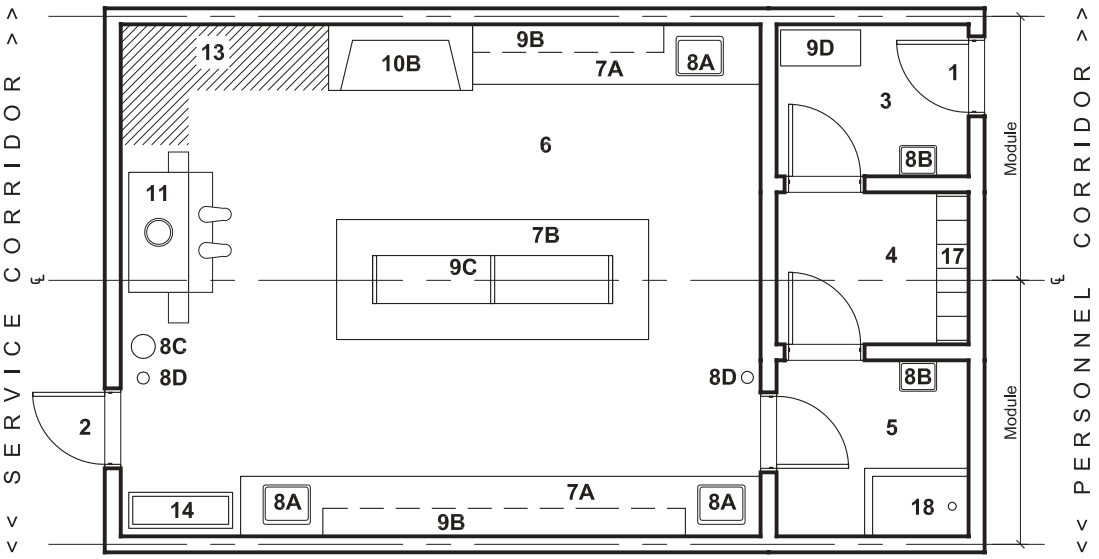
Adequate facilities for laboratory workers to change and shower must be provided when procedural requirements call for the use of full-body protective clothing. For the use of some substances, OSHA and NRC requirements specify that a shower be available as a part of the laboratory, as discussed in Chapter 2, Section 2.2.2.3 and shown in Figure 13-2. The use of other radioactive chemicals necessitates only that there be a shower available in the building. Operations and exposures that only require the use of gloves and a laboratory coat may not require the presence of shower facilities.

13.2.3 Work Surfaces

Work surfaces should be smooth, easily cleanable, and constructed from impervious materials such as stainless steel with integral cove joints. Strippable epoxy-type paint can be used as a substitute. The use of an impervious and disposable bench covering during work should be considered as an aid in the cleanup of radioactive spills.

13.2.4 Floors, Walls, and Ceilings

In areas using liquid or particulate radioactive or radiolabeled chemicals, floor coverings should be of monolithic materials, such as seamless vinyl or epoxy. Cracks in floors, walls, and ceilings may need to be sealed with epoxy or a similar material. All penetrations of walls, floors, and ceilings by utility conduits may need to be



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3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 13-2. Example of a two-module radiation laboratory layout with shower.

similarly sealed with an appropriate sealant such as silicone or similar material recommended by the radiation safety professional. Lighting may need to be provided by sealed vapor- and waterproof units, and lighting fixtures should be flush with the ceiling to eliminate dust collection. The decision to require the above construction methods will depend on the volatility, flammability, toxicity, state, and quantity of radiolabeled and other chemicals used in the facility.

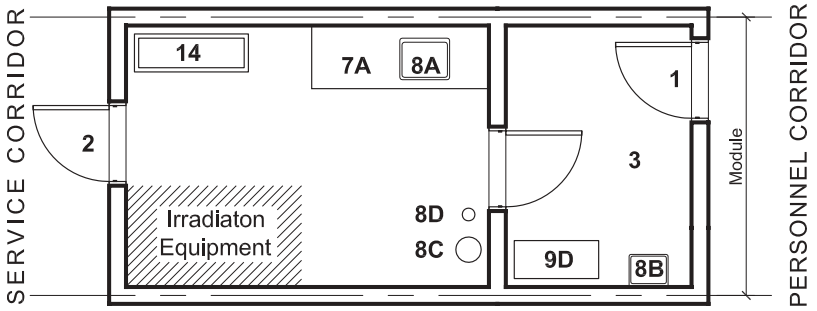
The weight of equipment and/or shielding requirements may affect the design or the capacity of the floor structure for such loads. Loading must also consider transport of equipment into the space. Ceilings should be a seamless, solid, sealed surface and not suspended grid with loose tiles or panels.

13.2.5 Hand-Washing Facilities

Hand-washing facilities should be located within the radiation laboratory and in change and shower rooms. Foot-controlled or infrared-sensing automatic water valves are an aid in limiting contamination spread.

13.2.6 Access Restrictions

Entrances to the laboratory should be posted with permanent signs indicating restricted access due to the use of radioactive materials or radiation producing equipment (e.g., an x-ray unit). Laboratories in which a person may receive in excess of 100 mrem in 1 h at 1 ft (0.3 m) from the radiation source or from any surface that radiation penetrates must have a sign on the entrance door stating "Caution: High Radiation Area." Laboratories in which radiation levels could reach 500 or more rads in 1 h at 39.37 in. (1 m) from a radiation source or any surface through which radiation penetrates must have a sign on the entrance door stating "Grave Danger: Very High Radiation Area" and must be equipped with entry control devices and/or anteroom as shown in Figure 13-3. The use of special key card access and intrusion alarm should be considered for these areas. Refer to 10 CFR 20 for exact requirements for "high" and "very high" radiation areas. Because of access restrictions and isolation of the laboratory, it is recommended that there be a viewing window in the doors. Such windows should not be of a size and construction that they compromise



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 13-3. Example of small irradiation laboratory layout.

design fire ratings. Radiation-producing equipment should be placed so that radiation beams are directed away from windows and entry or exit doorways.

13.3 HEATING, VENTILATING, AND AIR-CONDITIONING

13.3.1 Introduction

The recommendations provided in Chapter 2, Section 3 that apply to radiation laboratories, and all that are relevant to the particular laboratory should be implemented. Additional considerations are given below. Industrial hygiene or radiation safety professionals should be consulted for assistance when large amounts of radioactive materials or ionizing radiation-producing devices will be used.

13.3.2 Fume Hoods

The NRC recommends a face velocity of 150 FPM (0.75 m/s) of maximum open-face area for fume hoods handling radioactive materials. Where this is not required by regulation, we recommend 80–100 FPM (0.5 m/s) of maximum open-face area. An isotope fume hood with cleanable surfaces (Chapter 34, Section 5) should be used.

The use of variable-volume hoods is not recommended. This is because of the potential need to have air cleaners in the system and emission limits. Allowable emissions are based on maximum concentration of materials in the air stream. As the volume flow rate decreases, the concentration will increase due to less dilution.

Where the potential exists to generate aerosols, it is recommended that these hoods be secured by a separate fan and not be manifolded into the laboratory exhaust system. An exception could be made if an air cleaning device is in line before the hood exhaust is introduced to the manifolded system.

13.3.3 Gloveboxes

Work with volatile and powdery radioactive materials, or the use of amounts that may produce concentrations in air above values that define an airborne radioactive exposure of concern, calls for the use of a completely enclosed, ventilated work space, called a glovebox (or gloved box), rather than an isotope fume hood. The glovebox should meet the specifications of the American Conference of Governmental Industrial Hygienists (ACGIH, 2010) and those outlined in Chapter 29, Section 29.6.2.5 directional control. Other sources of information include ANSI Standard Z9.5 "Laboratory Ventilation" (ANSI/AIHA, 2012) and the American Glovebox Society Standard "Guidelines for Gloveboxes" (AGS, 2007). Local ventilation at the entrance port may be required. The glovebox is a closed system and should be kept under a negative static pressure of 0.25 in. w.g. (60 Pa) relative to the laboratory. The laboratory itself may be under a negative pressure of 0.05 in. w.g. (12 Pa) relative to the atmosphere to prevent exfiltration of potentially contaminated air, making the box interior 0.3 in. w.g. (80 Pa) lower than atmospheric pressure.

13.3.4 Spot Exhaust for Instruments

Analytical instruments that are used to weigh or manipulate radioactive chemicals should be equipped with spot exhaust ventilation at potential points of contaminant release or be completely enclosed in a ventilated enclosure such as a glovebox or an isotope fume hood. Specific design requirements will vary with the type of equipment and chemical used. The design principles in Chapter 5 of *Industrial Ventilation: A Manual of Recommended Practice for Design, 27th Edition* (ACGIH, 2010). Consultation with industrial hygienists and health physicists is highly recommended when the use of radioactive materials may generate radiation levels greater than 25% of the recommended maximum exposure levels.

13.3.5 Storage Facilities

Cabinets, refrigerators, and all other equipment items and areas used for storage of volatile radiolabeled materials should be provided with local or general exhaust ventilation sufficient to maintain an inward directional airflow and prevent buildup of radioactive contaminants within the storage space. Laboratory users must be consulted to determine whether any radiolabeled materials that may release vapors or gases will be stored in the facility. Chapter 1, Section 1.4.7 and Chapter 2, Section 2.4.6 contain design information for chemical storage facilities.

13.3.6 Filtration of Exhaust Air

Sometimes air exhausted from fume hoods, gloveboxes, and spot exhaust systems must be filtered before release to the environment to avoid atmospheric pollution and to conform with NRC regulations. Industrial hygienists and health physicists should be consulted for an evaluation of this need. The first stage of filtration should be a prefilter rated for 85% atmospheric dust efficiency followed by a HEPA filter with not less than 99.97%

efficiency for 0.3-μm particles. A second stage containing an absorbent such as activated charcoal may be required when the radioactive effluents are gases or vapors. The components of the air-cleaning train sequence and the size of the elements will depend on the radioactive materials used and the total quantity of air to be exhausted. All air-cleaning elements should be capable of being changed without exposure of maintenance personnel. Bag-in, bag-out procedures provide greatest personnel protection. See Chapter 31 for additional information on air cleaning. The filtration devices should be located as close as possible to the source of generation to reduce the length of duct that may become contaminated and thus increase the necessary decommissioning effort.

13.3.7 Exhaust Stream Monitors

The NRC requires continuous air monitoring of exhaust air streams for some radioisotopes when the concentrations exceed regulated levels. Access for sampling locations must be provided in the initial design when it is anticipated that effluent air monitoring may be needed. Monitoring pumps should be hard wired to prevent accidental outage.

13.3.8 Radioisotope Fume Hood Stack Design

There are regulations establishing the maximum allowable radioisotope emissions; they are calculated separately for each radionuclide. If filtration of exhaust air is not available or does not fully meet the requirements then exhaust stack and intake designs must be carefully evaluated to determine that building occupants or neighbors are not inadvertently exposed to unnecessary levels of radiation. See Chapter 1, Section 1.3.5 for more detailed discussion on stack design.

13.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

The recommendations contained in Sections 4 of Chapters 1 and 2 apply to laboratories using radioactive materials and should be followed.

13.4.1 Radioactive Waste

When special procedures for handling radioactive materials in laboratory waste are required, provisions for separate radioactive waste storage areas and easy access to shipping areas must be made in the building plans. All provisions of Chapter 1, Section 1.4.6 apply to radiation waste storage facilities plus the use of radioactive shielding when required. See Chapter 27, Hazardous Chemical, Radioactive, and Biological Waste Handling Rooms, for more details.

13.5 SPECIAL CONSIDERATIONS

13.5.1 Shielding

Some radiation-producing equipment and radioactive materials require the use of special shielding. Generally, cobalt and cesium irradiators should be placed in separate, small rooms that are lead lined or constructed with dense concrete walls, floors, and ceilings to shield the source. These facilities and the equipment used in them add many tons of extra weight to the structure and require special consideration during structural design.

13.5.2 Iodination Facility

Iodination facilities are becoming less critical in biomedical research due to the development of fluorescent and other labeling chemicals. If it is determined that one or more is necessary, then it may be desirable to designate one laboratory per building, or an appropriate number of floors, where iodinizations can be performed. This will allow for better control of this activity.

13.5.3 Renovation Considerations

All the provisions provided in Chapters 3 and 4 should be reviewed for their applicability and implemented where appropriate.

13.5.4 Security

The use of highly regulated materials in the radiation room will require the application of material and laboratory security. See the security considerations discussed in Chapter 1, Section 1.5.4.

Security must be provided for storage of radiation producing materials. Locked areas for storage and restricted access to the laboratory by the use of locked doors are minimum provisions. Access key cards should be used when a higher level of security is needed. See NRC Policy for additional information (NRC, 1998).

Equipment that contains large radioactive sources will require special security features including access restrictions, video monitoring and radiation alarms (DOE, 2009).

14

BIOSAFETY LABORATORY

14.1 DESCRIPTION

14.1.1 Introduction

Accidental contact with infectious and toxic biological agents is an occupational hazard for persons who work in laboratories handling oncogenic viruses, infectious agents, and similar harmful biological substances. Often, research activities with these substances call for additions of radioactive tracers and chemicals that are known to be mutagenic, teratogenic, or carcinogenic, thereby substantially increasing the hazardous nature of the work. From 1930–2000, the registry of laboratory-acquired infections listed more than 5,955 cases; it has been estimated that this number represents only a fraction of the total because reporting of these cases is not compulsory. More recently, from 2004–2010, seven laboratory-acquired "select agent" infections were reported to the CDC. Three hundred ninety-five select agent incidents were reported in the same 6-year period. Of these, there were 196 reported loss-of-containment incidents (NTI Global Security Newswire, 2011).

The CDC and the NIH have classified laboratories that handle hazardous biological agents into four biosafety categories (outlined below) that correspond to a four-tiered classification of infectious agents that increase in hazard from 1 to 4 for microbiological laboratories and for animal research laboratories (U.S. Health and Human Services [HHS], 2007). The publication *Biosafety in Microbiological and Biomedical Laboratories* latest edition (HHS, 2009) should be consulted to determine the biosafety laboratory level required for specific etiological agents, oncogenic viruses, and recombinant DNA strains. Additionally, it describes requirements for four levels of animal biosafety laboratories that are suitable for work with etiological agents having a corresponding level of hazard. These provisions are reviewed in Chapter 22, Animal Research Laboratory.

The NIH has an internal document on policy and guidelines for biosafety published online [NIH, 2012]. The U.S. Department of Agriculture has a three-tiered classification of infectious agents pertaining to plants and animals used in agricultural processes and products designated as BSL-1Ag to BSL-3Ag in the Agricultural Research Service (ARS) *Facility Design Standards* latest edition (USDA, 2012).

This chapter addresses laboratory design in relation to the safe handling of microbiological agents requiring a Biosafety Level 3 (BSL-3) facility; this is the most-complex and common biosafety facility built today. Design requirements for BSL-1 and BSL-2 laboratories are incorporated in this coverage of BSL-3 laboratories. BSL-4 laboratories will be defined, but not be covered in any detail in this text. Only a few facilities in the United States are currently certified for BSL-4 use: They require the services of design and construction experts specific to BSL-4 technology. Our discussion of BSL-4 labs will be adequate for familiarization on design principles, but not for their full design. BSL-3 biological

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

safety laboratories are designed as secondary containment facilities by the creation of physical enclosures and negative air pressure. They include within them primary containment facilities, i.e., biological safety cabinets (BSCs) in which hazardous operations are conducted. BSCs and their performance criteria are described in Chapter 32, Section 32.9.

A *Biosafety Level 1* (BSL-1) lab is suitable for work involving well-characterized agents not known to consistently cause disease in healthy adults and that are of minimal potential hazard to laboratory personnel and the environment. This laboratory is not necessarily separated from the general traffic patterns in the building. Work is generally conducted on open bench tops using standard microbiological practices. Special containment equipment and facility design are neither required nor generally used.

Nevertheless, it is prudent to equip undergraduate microbiology teaching laboratories (perhaps the only ones likely to use BSL-1 organisms exclusively) with facilities at least as secure as the next higher level to begin familiarizing microbiology students with the safety facilities and procedures they will need to use during their professional careers. Hand-washing facilities are required in the laboratory, and provision for storage of laboratory coats, gowns, or uniforms is recommended. Operable windows are discouraged, but if laboratories have windows insect screens must be installed. Most general-purpose laboratories, such as a general chemistry laboratory (Chapter 5), are suitable for work at BSL-1 provided that work surfaces are easily decontaminated and can resist frequently applied decontaminates.

A *Biosafety Level 2* (BSL-2) lab is similar to a BSL-1 and is "suitable for work involving agents of moderate potential hazard to personnel and the environment. It differs from BSL-1 in that access to the laboratory is limited when work is being conducted and all procedures in which infectious aerosols or splashes may be created are conducted in biological safety cabinets or other physical containment equipment" (HHS, 2009). Currently, most general autopsy and morgue facilities are designated as BSL-2 (National Association of Medical Examiners [NAME], 2009). Refer to Chapter 20, Morgue Facility, for more discussion. A BSL-2+ lab has no difference in requirements than BSL-2 facilities, but incorporates BSL-3 procedures and operations. It is not an official CDC/NIH designation. Local jurisdictions having authority may have their own requirements for biosafety and security. The BSL-2 laboratory can be designed to make accommodation for the conversion to a BSL-3 in the future.

One-pass ventilation facilities should be designed to maintain the BSL-2 laboratory negative pressure relative to adjoining space whose directional airflow could enter the BSL-2 laboratory. Hand wash sinks and emergency eyewash stations should be provided in BSL-2 laboratories.

Clinical laboratories that receive specimens for diagnostic services, serological identification of isolates, and processing of blood-borne pathogens such as hepatitis B virus and human immunodeficiency virus (HIV) can usually be operated safely within BSL-2 facilities. This biosafety level is consistent with the OSHA standard, Occupational Exposure to Blood Borne Pathogens (OSHA 1910.1030; 2012). When procedures might produce airborne droplets, BSCs must always be used. In addition, an eyewash station should be provided.

The *Biosafety Level 3* (BSL-3) lab is "applicable to clinical, diagnostic, teaching, research, or production facilities in which work is done with indigenous or exotic agents with a potential for respiratory transmission, and which may cause serious or potentially lethal disease as a result of exposure by the inhalation route. All laboratory manipulations should be performed in biological safety cabinets or other enclosed equipment, such as a gas-tight aerosol generation chamber" (HHS, 2009). In addition to all the requirements of a BSL-2 laboratory, the BSL-3 laboratory must be separated from areas that are open to unrestricted traffic flow within the building, and passage through a series of two self-closing lockable doors with emergency exit hardware (two-door anteroom described in Chapter 2, Section 2.2.2.3) is a basic requirement for entry into the laboratory from access corridors or from another space rated at a lower biological level. Clothes-changing areas may be included in anterooms. "A method for decontaminating all laboratory wastes should be available in the facility, preferably within the laboratory (e.g. autoclave, chemical disinfection, incineration, or other validated sterilization method)" (HHS, 2009). Floors should be monolithic, slip resistant, and coved for ease of cleaning, decontamination, and containment of liquids. For definition of these terms, refer to Chapter 2. All penetrations in floors, walls, and ceilings must be sealed including spaces and gaps around ducts, pipes, conduits, etc., for conducting sterilizations and pressure containment certification. If needed, install ventilation grilles in doors to assist directional airflow into BSL-3 laboratories; however, doors must be sealable for conducting sterilizations.

The *Biosafety Level 3 Enhanced* (BSL-3E) lab requires the following per the HHS (2007): "Enhanced environmental and personal protection may be required by the [infectious] agent summary statement, risk assessment, or applicable local, state, or federal regulations. These laboratory enhancements may include, for example, one or more of the following, according to

requirements by the jurisdiction having authority and no organism above BSL-3 may be used:

- Anteroom(s) for clean storage of equipment and supplies with dress-in and shower-out capabilities
- Gas-tight dampers to facilitate laboratory isolation
- Final HEPA filtration of the laboratory exhaust air [refer to Chapter 31, Air Cleaning]
- Laboratory (liquid) effluent decontamination (sterilization)
- Advanced access control devices, such as biometrics
- HEPA filter housings should have gas-tight isolation dampers, decontamination ports, and/or bag-in/bag-out (with appropriate decontamination procedures) capability"

The *Biosafety Level 4* (BSL-4) lab is "applicable for work with dangerous and exotic agents that pose a high individual risk of life-threatening disease, which may be transmitted via the aerosol route and for which there is no available vaccine or therapy." "The laboratory worker's complete isolation from aerosolized infectious materials is accomplished primarily by working in a Class III BSC or in a full-body, air-supplied and positive-pressure personnel suit" (HHS, 2009). Agents with a close or identical antigenic relationship to Biosafety Level 4 agents are handled at this level until sufficient data are obtained either to confirm continued work at this level, or to work with them at a lower level. The facility is either in a separate building or in a controlled area within a building, which is completely isolated from all other areas of the building.

In addition to containing all of the equipment and special construction details required for a BSL-3 laboratory, the Class III cabinet-equipped laboratory provides outer and inner change rooms separated by a shower; a two-door autoclave, pass-through dunk tank, and ventilated anteroom for gaseous decontamination of materials, supplies, or equipment passing out of the facility; and a hands-free or automatically operated handwashing sink near the door and in the outer and inner change rooms.

Backflow-prevention devices protect all liquid and gas services. "Services, plumbing or otherwise that penetrate the laboratory walls, floors, ceiling, must ensure that no backflow from the laboratory occurs. These penetrations must be fitted with two (in series) backflow-prevention devices. Consideration should be given to locating these devices outside of containment. Atmospheric venting systems must be provided with two HEPA filters in series and be sealed up to the second filter" (HHS, 2009). In addition, all liquid effluents from the facility (including floor drains, sinks, and autoclave chambers) must be decontaminated before being discharged to a sanitary sewer and the decontamination process must be validated physically and biologically and documented. "Effluents from [personnel] showers and toilets may be discharged to the sanitary sewer without treatment" (HHS, 2009). Criteria for shower and toilet effluent should be developed and protocols should be written for occupants using bathroom fixtures within BSL-3 and BSL-4 facilities.

A dedicated nonrecirculating ventilation system, balanced to ensure flow from areas of less potential hazard to areas of higher hazard potential, is required for a BSL-4 facility. All air introduced into and withdrawn from these high containment laboratories must pass through certified HEPA filters. Chapter 31, Air Cleaning, describes HEPA-filter operations. HEPA-filter housings, or caissons, should be designed to allow filters and caissons to be decontaminated before opening them to make a filter change.

The *BSL-4 Suit laboratory* requires facilities and equipment that have protective and containment functions similar to those of the BSL-4 cabinet laboratory. A Class II biological safety cabinet may be used in BSL-4 suit laboratories. In addition, a continuous breathing-air supply system with outlet fixtures attached to flexible tubing must be well distributed throughout the laboratory for personnel to connect to during their occupancy. The most significant high-containment facility feature is a self-starting emergency electrical power source for the exhaust systems, life-support systems, alarms, lighting, entry and exit controls, and biological safety cabinets when the entire facility cannot be so accommodated. Additional area is required to support the suit laboratory for the following facilities: a suit dressing room; a suit decontamination shower, in addition to a personal shower; and a suit repair shop and storage room.

Table 14-1 shows an estimate of relative costs for new construction of BSL-1 to BSL-4 laboratory facilities. Table 14-2 illustrates the overall criteria and impact on facilities from BSL-1 to BSL-4 in a checklist.

14.1.2 Work Activities

The activities performed in BSL-3 laboratories include work with low- to moderate-risk biological agents for purposes such as research, teaching, and clinical diagnosis. "Primary hazards to personnel working with these agents relate to autoinoculation, ingestion, and exposure to infectious aerosols" (HHS, 2009). BSL-3 laboratories are called for, even when dealing only with Safety Level 1 and 2 agents, whenever large quantities are manipulated and when aerosolization processes are

TABLE 14-1. Comparison of Area and Cost Factors for Biosafety Level Laboratories

	BSL-1	BSL-2	BSL-3 Standard	BSL-3 Enhanced	BSL-4 Cabinet	BSL-4 Suit
Net Area (NSF)	1,000	1,000	1,100	1,400	1,700	2,400
Gross Area (GSF)	1,538	1,667	2,200	2,979	4,474	7,273
NSF / GSF Ratio	0.65	0.60	0.50	0.47	0.38	0.33
Relative Cost Factor	1	1.25	2	2.5	4	6

TABLE 14-2. Checklist of Factors and Features for Biosafety Level Laboratories

	Infectious Agent	BSL-1	BSL-2	BSL-3	Enhanced BSL-3E	Cabinet BSL-4	Suit BSL-4
Hazard	Not harmful to humans or environment, work possible on open bench	✓					
	Moderate hazard to people, environment; vaccine and treatment known		✓				
	Potential for aerosol transmission			✓	✓		
	Serious or lethal hazard to people; vaccine and treatment known			✓	✓		
	Serious, lethal, or unknown hazard to people; no vaccine or treatment available					✓	✓
Personnel	Health monitoring			○	○	✓	✓
	Baseline serum level measured			✓	✓	✓	✓
	Training		✓	✓	✓	✓	✓
	Legal Issues & Lab Practices						
Certification	Certification required (NIH policy guide)			✓	✓	✓	✓
Practices	Pressure-decay test required			○	○	✓	✓
	Sterilize lab clothing before laundering			✓	✓	✓	✓
	Sterilize all solid and liquid material waste			✓	✓	✓	✓
	All work w/ infectious agent done in BSC		✓	✓	✓	✓	✓
	Utility Features						
Electric	Emergency power generation system			✓	✓	✓	✓
Plumbing	Liquid effluent kill-tank			○	○	✓	✓
Fire Protection	Class A FP system and wet sprinklers	✓	✓	✓	✓	✓	✓
	Safety Equipment						
Sterilizer	Autoclave available in bldg		✓				
	Autoclave, 1-door in suite			✓			
	Autoclave, 2-door in suite				✓	✓	✓
	Dunk tank for item transfers out of containment lab			○	○	○	○
Certified	Biosafety Cabinet II Type A	○	✓	✓			
BSC	Biosafety Cabinet II Type B			✓	✓		✓
	Biosafety Cabinet III					✓	
Splash	Emergency deluge shower	✓	✓	✓	✓		
Protection	Emergency eyewash fountain	✓	✓	✓	✓	✓	
Personal	Handwash sink	✓	✓	✓	✓	✓	✓
Hygiene	Laboratory coat		✓	✓	✓	✓	
	Personal protective equipment		✓	✓	✓	✓	
	Positive pressure-air sealed full-body suit						✓
Life Safety	Self-contained breathing air					✓	✓
Sharps	Needles/sharps container	✓	✓	✓	✓	✓	✓
Materials Transfer	Pass-through box with interlocking doors		○	✓	✓		
	Facility Feature						

(*Continued*)

TABLE 14-2. (*Continued*)

	Infectious Agent	BSL-1	BSL-2	BSL-3	Enhanced BSL-3E	Cabinet BSL-4	Suit BSL-4
Doors	Automatic door closer	○	✓	✓	✓	✓	✓
	Door locks	○	✓				
	Door locks with access control system	○	○	✓	✓	✓	✓
Surfaces	Cleanable floors	✓					
	Cleanable floors, ceilings, walls	○	✓	✓	✓	✓	✓
	Cleanable lab furniture	○	✓	✓	✓	✓	✓
	Cleanable work countertops	✓	✓	✓	✓	✓	✓
	All penetrations in lab sealed			✓	✓		
	All penetrations in lab sealed gastight					✓	✓
	Water-resistant floors	✓	✓				
	Water-resistant floors and walls			✓	✓	✓	✓
	Water-resistant work counters	○	✓	✓	✓	✓	✓
Air-Lock	Provide air-lock(s)			✓	✓	✓	✓
	Provide air-lock with gowning			✓			
Anteroom	Provide anteroom with gowning and/or changing			○	✓	✓	✓
	Provide anteroom for gowning and shower-into lab					✓	✓
	Provide anteroom for clothes change and shower-out lab				✓	✓	✓
	Provide anteroom for suit decontamination shower-out						✓
Equip Decon	Provide a gastight room for equipment and furniture gaseous sterilization			○	✓	✓	✓
Windows	Exterior windows	○	○	○	○	✗	✗
	Exterior windows - operable with insect screens	✓	✓	✗	✗	✗	✗
	Interior windows view into lab	○	○	○	✓	✓	✓
	Ventilation Features						
Airflow	Airflows into lab, negative pressure	○	✓	✓	✓	✓	✓
Exhaust	Natural ventilation possible	○	○	✗	✗	✗	✗
	Mechanical exhaust	○	✓	✓	✓	✓	✓
	Mech exhaust with HEPA filters			✓	✓		
	Mech exhaust independent of general building exhaust with 2 HEPAs in series			○	○	✓	✓
	In-place filter-testing facilities			○	○	✓	✓
	Vacuum line require HEPA filter			✓	✓	✓	✓
Supply Air	Natural ventilation possible	○	○	✗	✗	✗	✗
	HVAC supply required		✓	✓	✓	✓	✓
	HVAC supply independent of general building supply			✓	✓		
	HVAC supply independent of general building supply with HEPA filters				○	✓	✓
	HVAC supply automatic shutdown interlocked with exhaust			✓	✓	✓	✓
	Supply backflow prevention with dampers			✓	✓	✓	✓
	Breathing air system- protected, separate					○	✓
Symbol Key ○	Optional according to agent, volume of agent, and jurisdiction having authority	✓ Recommended or Required				✗ Not Allowed	

involved. Often, microgram to milligram quantities of radionuclides, carcinogens, teratogens, and mutagens are used as adjuncts to work with biological agents. In no case is it intended that BSL-3 laboratories can also be used for work with large quantities of gaseous and liquid chemicals that are hazardous by virtue of their toxicity, radioactivity, or flammability. In this case, additional safety features should be provided such as a chemical fume hood designed for this class of service and appropriate chemical storage facilities.

14.1.3 Equipment and Materials Used

All equipment that will be located and used in biosafety laboratories should be listed and described during the design phase so that door openings will be of adequate clear width and height. The major safety equipment item in biosafety laboratories is the biosafety cabinet (BSC), designed to provide personnel, product, and environmental protection when working with hazardous biological agents. Biological safety cabinets are described and illustrated in Chapter 32, Section 9. The most widely used biological safety cabinet is officially designated "Class II (Vertical Laminar Flow) Biosafety Cabinetry," and its construction, performance, and certification testing are covered by NSF International, Standard No. 49 (NSF/ANSI, 2011). Class II Type A BSCs recirculate air through HEPA filters either into laboratories or vented to the outside. (See Chapter 32, Section 32.9 and Figures 32-5 and 32-6.) Class I cabinets provide personnel and environmental protection, but no work protection; for that reason, they are seldom used for work with biological agents that must be protected from contamination. Class III cabinets are total-enclosure, negative-pressure gloveboxes equipped with at least one double-door lock containing a decontamination device, such as a chemical dunk tank, fumigation chamber, or equivalent (NCI, 2009), for decontaminating items withdrawn from the cabinet. Class III cabinets provide the highest level of personnel, work, and environmental protection, and they are used in BSL-4 laboratories. (See Chapter 32, Section 32.8 and Figures 32-4A and 4B.) A chemical dunk tanks is another device that can be built into walls of BSL-3 and BSL-3E laboratories with outside containment facilities. A chemical dunk tank is a stainless steel cabinet that holds a basin of disinfection liquid. It has a fixed vertical barrier at the top of the cabinet that drops down into the disinfection liquid in the center of the tank. In containment laboratories, workers wear long gloves to lower items into the liquid and to push them down and beneath the barriers. Persons outside containment laboratories, who also wear long gloves, reach into the tanks and extract the items, allowing the drips to drop back into the tanks.

Additional equipment items found in biological safety laboratories include centrifuges (preferably with sealed rotor heads or centrifuge safety cups), high-speed blenders, sonicators, and lyophilizers. Each of these equipment items has an ability to generate large numbers of respirable aerosolized particles that represent a potential infective dose when working with hazardous biological agents. Incubators, sterilizers, and refrigerators are also commonly found in biohazard laboratories. Specialized analytical devices that are likely to be present include gas and liquid chromatographs, mass spectrometers, and liquid scintillation counting devices. Instruments for DNA extraction, amplification, and low volume sequencing may be used in BSL-3 laboratories. High-throughput sequencing instruments are generally located outside BSL-3 laboratories. This separation requires transfer of DNA products out to other lower biosafety level laboratories. Ventilated pass-through chambers may be used for these transfers. One or more conventional chemical fume hoods or a radioisotope fume hood may be present when hazardous chemical procedures that do not require a sterile air environment are carried out in connection with the biological work.

Autoclaves are the most commonly used equipment for sterilizing materials leaving BLS-3 laboratories. They are two-door, pass-through units equipped with special biological seals, properly installed only on the BSL-3 side (contaminated side) of the unit. The second door opens into a support space outside the containment facility, allowing personnel to remove sterilized materials for disposal or recycling. Exhaust canopy hoods must be installed above both doors to capture, heat, steam, and odors released when doors open after each cycle. The size of an autoclave chamber should be selected to economically accommodate the largest expected single item or common waste load that requires decontamination. All items leaving BSL-3 laboratories must be sterilized. This includes bulky items such as laboratory furniture and equipment that undergo gaseous sterilization within recommended separate gaseous decontamination chambers adjacent to BSL-3 laboratories. Housekeeping equipment, such as mops, brooms, and cleaning agents, as well as hand tools for common repairs used within BSL-3 laboratory suites must also be sterilized before they leave the BSL-3 lab.

14.1.4 Exclusions

Biosafety laboratories are not usually designed for work with greater than trace amounts of radioisotopes, carcinogens, mutagens, teratogens, or highly toxic systemic poisons. Restrictions on quantities of flammable solvents very closely follow the safe-handling practices

applicable to analytical chemistry and similar laboratories described in Chapter 2, Section 2.4.6.3. There is rarely, if ever, a need for high-voltage and/or high-current electrical services or for radiofrequency generators and other electrical operations with a high potential for fire, explosion, shock, or electrocution. Other high-energy-releasing sources, such as lasers, x-rays, and gamma energy emitters that are lethal to biological agents, are unlikely to be present in biosafety laboratories.

14.2 LABORATORY LAYOUT

14.2.1 Introduction

Biosafety Level 1 or 2 laboratories may be a single room amid other laboratories of divergent uses or occupy entire floors of laboratory buildings. BSL-3 laboratories are more likely to be suites of rooms interconnected through pressurized and secure internal corridors with entrances from building corridors. Biosafety laboratories need access to essential common service facilities, for example, animal quarters, supply rooms, and washing and sterilizing services. The minimum dimensions for a biosafety laboratory containing one Class II BSC with auxiliary equipment and suitable for a single worker is 8×12 ft. In addition to a 4- or 6-ft-wide BSC, it should include washing facilities, hand- washing facilities, autoclave, and equipment. There should be a space for donning and discarding personal protective garments at the entry. A separate, but adjacent gowning room and individual lockers should be provided for personal articles that should not be brought into containment laboratories. A typical layout of a Biosafety Level 3 laboratory is shown in Figure 14-2A. The recommendations contained in Chapters 1 and 2, Section 2 apply to biosafety laboratories and should be followed except as supplemented or modified in the following sections.

14.2.2 Access Restrictions and Control

Access into BSL-3 laboratory facilities needs to be strictly regulated and enforced. Doors are locked at all times and are equipped with emergency exit hardware. Only authorized personnel are allowed to enter; they complete thorough training in BSL-3 procedures and emergency protocols, as well as participate in a comprehensive vaccination and medical surveillance program, written specifically for operations in that laboratory. Access to BSL-3 laboratories should be limited by providing self-closing and self-locking secure doors. Two-door anterooms connect BSL-3 laboratories to public corridors or lower-level biosafety laboratories, may also be used to change or gown before entering the BSL-3 laboratory, as described in Section 2.2.2.3. All self-closing and self-locking doors must present no barrier to egress in the event of an accident inside the laboratory.

Because access to a BSL-3 laboratory is severely restricted, it is helpful to install internal viewing windows consistent with the fire rating of the wall. Ease of surveillance of laboratory operations promotes safety. All windows must be sealed and double-glazed with

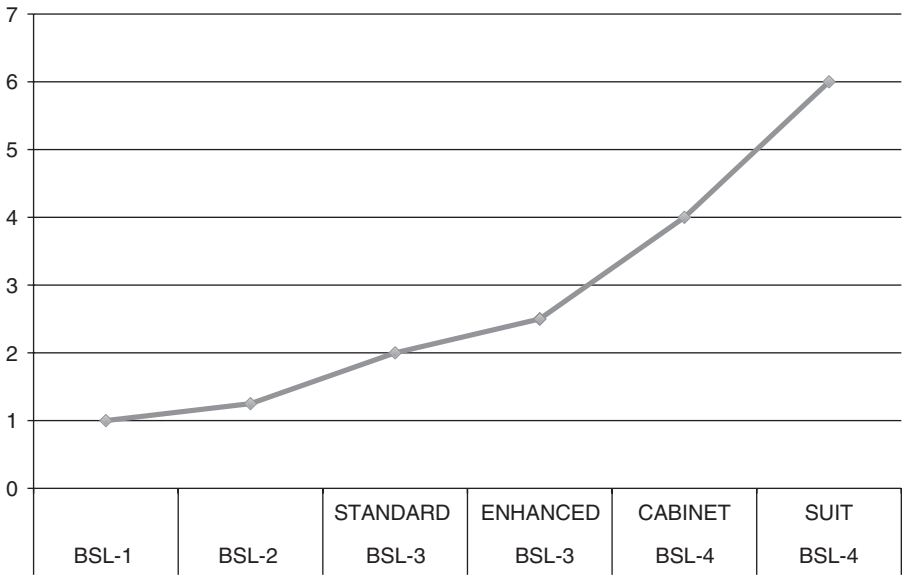
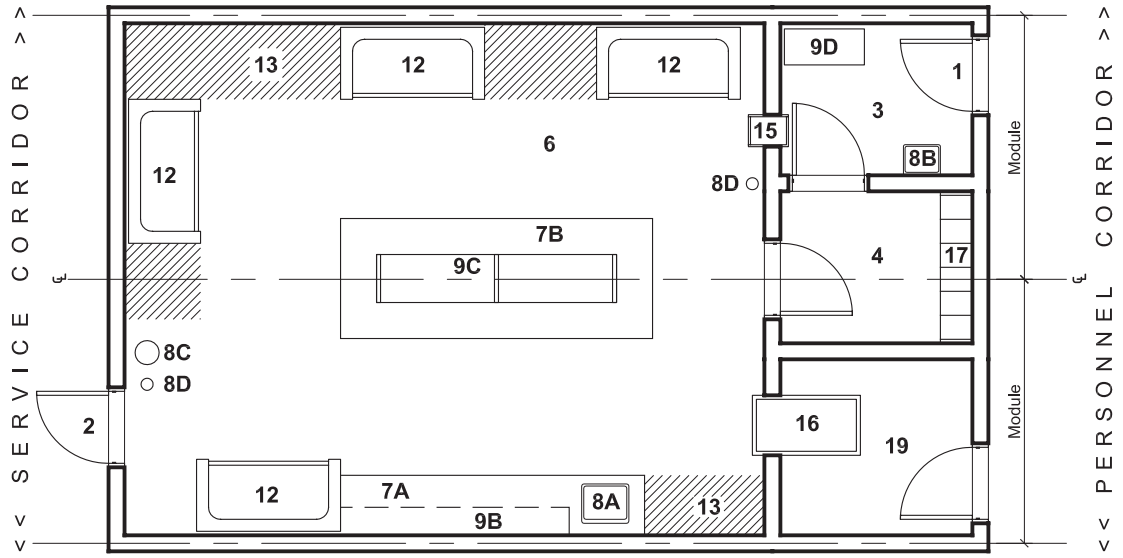


FIGURE 14-1. Index of cost factors for biosafety level laboratories.



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

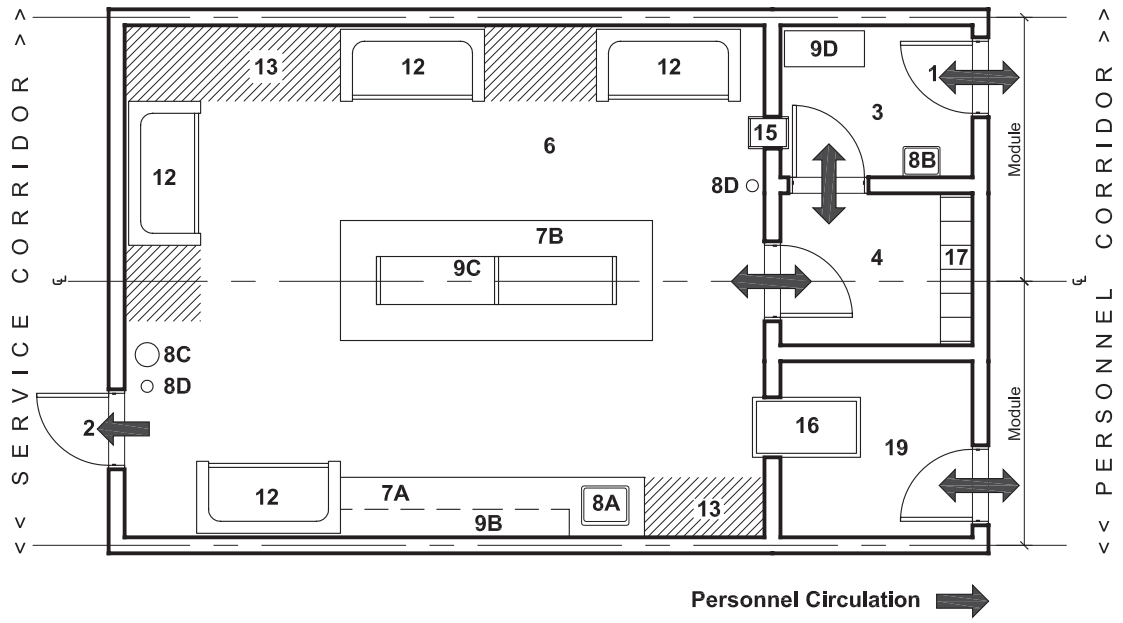
FIGURE 14-2A. Example of a 2-module biosafety Level 3 laboratory layout.

laminated glass. Systems for voice communication are needed between laboratory personnel and others outside the laboratory. Various persons such as emergency responders, biosafety officers, mechanical engineers, and operations personnel look through windows and talk to occupants to quickly assess conditions, rather than having to gown and enter containment laboratories.

14.2.3 Circulation

Figures 14-2B, 2C, and 2D illustrate personnel circulation, material flow, and air pressure relationships in a small and self-contained BSL-3 laboratory suite. Authorized personnel and clean materials enter from a personnel building corridor or from another lower-rated biosafety laboratory, through a locked and secure door into an anteroom. Personnel then pass through a second locked door into a gowning room containing lockers for storing street clothes before going through another secure door into the BSL-3 laboratory proper. In small BSL-3 laboratory suites, gowning functions can be accommodated within anterooms, thereby saving space and reducing the number of locked doors. In medium- and larger-sized BSL-3 suites with many persons entering and exiting, a separate gowning room, as shown in Figure 14-4, is recommended to help personnel traffic to move smoothly. Two gowning rooms should be planned, if separation of men and women is required. It is possible to add showers and toilets to gowning facilities should it become desirable in the future to upgrade the biosafety level of the laboratory.

Materials, such as clean supplies, small items of equipment and instruments, even clinical specimens wrapped securely in double-containment packaging can enter BSL-3 laboratories through secure and ventilated



KEY

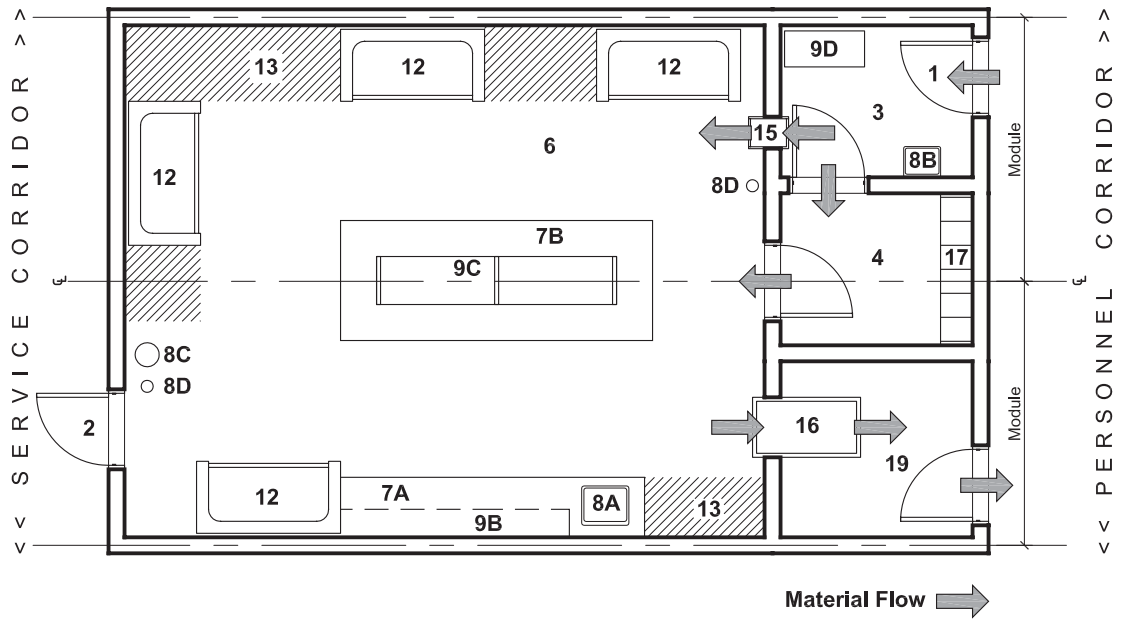
1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 14-2B. Diagram of personnel circulation in and out of a BSL-3 lab.

chambers. Pass-through chambers have stainless steel interiors sealed with one door to the outside—the uncontaminated zone—and another door into the BSL-3 containment zone. Pass-through chamber doors are interlocked so that personnel can open only one door at a time with an interval to exhaust the chamber. Pass-through chambers can be located within the outer anteroom, behind a secure, locked door. This reduces the number of persons required to enter BSL-3 laboratories. Pass-through chambers can be equipped with a light or audible alarm to alert personnel inside BSL-3 facilities that something has been delivered to the lab.

14.2.4 Laboratory Facilities

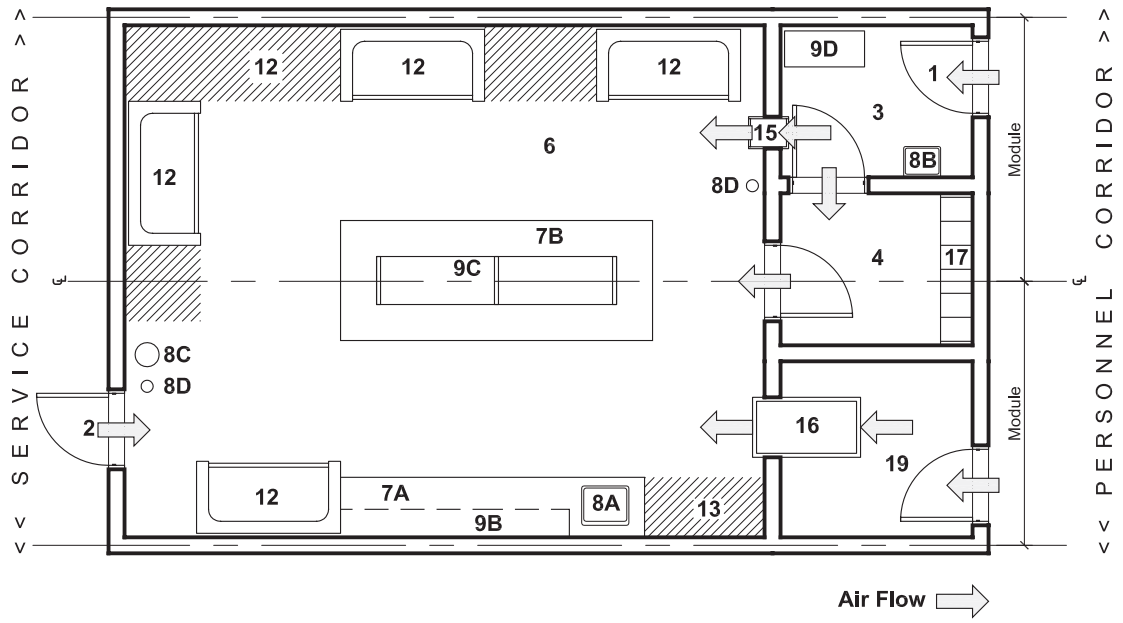
A small BSL-3, illustrated in Figure 14-2A, shows a two-module containment space laboratory with a single secure primary entry/exit and secondary emergency exit. Because established protocols often require a minimum of two persons to occupy a BSL-3 laboratory to increase personal safety for occupants, the Figure 14-2A layout accommodates a minimum of two persons; Figures 14-2B, 2C, and 2D show patterns of circulation for people and materials, and airflow. Figure 14-3A is a variation of the two-module BSL-3; it has a personnel decontamination shower-out facility. Figures 14-3B and C show similar patterns of circulation of materials and airflow. A sample layout for a medium-size laboratory, illustrated in Figure 14-4, contains eight biological safety cabinets, one chemical fume hood, plus open benches for equipment, instruments, and procedures that do not involve chemical, radiation, or biological hazardous materials. There is a separate equipment zone, containing centrifuges, refrigerators, freezers, or other large



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

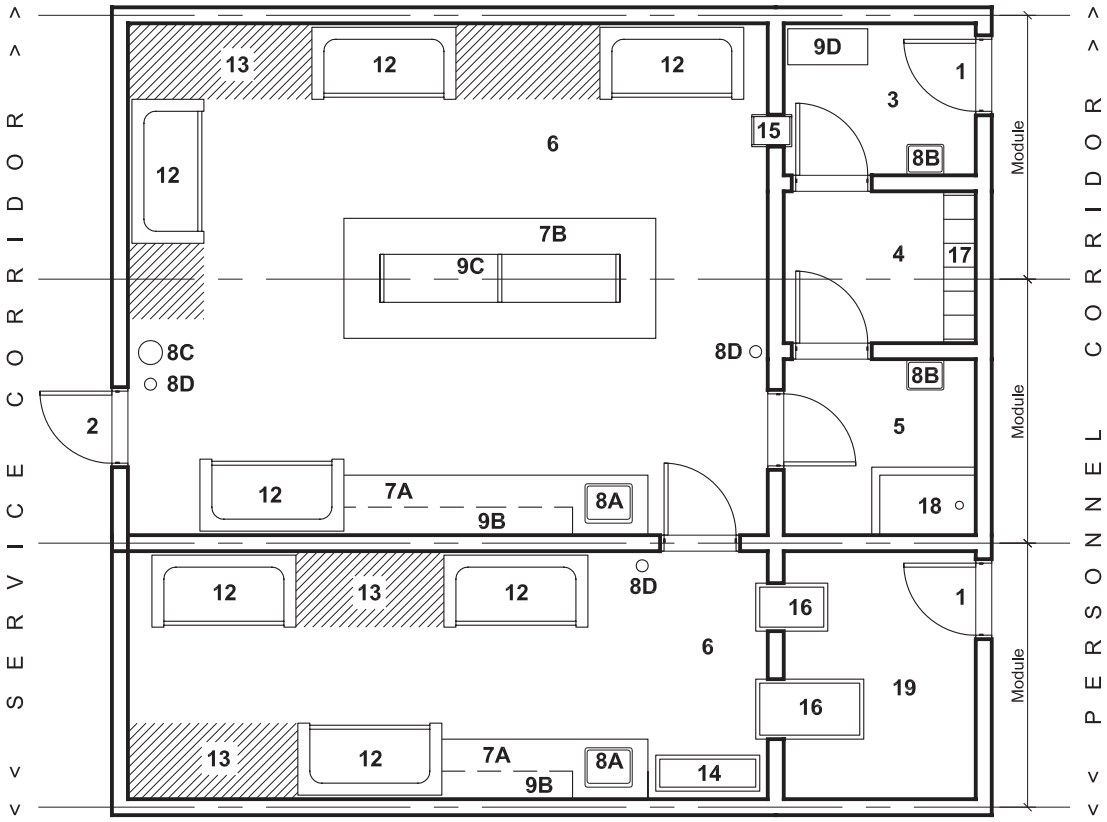
FIGURE 14-2C. Diagram of material flow in and out of a BSL-3 lab.



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

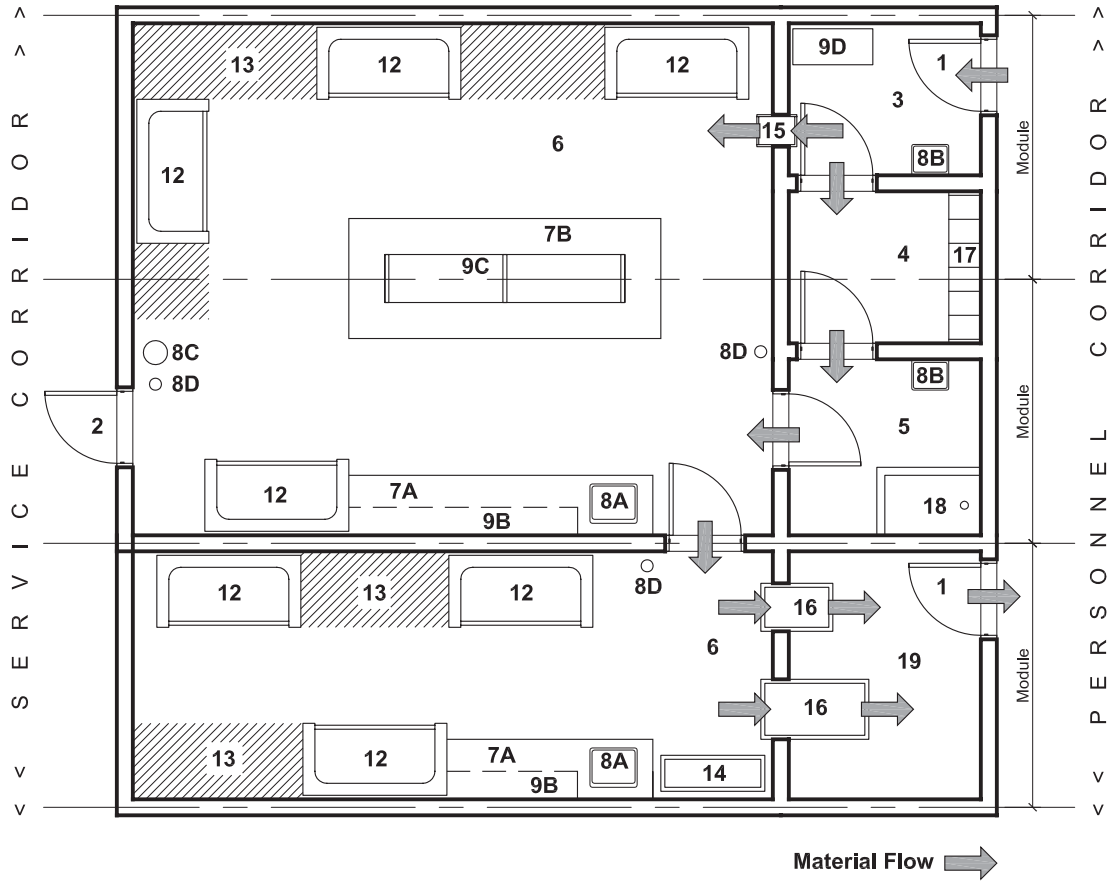
FIGURE 14-2D. Diagram of directional air flow in and out of a BSL-3 lab.



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

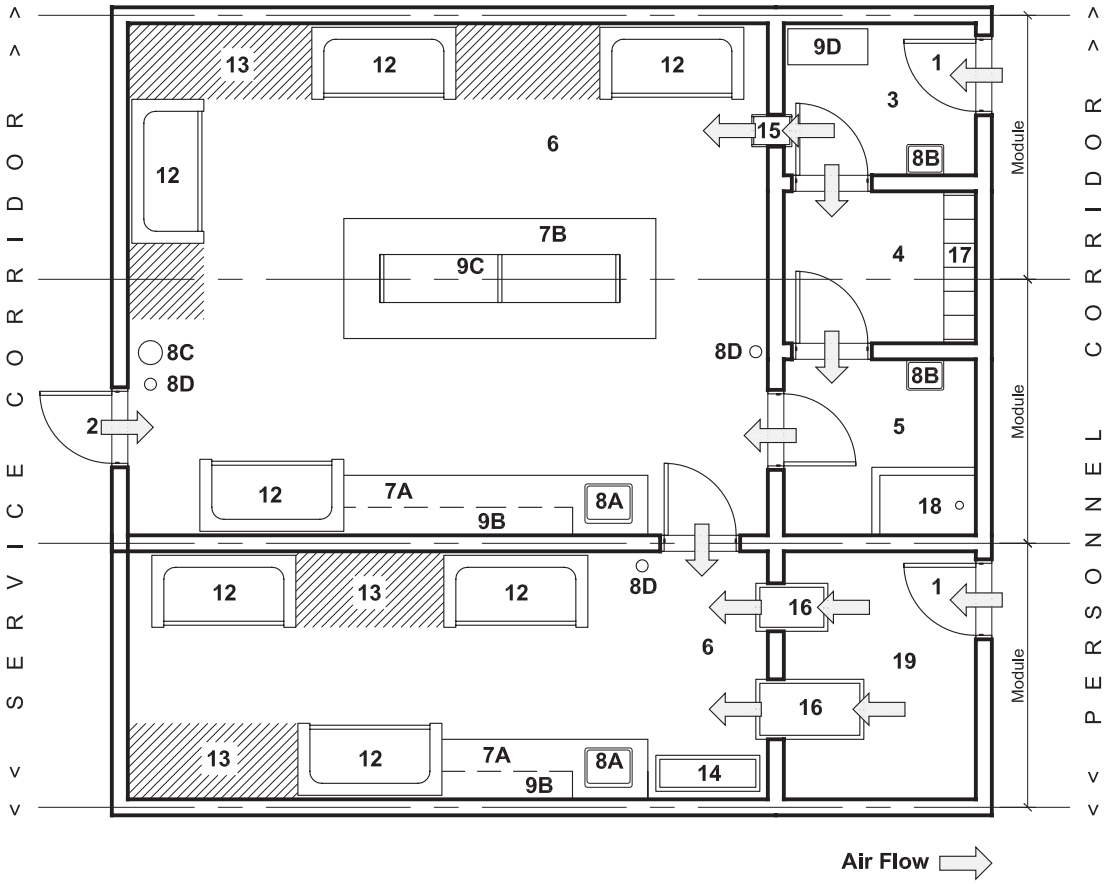
FIGURE 14-3A. Example of a 3-module biosafety Level 3 laboratory layout with shower.



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

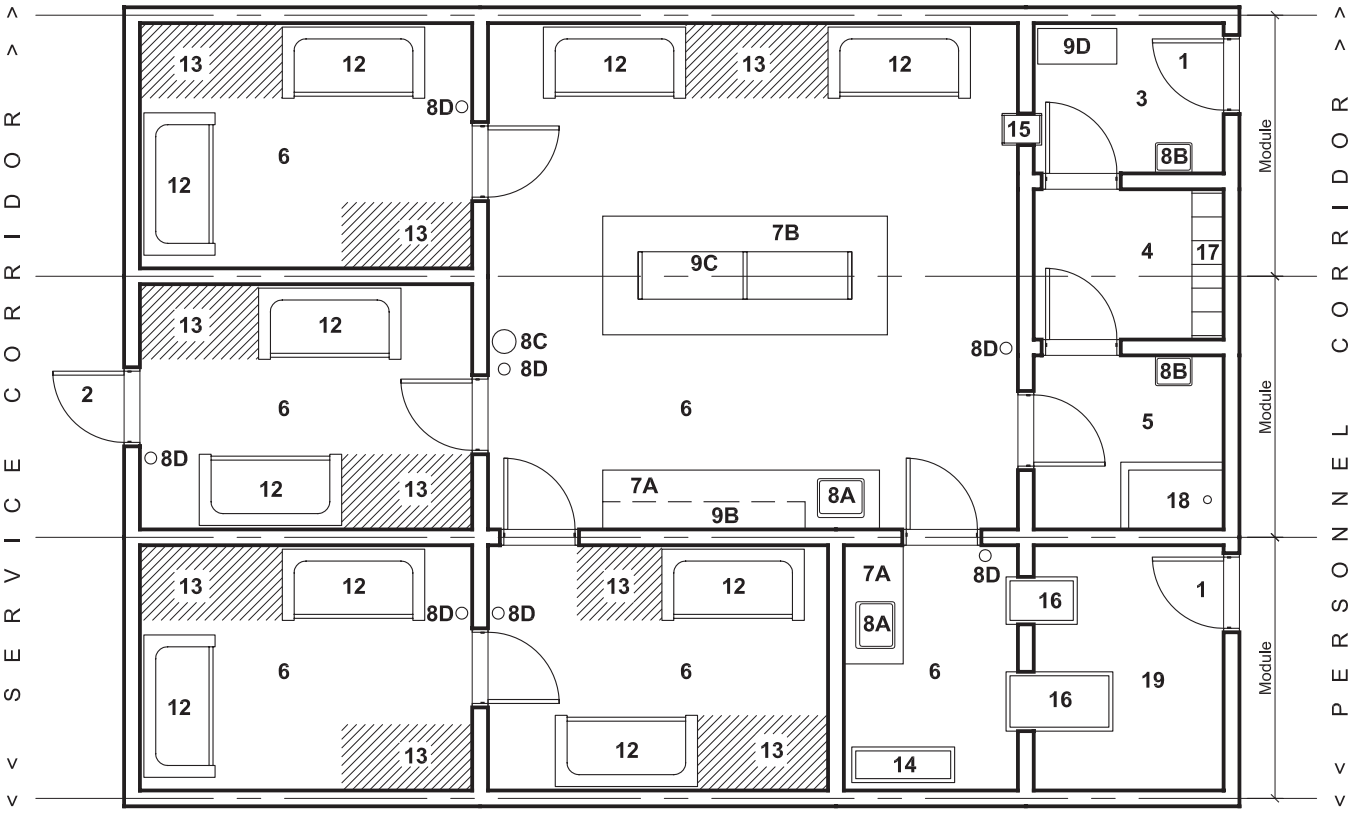
FIGURE 14-3B. Diagram of material flow in and out of a BSL-3 lab.



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 14-3C. Diagram of directional air flow in and out of a BSL-3 lab.



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 14-4. Example of a biosafety Level 3 laboratory with multiple cell culture rooms.

equipment; this separation reduces noise into the main containment laboratory.

Other options for layouts of medium- and large-size laboratories should be based on the principle of hazard zoning described in Chapter 2, Section 2.2.4. If cell culture activities pose the highest risk in a BSL-3 laboratory, due to the nature of the infectious agent or processes being used, consider planning the suite with cell culture room(s) separate from all other preliminary preparation activities and from the common equipment zone, as illustrated in Figure 14-4. This layout principle is effective in large BSL-3 labs in clinical settings where scientists prefer to separate infectious agents and different strains of the agents to reduce risk of cross-contamination, particularly if DNA/RNA extraction is performed.

Personnel egress from medium- and large-size laboratories begins with personnel going into the degowning room, removing and placing soiled laboratory clothing into a hamper or pass-through into the sterilization area

for decontamination before the clothing is sent out to commercial laundries. The degowning room contains a sink for hand-washing and a full-body shower, if required, and has access to lockers containing coveralls. After degowning, personnel enter the gowning room to retrieve their street clothes and dress. Smaller BSL-3 laboratory suites may combine gowning and degowning; in this case, personnel must remove laboratory PPE prior to leaving the containment laboratory.

All materials, including waste, are removed from BSL-3 laboratories through two-door steam autoclaves. Figure 14-3C illustrates a typical directional airflow and air pressure pattern for medium-sized laboratories. Air pressure in common access corridors, designed by a plus (+) sign, is always higher than in biosafety laboratories. All two-door access anterooms are designed for a pressure higher than the corridor, equal to about 0.05 in. w.g. (12.5 Pa). A similar reduction in air pressure, and continuation of directional airflow into the containment laboratory, occurs between entry anterooms and gowning or sterilizer rooms. Air pressure drops once again between these facilities into the containment laboratories. This means that the laboratories, where work with infectious agents takes place, will be at a lower pressure, approximately 0.15 in. w.g. (37.5 Pa) below that of adjacent spaces located outside the BSL-3 suite. When gowning and degowning rooms are incorporated into entry and egress air locks (as shown in Figure 14-3C), negative pressures lower by one-third. Arrows indicate airflow directions. Each two-door compartment in the suite will need to have supply and exhaust air grilles for heating, cooling, and air purging, but in all cases the supply will be less than the exhaust by the amount needed to maintain all required directional airflow relationships. Air pressure requirements are described below in Section 14.3.2.

14.2.5 Sterilization Facilities

In medium- and large-size BSL-3 suites, sterilization equipment and the cleanup work zone may be separated from the primary laboratory to contain heat and odors; it remains within the BSL-3 containment zone. Laboratory personnel require sufficient area to stage and pack waste materials and load them into autoclave(s). Because decontamination is required by federal regulations and biosafety standards, providing two autoclaves, for example, one large and a smaller one; each can be used as back-up to the other when preventive maintenance is performed, in an emergency, or equipment breaks down.

For equipment or other items that cannot fit into autoclave chambers, gaseous decontamination methods must be used or a thorough manual wipe-down with appropriate decontamination materials and procedures. A separate, secure, and sealable room is required to perform gaseous decontamination (see Figure 14-4). Equipment such as a biological safety cabinet or a large ultra-cold freezer should easily fit into gaseous decontamination rooms. During fire or other emergency conditions, laboratory occupants can safely exit BSL-3 suites through empty equipment decontamination rooms, after removing their contaminated PPE in the lab. Emergency egress hardware should be installed on exit doors to the corridor to allow this function while maintaining the security of BSL-3 laboratories.

14.2.6 Laboratory Furniture

Laboratory furniture must be sturdy, easily cleaned, and constructed with impervious materials. Laboratory personnel generally perform all cleaning tasks within BSL-3 laboratories, so arrangement of furniture and equipment with sufficient clearance around immobile items permits lab personnel to clean the floor and counter surfaces. Mobile or movable laboratory casework permits thorough surface cleaning and effective gaseous decontamination. Laboratory casework that hangs from wall frames or is held above the floor on C- or P-frame supports aids in thorough floor cleaning. Sloped tops on wall-mounted storage cabinets reduce dirt that laboratory personnel must clean. Horizontal work surfaces that are sturdy and durable with scratch, abrasion, and chemical-resistant materials should be installed. Sinks must have hands-free faucets and be constructed with smooth, rounded welded joints and integral back splash and drain boards on one or both sides according to laboratory operations for cleaning. Because all wall and floor penetrations must be completely sealed, the method of attaching casework and equipment to reduce these penetrations must be considered.

14.2.7 Floors, Ceilings, and Walls

Room partitions in biosafety laboratories should extend to the underside of the structure and be completely sealed to that structure, making the seal airtight to provide adequate containment during normal operations and decontamination processes. Biosafety laboratory spaces require impervious surfaces and sealed structural joints that are vermin proof and easily cleaned and decontaminated. Walls and floors should be monolithic with interior finishes of washable, durable, chemical-resistant baked enamel, epoxy, or polyester or polymer coatings. Monolithic floor coverings should be carried up walls to form integral bases a minimum of 8 in. (20 cm) above the finished floor, and with smooth,

rounded cove transitions at the floor for thorough cleaning. Similar cove joints are desirable in wall-to-wall joints and wall-to-ceiling joints, for ease of cleaning. If BSL-3 laboratory ceilings are suspended from the structure above, provide solid, seamless ceiling surfaces with interior finishes of washable, durable coatings. These construction considerations are required as secondary containment for accidental release of hazardous materials in BSL-3 laboratories. For certification of BSL-3 facilities, construction of the interior enclosure, joints, and all penetrations should be sealed gas-tight to successfully perform pressure decay testing. Section 14.3.2 below offers the parameters for pressure-decay testing.

14.2.8 Hand-Washing Facilities

Each biosafety laboratory room should contain one or more foot- or elbow-operated hand-washing sinks dedicated to hand washing. Infrared-actuated automatic water faucets are a good choice for BSL-3 laboratories, as long as there is a manual back-up method.

14.3 HEATING, VENTILATING, AND AIR-CONDITIONING

14.3.1 Introduction

Biosafety laboratories, containing several biological safety cabinets that must be vented to the roof, often require complex HVAC systems and sophisticated controls to maintain adequate air supplies, as well as the correct temperature and pressure relationships among adjacent spaces.

The HVAC comfort requirements for a biosafety laboratory with regard to temperature, humidity, and minimum air exchange rates are those outlined in Chapters 1 and 2, Section 3. Personnel working in BSL-3 wear lab coats, tyvek coveralls, and other PPE that may cause personnel to feel uncomfortably warm at standard activity levels and under normal conditions. Operating temperature set points in BSL-3 laboratories may be lower than in some other laboratory types.

14.3.2 Ventilation

Class II, Type A biosafety cabinets (see Chapter 32, Section 9) are designed for exclusive use with biological hazards and may discharge all the exhaust air to the laboratory after filtration through a HEPA filter. Type A cabinets may also discharge exhaust air through a building exhaust system or into a dedicated exhaust stack, but should not be hard-ducted to any system containing an exhaust fan because these cabinets are only designed to operate correctly as self-contained units. Therefore, when a Type A biological safety cabinet is to be vented through an exhaust system, there must be at least a 1-in. opening between the end of the cabinet discharge port and the start of the exhaust system duct to prevent detrimental interactions between the cabinet fan and the exhaust system fan (NSF, 2012). This is called a *thimble connection*. Biosafety cabinets must be configured and sold as either Type A or Type B. Class II, Type B biosafety cabinets, described in Chapter 32, Section 9, are designed for use when treating hazardous biological agents with small quantities of radioactive tracers or carcinogenic chemicals. They are designed only to discharge all exhaust air to the atmosphere through dedicated exhaust systems that terminate above the roof level of laboratory buildings. Therefore, the number and type of all fume hoods and Class II biosafety cabinets that will be vented to the atmosphere must be identified early in the design process so that adequate supply air can be provided to satisfy exhaust requirements and maintain predetermined pressure gradients.

Practice varies with regard to shutting down airflow in vented biosafety cabinets. Some labs run them continuously; this practice increases energy consumption. If, however, they are shut down during nonworking hours, the HVAC system must be carefully modulated to reduce supply airflow to maintain the design room air-pressure gradients. Variable-air-volume (VAV) systems, described in Chapter 34, are frequently used for this service. They require sensitive pressure sensors and rapid-response feedback mechanisms, as well as visible gauges for monitoring correct functioning.

Vented autoclaves, fermenters, and other equipment commonly found in BSL-3 laboratories require canopy-type hoods or high-velocity, low-volume slot-type local exhaust points (ACGIH, 2010a). It may only be necessary to operate the exhaust system when the autoclave or reactor is opened. However, a canopy-type hood can be used continuously to draw off the high heat load associated with autoclaves as well as with fermenters when they are being sterilized between runs.

Exhaust systems are required to evacuate decontamination gases from equipment decontamination rooms within BSL-3 laboratory suites. If pass-through chambers are installed for transferring infectious materials from anterooms into BSL-3 laboratories or into cell culture rooms, these chambers should be exhausted into the BSL-3 duct system.

14.3.3 Filtration

For BSL-3 and BSL-4 classes of agents, all exhaust air from biological safety cabinets, even when discharged

directly to the atmosphere, must be filtered through HEPA filters for environmental protection. When some BSL-3 laboratory air is discharged to the atmosphere through a separate system, it also should pass through a HEPA filter before discharge. For assured containment under all circumstances, all BSL-3 supply air ducts should be provided with HEPA filters located as close to the biosafety laboratory as practicable. This will provide protection against contaminated back flows during periods when power is lost or the system pressure controls fail. This feature is not required by HHS (2009) for BSL-3 laboratory facilities, unless risk assessment requires this feature. When BSL-3 occupants will use trace quantities of especially toxic, volatile chemicals in conjunction with biological experiments, it may be prudent to add an efficient absorber (generally, activated carbon) as a second effluent air-cleaning stage, as described in Chapter 31, Section 31.2.3. HEPA filters that permit in-place decontamination and replacement are located close to each exhaust air use point: "The Class III cabinet must also have a HEPA filter on the supply air intake and two HEPA filters in series on the exhaust outlet of the unit. There must be gas-tight dampers on the supply and exhaust ducts of the cabinet to permit gas or vapor decontamination of the unit. Ports for injection of test medium must be present on all HEPA filter housings" (HHS, 2009).

14.3.4 Controls

Pressure control can be maintained within a biosafety laboratory by providing a constant ratio of supply to return and exhaust air with the aid of differential pressure controllers, modulating dampers, fan inlet vanes, variable-speed devices, or combinations of all of these. Airflow variations should be minimized as an aid in providing control over room pressure. Continuous operation of hoods, cabinets, and local exhaust facilities is an important aid in maintaining reliable pressure control at all times. Two-door anterooms between adjacent areas aid maintenance of pressure control, but at the cost of increased energy consumption. Where possible, locate duplicate critical monitors within sight of windows into BSL-3 laboratories as described here in Section 14.2.2 so that laboratory personnel can view them and contact operating personnel, if they notice an abnormal reading.

14.3.5 Alarms

Malfunction alarms should be provided for the HVAC systems in Biosafety Level 3 laboratories. Additional alarms should be provided to notify personnel when HEPA filters are becoming loaded with dust to a critical point. The information on air-cleaning-system monitoring instruments and alarms contained in Chapter 23, Sections 23.3.2.2 and 23.3.2.4 for microelectronics and clean room laboratories also apply to biosafety laboratories.

14.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

All provisions in Chapters 1 and 2, Sections 4 that apply to biosafety laboratories should be reviewed and implemented when applicable. Required safety equipment, such as emergency eyewash fountains, should be installed at locations accessible from all parts of BSL-3 suites. Emergency safety deluge showers may be required in BSL-3 laboratories following a risk-assessment on chemical use and procedures conducted in the laboratory.

In BSL-3 enhanced laboratories, sprinkler effluent and other liquid effluents may go down facility drains, including sinks and floor drains, but effluent must be collected and treated by chemical or heat sterilization. This equipment assembly that contains and treats effluent is called a *kill tank*. The size of the kill tank depends on the peak volume of liquid estimated to drain during a fire event or spill. It is also dependent upon whether effluent is treated in a continuous decontamination process or in a batch process. Systems where effluent drains into kill tanks by gravity eliminate risk of pump failures. Kill tanks are generally located on the floor directly below containment facilities, or alternatively, on the lowest level of the facility. Full kill tanks are extremely heavy, so structure supporting the floor beneath tanks must be designed and constructed to hold this heavy load.

14.5 SPECIAL REQUIREMENTS

14.5.1 Warning Signs

Proper identification of hazardous biological agents is necessary to restrict traffic into hazardous areas and to alert all who enter the area to take precautionary measures. Additional signage requirements are described in Chapter 1, Section 1.4.10. A standardized, easily recognized sign is customarily used for this purpose. It is displayed at each entry to the restricted area at a place in which it can be seen easily and is displayed *only* for the purpose of signifying the presence of actual or potential biological hazards. Because entry control is very important for biosafety laboratories, an internationally

FIGURE 14-5. International symbol of a biosafety facility.

recognized biohazard warning sign, colored magenta, has been adopted. It is shown in Figure 14-5.

14.5.2 Security

The use of classified proprietary, highly toxic, or pathogenic materials in biosafety laboratories may require material and laboratory lock-up. Security considerations cited in Chapter 1, Sections 1.5.4.1 and Chapter 2, Section 2.5.1 contain additional specific information.

14.5.3 Biosafety Cabinet and HEPA Filter Certification

Standard NSF-49 (NSF/ANSI, 2011) recommends cabinet certification on installation, after a move, and at least once annually. During the laboratory design phase there must be recognition of the special requirements that will be needed for conducting these periodic tests. There will also be times when repairs to the cabinets are needed, and the tests must be preceded by decontamination with formaldehyde or other materials. At the conclusion of the decontamination, the decontamination chemical must be disposed of safely by venting to the atmosphere or by chemical reaction at the cabinet. The method that will be used should be identified during the design phase, and suitable facilities should be provided.

HEPA filters in ventilation systems, both supply and exhaust, require leak testing after installation and recertification at least annually. When the pressure drop through the filters reaches the maximum design level, they must be replaced. In some cases, it will be necessary to decontaminate them before access and removal. Unless all of these requirements are clearly identified during the design phase and suitable means provided to carry them out easily and effectively, the laboratory will not be usable for its original and safety purpose until costly and obtrusive structural revisions can be made.

14.5.4 Personal Protective Equipment

Personal protective equipment, such as laboratory coats, gloves, safety glasses, and disposable respirator masks, should be issued to and worn by all who enter Biosafety Level 3 laboratories. In some cases, shoe covers, head covers, and coveralls will also be required. Selection of adequate PPE is the responsibility of the laboratory directors, but provision for storage of clean garments and safe disposal or sterilization of those that become soiled must be delineated at the laboratory design stage.

Respirators may be used in biosafety laboratories. Locations must be designated for storing respirators for all persons in the laboratory to keep them clean and undamaged. Each person in a containment laboratory has a respirator that is sized and correctly fitted to his or her face, so providing appropriate storage is important. In addition, if the risk assessment or the jurisdiction having authority requires installation of self-contained breathing apparatus (SCBA) install the cabinet(s) with two or more units and back-up tanks in an accessible location.

14.5.5 Decontamination

It is sometimes necessary to decontaminate biological safety cabinets with gaseous formaldehyde or hydrogen peroxide vapor, and it is sometimes necessary to decontaminate entire laboratories by this method. This is generally done when laboratories are temporarily closed when research programs change or laboratories are decommissioned prior to renovation or other facility changes. To decontaminate an entire laboratory with gaseous formaldehyde or hydrogen peroxide vapor, it is necessary to isolate the space in a gas-tight condition. Although temporary plastic curtains and caulking compounds may have to be resorted to achieve ultimate leak tightness, forethought in the design of biosafety laboratories can simplify the job enormously with an equivalent saving in expense and downtime. Installation of conventional suspended ceilings, which may interconnect through the plenum above ceilings to other laboratories and offices, is not allowed in BSL-3 facilities. Walls separating containment laboratories from other facilities must extend to the underside of the structure and be completely sealed gas-tight. At the conclusion of the decontamination period, it will be necessary to ventilate laboratory spaces directly to the atmosphere to purge them of all formaldehyde or other decontamination agent before the laboratories can be reentered.

Formaldehyde is a human carcinogen (NCI, 2009) and scrupulous attention to correct safety practices and the faithful use of PPE are essential when

decontaminating with formaldehyde. Hydrogen peroxide vapor is a serious respiratory irritant and requires the same safeguards.

14.5.6 Waste Disposal

Some of the wastes from biosafety laboratories will be similar to the infectious wastes generated in hospitals and must be handled by identical methods. All infectious wastes must be sterilized before release or removal from containment laboratories for sterilization before disposal. Noninfectious hospital-like wastes must be packaged and disposed of as "red bag waste" to comply with regulations.

Hypodermic needles are frequently used in biosafety laboratories, and provisions must be made for approved needle disposal. This calls for needle boxes in the laboratory and disposal by approved methods such as incineration. See Chapter 27, Hazardous Chemical, Radioactive, and Biological Waste Handling Rooms, for more information on hazardous waste disposal.

14.5.7 Renovations

Before the start of renovations, BSL-3 laboratories require safe removal or destruction of all infectious agents and decontamination of the decommissioned spaces. To conduct this procedure satisfactorily, it will be necessary to seal the spaces gas-tight to prevent loss of decontamination gas or vapor and to avoid inadvertent toxic impact on personnel outside the facilities. Therefore, it is highly desirable in the design phase of new BSL-3 laboratories to be aware of this future requirement and to make suitable provisions to include it in the construction phase.

15

CLINICAL LABORATORIES

15.1 DESCRIPTION

15.1.1 Introduction

Clinical laboratories provide all of the routine clinical testing required for patient care. Inpatient and outpatient specimens are collected; tests are conducted; and residual specimens and completed test materials of a chemical, biological, and radiological nature are disposed of in a safe manner; and reports are generated. As the numbers of tests and types available for diagnostic purposes have increased, clinical laboratories are gaining more importance. Many of the decisions made on patient admission, discharge, medication, and treatment are based upon clinical laboratory patient test results. Figure 15-1 shows the cycle from specimen collection to the clinical laboratory testing.

Unlike a research laboratory, clinical laboratories are more process oriented and designed to provide desired test results quickly and efficiently. Many of the concepts in process engineering are adopted in the design of clinical laboratories.

15.1.2 Work Activities

Clinical laboratory activities include common procedures associated with hematology, bacteriology, virology, and pharmacology. They involve making aliquots, mixing, blending, centrifuging, heating, cooling, distilling, evaporating, diluting, plating-out pathogens, examining specimens under the microscope, and making radiochemical measurements, plus many similar operations. The use of automated, computer-controlled instruments to perform routine tests in busy hospital laboratories has become prevalent, thereby reducing the need for handling chemicals.

Per Battisto (2004), the clinical laboratory in general has three classifications:(1) Clinical pathology (discussed in this chapter); (2) anatomical pathology, which involves the analysis of tissues and cells and the processing of surgical and gynecological specimens including histology and cytology (Chapter 17), gross anatomy (Chapter 18), and autopsy laboratories (Chapter 19), and morgue facilities (Chapter 20); and (3) blood bank, which is discussed in this chapter, Section 15.2.5.4, Blood Transfusion Laboratory. Clinical laboratories can also be classified by the work done in the facility:

- Clinical Chemistry Laboratory
- Acute Care Laboratory (STAT Lab or Rapid Response Lab)
- Microbiology Laboratory
- Blood Transfusion Laboratory
- Tissue Typing Laboratory
- Clinical Immunology Laboratory
- Thyroid / Endocrine Laboratory
- Neurochemistry /Amino Acid Laboratory
- Point of Care Testing (PoCT)

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

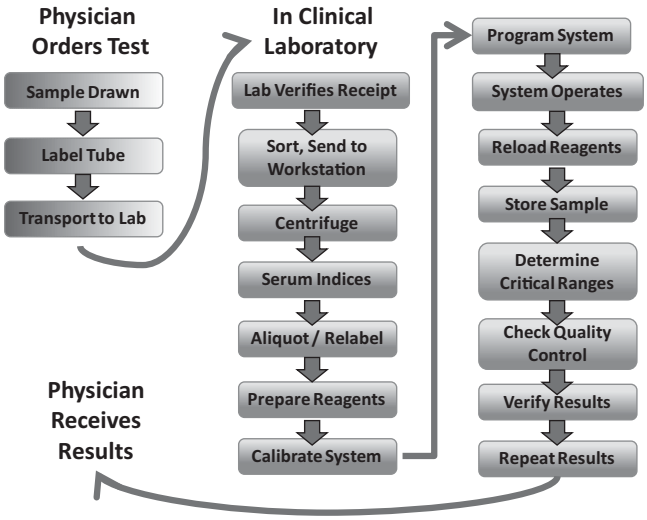


FIGURE 15-1. Clinical test cycle. (Adapted from and courtesy of Jack Zakowaski and Diane Powel, IVD Technology.)

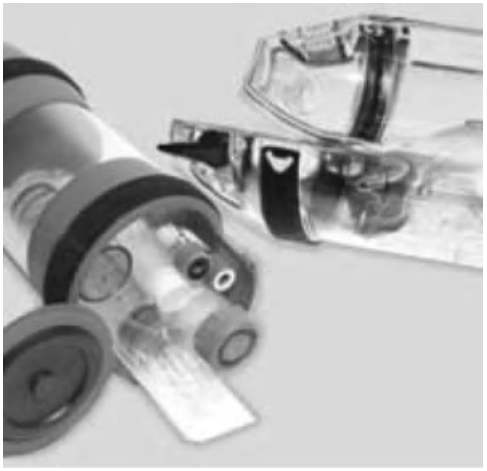


FIGURE 15-2. Pneumatic tube.

- Infectious Disease Molecular Diagnostics Laboratory
- Gastrointestinal Laboratory
- Pharmacogenetics Laboratory
- Hematology Laboratory(see Section 15.2.5.1 Clinical Chemistry Laboratory)
- Special Clotting Laboratory(see Section 15.2.5.1 Clinical Chemistry Laboratory)

Details of these clinical laboratories are described below in Section 15.2.5.

Clinical laboratories are not usually located in medical schools; they are associated with hospitals, clinics, or independent contract testing companies. They either specialize in certain specific types of tests or attempt to perform them all. An example of the former type is a hematology laboratory (where only human blood tests are processed) or a comprehensive analytical laboratory (where blood, urine, stool, and other bodily fluids are analyzed). In clinical laboratories, the trend continues toward computerization, miniaturization, and automation. In the past, even when automatic systems were used, some samples required preparation and processing on a manual basis.

Today's most advanced equipment, however, can perform almost every routine test on a single sample by programming the testing system. A large number of tests can be completed very rapidly by automation. Refer to Section 15.2.3 below for more details.

In hospitals, rapid delivery of specimens to clinical laboratories is often necessary, and pneumatic tube systems are sometimes used for this service. A tube system connects the patient area to the clinical laboratory. A fan or a pump provides a vacuum in the tube. A specially designed carrier inserted from a dispatch station can quickly arrive at the laboratory receiving station. Figure 15-2 shows a sample of a carrier.

Accessioning, which is the logging-in and distribution of the specimens in the required testing sequence, is a critical function in clinical laboratories. The objective is to achieve rapid turnaround and accurate results that will be transmitted to physicians as part of the patient's medical records. Turnaround time (TAT) and accuracy of results are critical metrics for clinical laboratories.

15.1.3 Materials and Equipment Used

The amount and variety of materials and equipment present in clinical laboratories depend upon the type of facility it serves: a large general teaching hospital, a satellite medical center, a clinic, or a doctor's office. Typical equipment includes microscopes; hot plates; mixers; autoclaves; balances; centrifuges; and such special instruments as blood cell counters; atomic absorption spectrometers; gas and liquid chromatographs; and mechanized, automatic specimen-analyzing blood chemistry devices. Because many manual operations are still performed in microbiology laboratories, handling of presumptively infectious specimens and examination of bacterial, viral, and fungal cultures derived from infectious specimens should be conducted in biological safety cabinets and with appropriate personal protective equipment. See Chapter 14, Biosafety Laboratory, Section 14.1.3 and Chapter 32, Laboratory Hoods and Other Exhaust Air Contaminant-Capture Facilities and Equipment, for information on biological safety cabinets. A large variety in small quantities of

organic solvents, acids, and bases, as well as radioactive materials may also be used in clinical laboratories.

All clinical laboratories are BSL-2 (or higher) as they use human blood specimens. Review the Universal Precautions and the Bloodborne Pathogen Standard (29CFR 1910.1030; OSHA, 2012) for additional details.

15.1.4 Exclusions

Clinical laboratories seldom engage in research for its own sake or conduct unusual test procedures, although some types of medical research use routine clinical test results as essential elements of data. No animals are used in clinical laboratories. There are some access restrictions for specific clinical laboratory functions (see Section 15.2.5).

15.2 LABORATORY LAYOUT

15.2.1 Introduction

The layout of a clinical laboratory will be determined by its size and by the nature and number of clinical tests that will be performed, as well as by the number of staff, shifts, and automated instruments. It usually resembles a combination of analytical chemistry and biosafety laboratories. Large clinical laboratories resemble team laboratories in that many diverse activities take place in the same space. Chapters 5 and 21 provide more information. Good practice standards for laboratory layouts, as outlined in Chapters 1 and 2, Section 2, should be followed. The Joint Commission, also known as JCAHO (2009), may impose special requirements. In addition, special process workstations, laboratory benches, and seating should be carefully designed to promote the ergonomic safety of workers because clinical laboratory activities are highly repetitive and many have the potential to cause repetitive stress injuries. Clinical laboratories also include office space, lockers, and other personnel support spaces, and significant area for storage facilities. These may be within or outside the secure zone of the laboratory.

15.2.2 Specimen Handling

The facility must include an efficient system to get specimens from patients to the laboratory. This may require manual transport or an automated system. Pneumatic tubes are an example of an automatic system. Space must be provided in the laboratory layout for a receiving station(s) and accessioning counters or tables to record receipt and transfer of specimens. It is critical that each patient sample is accurately identified. Bar code systems are routinely used in clinical laboratories; to maintain rapid TAT and accuracy, bar code labels are routinely used. Space for bar code readers and printers is required where specimens are accessioned and received.

15.2.3 Future Trends: Automation

There is a marked trend to completely automate clinical laboratory functions by installing robotic instruments. Automation in clinical laboratories has evolved from automating specimen and liquid handling manipulation to an information-based system driven by technology solutions. Robotics is not a total panacea for crowded staff conditions; it presents real challenges to the laboratory designer in terms of space layout.

Automation in clinical laboratories is in two forms.

1. Automation of individual equipment or process—reducing manual effort and time duration. Some examples of automated equipment (Steitberg et el., 2009) are
   a. Automated Centrifuge: This equipment significantly reduces manual labor and promotes efficiency. For example in a manual operation, if a centrifuge is not opened when samples are ready, there is a delay. Conversely, premature unloading of centrifuges has inherent inefficiency.
   b. Intelligent Aliquot System: This consists of a serum-level detector, secondary tube labeler, and aliquot unit. It also has improved efficiency. Before such units were available, most clinical laboratories prepared aliquots when necessary. Ongoing availability allows immediate testing and has inherent efficiency. See Figure 15-3 for an example.
2. Automation that connects different processes and tests in series is even more automated and time efficient. Several layouts ranging from equipment in linear, I-, U-, or L-shaped arrangements have been developed to provide further planning efficiency. Figure 15-4 shows layouts as examples only; no attempt has been made to identify any specific equipment. Dimensions provided are also only examples and should not limit actual required dimensions.

Other ways to classify automation in clinical laboratories are

1. Islands of automation: Several analyzers are ganged together.
2. Total lab automation (TLA): Here preanalytical functions are combined with analyzers.
3. Continuous processing vs. batch processing

FIGURE 15-3. Example of automation.

Before selecting a level of automation, laboratory managers and designers should conduct studies and estimates of laboratory test volumes, both for the present and the future. In many older laboratories, the addition of automation arrays have sometimes created more crowded and potentially unsafe conditions

15.2.4 Ergonomic Considerations

Where possible, to accommodate different sizes of equipment and personnel height vertically adjustable work surfaces should be provided. In addition with the increases in computerization in the laboratory, ergonomically proper data entry workstation arrangements should be made. See Chapter 2, Section 2.2.4.

15.2.5 Common Elements

Clinical laboratories may provide a wide range of standard tests on patient specimens in an open laboratory layout. Layouts follow guidelines given in Chapter 21, Open or Team Research Laboratory, and Section 2 of Chapters 1 and 2. Layouts must be based upon efficient process analyses. All laboratory surfaces and furniture should be cleanable and nonporous. However, the following clinical laboratory functions should be located in separate spaces for the purpose of contamination

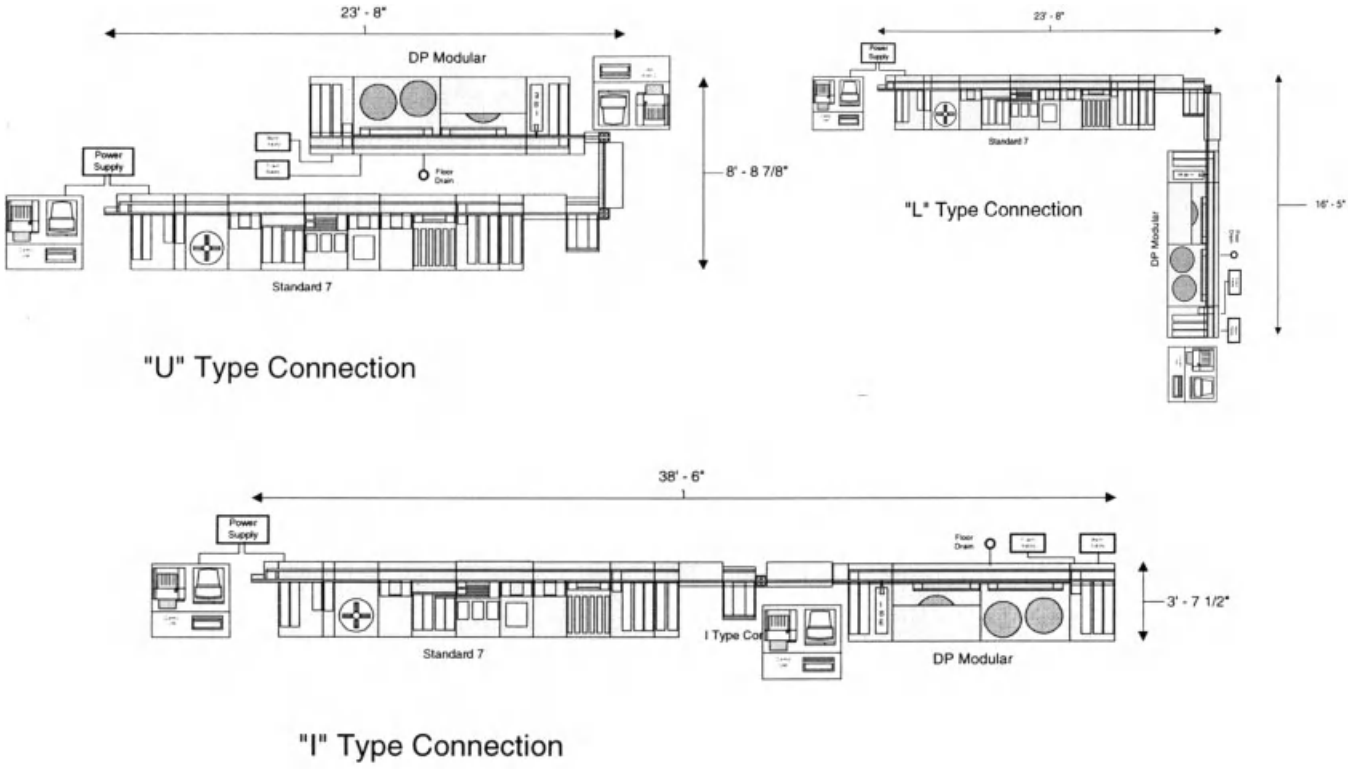


FIGURE 15-4. Automation in clinical laboratories.

control or for maintaining clean, tightly controlled environmental conditions. These laboratories are described here. Cleanliness and protection of specimens from contamination is a primary goal in these separate spaces.

15.2.5.1 Clinical Chemistry Laboratory. The clinical chemistry laboratory may be organized into several major sections for specific testing equipment and protocols: biochemistry, hematology, and coagulation. In addition, receipt of specimens, accessioning, primary sample preparation, solutions aliquot, and distribution are major functions of main clinical laboratories. Open laboratory layouts allow for zoning different, but compatible functions. Flexibility is an important functional requirement for the design of main clinical chemistry laboratories due to frequent upgrades and replacement of major instruments.

Many clinical chemistry laboratory instruments and equipment are individually automated and computer operated. In addition, instruments can be connected to other instruments and automated processes in long linear arrays, similar to industrial assembly lines. Linear arrays can be modified into L- and U-shapes to improve area efficiency and to fit into existing spaces.

Chemistry sections of main clinical laboratories generally handle the highest specimen and testing volumes. The chemistry section menu of tests includes general chemistries, blood gas analysis, therapeutic drug testing, endocrine testing, comprehensive emergency toxicology, and psychotropic drug testing services. Certain processes and reagent preparation and handling may require use of chemical fume hoods. Chemical hoods should be located within chemistry sections of clinical laboratories according to guidelines shown in Chapter 32, Laboratory Hoods and Other Exhaust Air Contaminant-Capture Facilities and Equipment, and in Chapter 5, General or Analytical Chemistry Laboratory. Hematology sections test for cell counts of blood and other body fluids and measures prothrombin time (PT), partial thromboplastin time (PTT), fibrinogen, D-dimer, and erythrocyte sedimentation rate. For chemotherapy patients, an automated estimate of absolute neutrophil count may be needed quickly. Specialized flow cytometric techniques provide the ability to analyze T-cell subsets in human immunodeficiency virus (HIV) infection and to analyze reticulocytes. Wright-Giemsa, iron, and enzyme cytochemical stains are used in the workup of acute leukemia and hairy cell leukemia.

Special clotting sections of clinical laboratories provide tests for evaluation of coagulopathy that include polymerase chain reaction (PCR) testing of activated protein C resistance. An active and comprehensive consultation service conducted by physicians on the Coagulation Service is available. This may require a separate office in which patients are seen.

Microbiology section deals with infectious materials that require containment in Biosafety cabinets. A fume hood may also be needed (see Section 15.2.5.3 for more information). Additionally, radioactive isotopes may be used, requiring a special chemical hood. These special venting provisions are required to ensure the safety of the staff. Chapter 32, Laboratory Hoods and Other Exhaust Air Contaminant-Capture Facilities and Equipment, should be consulted for additional details.

In the Nuclear Medicine section, radioactive isotopes (e.g., radioactive xenon) are used in diagnostic procedures in this area. Chapter 13 should be reviewed for additional details.

15.2.5.2 Acute Care Laboratory (STAT Lab or Rapid Response Lab). Acute care laboratories in health care facilities are operated 24 hours a day, 7 days a week. The laboratory serves all acutely and critically ill patients, individuals in intensive (ICU) or intermediate care units, patients requiring oxygen therapy or artificial ventilation, and all patients with threatened cardiovascular collapse. Many of the tests performed in this laboratory are also performed elsewhere, but the critical timeliness of these tests requires them to be conducted promptly in this laboratory and the results transmitted immediately. The tests provided by the laboratory usually include blood gases (PO_2, PCO_2), pH, blood oxygen content, electrolytes (sodium, potassium, and ionized calcium), total protein, osmolality, blood glucose, and hematocrit. Due to the criticality of these tests to patients' survival, equipment in this laboratory must be supplied with emergency or back-up power. In some cases, they may be connected to uninterruptible power supply (UPS) electric power and provide all piped utilities with back-up supply and control systems so they are always available and do not fail.

Layouts of acute care laboratories follow the guidelines of a general or analytical chemistry laboratory (Chapter 5). Acute care laboratories may be located close to ICUs, operating rooms (ORs), or other hospital areas where care is provided to the most ill patients. These laboratories may be separate and removed from the main clinical chemistry laboratory. Because acute care laboratories house fewer functions and have lower specimen volumes, the laboratory area required is less. Large hospitals may provide more than one acute care laboratory, each convenient to critical patient service areas.

15.2.5.3 Microbiology Laboratory. Microbiology laboratories provide test menus in bacteriology, virology,

parasitology, mycobacteriology, mycology, and serology of infectious diseases.

Because infectious agents, at times of unknown severity or origin, are present in microbiology laboratories, these laboratories are designed and operated as Biosafety Level 2 facilities and guidelines for layouts are shown in Figures 14-6, and 14-7 in Chapter 14.

In addition to conventional methods, the laboratory offers several rapid diagnostic tests and detection of difficult-to-culture pathogens using nucleic acid probe technology. The molecular diagnostics section of the laboratory may offer:

- Nucleic acid amplification testing for the detection of herpes simplex virus from cerebrospinal fluid (CSF) specimens
- HIV-1 RNA quantitation (viral load) from plasma specimens
- *Mycoplasma pneumoniae* from respiratory specimens
- *Mycobacteria tuberculosis* from AFB smear-positive sputum specimens

The gastrointestinal testing section within virology usually performs diagnostic hepatitis virology tests other than those used for routine screening of blood donors. Biological safety cabinets as well as an autoclave should also be available.

15.2.5.4 Blood Transfusion Laboratory. Blood transfusion laboratories are usually responsible for the storage and dispensing of all blood components, all patient samples' testing, and the preparation of frozen red blood cells, plasma, platelets, and other specialized blood components. In addition, these laboratories may support the transfusion needs of a number of specialty services including cardiac and vascular surgery, bone marrow and solid organ transplantation, burn service, mass casualty treatment facility, and the neonatal intensive care unit. It may also operate as an AABB (American Association of Blood Banks) accredited reference laboratory for the resolution of difficult serological problems.

Blood storage areas (blood banks) require locked doors and access control to keep out unauthorized persons. Blood products for transfusion must be kept uncontaminated and stored at tightly controlled, continuously monitored temperatures. Samples need refrigeration to 39.2°F (4°C) immediately after collection. They can also be shipped in refrigerated packaging at 39.2°F (4°C). At that temperature they are stable for 7 days. If it is anticipated that analysis cannot occur within 7 days, samples should be frozen immediately at –70°F (–20°C) is not sufficient). The U.S. FDA heavily regulates the recordkeeping of blood products; this activity requires data entry, bar coding, and label printing. Office facilities are required within these laboratories.

The layout of blood transfusion laboratories includes arrangement of one or more large blood-bank refrigerators, freezers, centrifuges, and lyophilizers. Laboratory benches are required for some processes and equipment, such as filling, assembling, and labeling product containers. In addition, clear floor area is required for boxes of finished products and supplies, as well as for transfer of these boxes in and out of these laboratories. Due to the size and number of large floor-mounted equipment and transport activities, a flexible laboratory design is highly desirable, including use of mobile benches and storage shelf units. Hand-washing and laboratory cleanup stations with large sinks must be distributed to offer easy access for personnel.

15.2.5.5 Tissue Typing Laboratory. Tissue typing laboratories perform all of the testing required for bone marrow and solid organ transplantation services. Tests usually include both serologic and DNA-based tissue typing, determination of HLA antibody frequency (PRA) and specificity, lymphocytotoxicity cross matching, mixed lymphocyte culture assays, and monitoring for chimerism and bone marrow engraftment.

To reduce risk of contaminated air and particles from entering, this laboratory should be located in a separate and secure space and may or may not be adjacent to the main hospital clinical laboratory. Layouts of tissue typing laboratories follow the guidelines for a Biosafety Level 2 (BSL-2) laboratory as described in Chapter 14, Biosafety Laboratory. Biological safety cabinets are used to prevent cross contamination of human specimens.

15.2.5.6 Clinical Immunology Laboratory. Clinical immunology laboratories use agarose gel electrophoresis, immunoelectrophoresis, and immunofixation to detect monoclonal proteins in serum, urine, and CSF. Other procedures may include immunofluorescence, immunodiffusion, and radioimmunoassay for detection of antinuclear antibodies, antinative DNA antibodies, cytoproteins, cancer antigens, and antibodies to hypersensitivity pneumonitis antigens, as well as enzyme-linked immunosorbent assay (ELISA) for the detection of antibodies.

To maintain cleanliness in these laboratories and reduce risk of contamination of specimens, a separate space is required for this function. The layout of these laboratories follows guidelines given in Chapter 5, General or Analytical Chemistry Laboratory. The

majority of analytical equipment here is bench-top mounted. However, benches that are height adjustable are very desirable to reduce lab workers' fatigue and improve ergonomic safety.

15.2.5.7 Thyroid / Endocrine Laboratory. Thyroid/endocrine laboratories provide a full range of diagnostic testing, test interpretation, and management consultation for patients with endocrine and metabolic disorders, plus state-of-the-art metabolic assays for the diagnosis of endocrine disorders including thyroid, pituitary, adrenal, and bone disease. Processes and instruments specific to endocrine testing should be separated from the main hospital clinical laboratory. Layout of these laboratories follows guidelines given in Chapter 5, General or Analytical Chemistry Laboratory.

15.2.5.8 Neurochemistry/Amino Acid Laboratory. Neurochemistry/amino acid laboratories provide diagnosis and treatment of disorders associated with the abnormal metabolism of amino acids, organic acids, carnitine, and their derivatives. This laboratory offers diagnostic testing for patients suspected of having an inborn error of metabolism and subsequent treatment for patients with various disorders including homocystinuria, maple syrup urine disease, urea cycle disorders, hyperammonemic syndromes, methylmalonic acidemia, and other associated organic acid disorders.

This laboratory may also offer special tests and procedures including testing for biochemical genetic metabolic disorders, quantitative amino acid analysis, organic acid analysis by gas chromatography-mass spectrometry, free and total carnitine determination, biotinidase activity, orotic acid, total homocysteine, argininosuccinate lyase activity, screening for succinyl purines, and DNA diagnostic tests.

Processes and instruments specific to neurochemistry and amino acid testing should be separated from the clinical chemistry laboratory. Because chemical and DNA testing is performed, layout of these laboratories follows guidelines given in Chapter 5, General or Analytical Chemistry Laboratory, but layout will also include locating biological safety cabinets to protect specimens during DNA extraction.

15.2.5.9 Point of Care Testing (PoCT). PoCt is provided at the patient's bedside in patient rooms, in the OR, ICU, or neonatal ICU (NICU) where a quick tests and results are needed to aid in patient treatment. These test devices are either handheld or are smaller versions of larger instruments. These tests usually support, but do not replace many traditional clinical laboratory tests. The menu for these tests is small though increasing.

15.2.5.10 Infectious Disease Molecular Diagnostics Laboratory. This is a growing field with great promise. There is limited standardization of technique and processes. This laboratory may require a BSC and layout similar to a microbiology laboratory described in Section 15.2.5.3. Today, a significant amount of testing is done manually, but automation is imminent. As the quantity of laboratory equipment will probably increase, some expansion space is recommended.

15.2.5.11 Pharmacogenetics Laboratory. Another growing field is pharmacogenetics. This laboratory determines how a particular patient will respond to a specific medication. These laboratories may become more popular as demand for "personalized" medicine grows. It should be designed as a microbiology laboratory described in Section 15.2.5.3.

15.3 HEATING, VENTILATING, AND AIR-CONDITIONING

The HVAC system for clinical laboratories must maintain reasonable temperature control to ensure the correct operation of electronic and other testing devices that will normally be present. Clinical laboratories should be at negative pressure with respect to the rest of the hospital. There may be a desire to have different pressure or directional air flow between the laboratories. This requirement is difficult to maintain without anterooms or air locks (Chapter 2, Section 2.2.2.3), and good seals of gaps in laboratory enclosures and openings in enclosures for pipes, ducts, and conduit. The recommendations contained in Chapters 1 and 2, Section 3 are generally applicable to clinical laboratories and should be considered for implementation with the following additions and comments.

15.3.1 Chemical Hoods

Chemical hoods, when they are used, should conform to the recommendations contained in Chapter 2, Section 2.3.4.4 and in Chapter 32. Perchloric acid hoods are required in this type of laboratory only when perchloric acid digestions of samples are conducted routinely. When perchloric acid hoods are needed, the recommendations contained in Chapter 2, Section 2.3.4.4.3 and Chapter 32.4 should be followed.

15.3.2 Local Exhaust Air Hoods

When there are discrete systems or processes in clinical laboratories that emit dangerous or obnoxious fumes

(e.g., some hematology procedures) or large amounts of heat (e.g., autoclaves), providing local exhaust air facilities for each device reduces the total ventilation air requirements for the laboratory. Local exhaust facilities may consist of an enclosure housing the entire process equipment system, a canopy hood directly over the process or equipment, an engineered slot-type capture hood especially designed and built for the application, or a simple, open-ended flexible exhaust hose to handle a small emission source such as an atomic absorption instrument. See Chapter 32 for more information on selecting and designing appropriate local exhaust hoods.

15.3.3 Biological Safety Cabinets

Biological safety cabinets are needed in many clinical laboratories to handle specimens from infectious patients. Universal precautions assume that all body fluid specimens may be infectious. Biosafety cabinets should be ventilated in accordance with the requirements outlined in Chapter 14, Section 14.1.3. Most Class II biological safety cabinets used in hospital clinical laboratories will be a Type A model that permits recirculation of air inside the laboratory rather than requiring a direct exhaust connection to the roof. When volatile chemotherapy drugs will be associated with clinical specimens, consider using a Type B cabinet that is totally exhausted to the outdoors.

15.3.4 System Components

A central building HVAC system generally serves hospital-based clinical laboratories. Accepted practices of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE, 2009, 2010, 2011, 2012) and the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA, 2005) are satisfactory.

15.3.4.1 Supply Air Systems. Clinical laboratories acquire large, bulky, automatic electronic analytical equipment on an ongoing basis. Consequently, the distribution of supply air becomes more difficult, not only to maintain a uniform temperature in the laboratory, but also to prevent drafts and unsatisfactory air distribution patterns. For best results, supply air should be provided by a ducted distribution system located above the ceiling. Discharges to the laboratory should be through multiple outlets designed to avoid drafts. The Facility Guidelines Institute (FGI, 2010) and the ASHRAE standard 170, Ventilation of Health Care Facility (ASHRAE, 2008), provide guidelines on supply air filtration.

15.3.5 Temperature Control

A uniform temperature (±75°F, –24°C) is needed for the reliable operation of some analytical devices. Some equipment may require lower space temperature. Actual temperature requirement of equipment should be confirmed. Heating and air-conditioning control systems must be provided to achieve thermal consistency. When tight humidity control is required, although it is seldom necessary, the simultaneous operation of heating and cooling systems may be needed. Many kinds of HVAC systems, including local cooling units and central systems, have been successfully used for servicing hospital clinical laboratories. An important consideration is that all elements of temperature control systems should be interlocked so that a uniform temperature can be maintained throughout the year. In a facility retrofit, it may be cost effective to install a separate air cooling and heating system for a clinical laboratory rather than connecting the laboratory to the building system because laboratories have different HVAC requirements than those in hospitals. When not separated, a large hospital central system must be operated at an inappropriate, and hence uneconomical, level to maintain desired conditions for a small laboratory suite.

15.3.6 Heat Gain Calculations

To calculate the cooling needs of a clinical laboratory, information is needed on the heat emission rates of commonly used equipment and instruments. Table 15-1 (reprinted here from Alereza, 1984) gives the heat load from commonly used items. Other references are in *ASHRAE Laboratory Design Guide* (McIntosh, Dorgan, & Dorgan, 2004). Information on many of the new instruments and other devices used today is not readily available, and manufacturers must be contacted to get the information.

HVAC engineers must also consider diversity. All of the equipment in clinical laboratories may not operate continuously at full load. A reasonable diversity estimate would eliminate overdesign of the HVAC system. At the same time, clinical laboratories tend to add new systems continuously. A safety margin should be included in the heat gain calculations; 20% is a reasonable safety factor.

15.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

15.4.1 Introduction

The recommendations contained in Chapters 1 and 2, Section 4 are generally applicable to clinical laboratories

TABLE 15-1. Heat Release Rate of Hospital Clinical Laboratory Equipment

Equipment Type	Size			Maximum Input Rating (BTU/h)		Recommended Rate of Heat Gain (BTU/h)[a]	
	Ave	Small	Unit	Ave	Low	Ave	Low
Autoclave (bench)	0.7 (0.02)		ft^3 (m^3)	4,270		480	
Bath: hot or cold circulating, small	1.0 (3.8)	9.7 (36.7)	gallon (liters)	6,140	2,560	1,0602,010	(sensible) 440 (latent) 850
Blood analyzer	120		samples/hour	2,510		2,510	
Blood analyzer with CRT screen	115		samples/hour	5,120		5,120	
Centrifuge (large)	8	24	places	3,750		3,580	
Centrifuge (small)	12	4	places	510		480	
Chromatograph				6,820		6,820	
Cytometer (cell sorter)	1,000		cells/sec	73,230		73,230	
Electrophoresis power supply				1,360		850	
Freezer[b], blood plasma, medium, –40°F (–22°C)	13 (1.2)		ft^3 (m^3)	340		136	
Hotplate, concentric ring, 212°F (100°C)	4		holes	3,750		2,970	
Incubator, CO_2, 130°F (54.4°C)	10 (0.28)	5 (0.14)	ft^3 (m^3)	9,660		4,810	
Incubator, forced draft, 140°F (60°C)	80 (2.26)	10 (0.28)	ft^3 (m^3)	2,460		1,230	
Incubator, general apps, 160°F (71°C)	11 (0.31)	1.4 (0.04)	ft^3 (m^3)	220	160	110	80
Magnetic stirrer				2,050		2,050	
Microcomputer[c]	256	16	Kbytes	2,047	341	1,800	300
Minicomputer[c]				15,000	7,500	15,000	7,500
Oven, general purpose, small, 460°F (238°C)	2.8 (0.08)	1.4 (0.04)	ft^3 (m^3)	2,120		290	
Refrigerator[d], laboratory, 39°F (3.9°C)	106 (3.0)	22 (0.62)	ft^3 (m^3)	80		34	
Refrigerator[d], blood, small, 39°F (3.9°C)	20 (0.57)	7 (0.2)	ft^3 (m^3)	260		102	
Spectrophotometer				1,710		1,710	
Sterilizer, free-standing, 270°F (132°C)	212 (6.0)	3.9 (0.11)	ft^3 (m^3)	71,400		8,100	
Ultrasonic cleaner, small	1.4 (0.04)		ft^3 (m^3)	410		410	
Washer, glassware	7.7 (0.22)		ft^3 (m^3)	15,220		10,000	
Water still[e]	15 (56.8)	5 (18.9)	gallon (liters)	14,500		320	

Source: Alereza (1984). Adapted with permission from ASHRAE.

[a]For hospital equipment installed under a hood, the heat gain is assumed to be zero.

[b]Heat gain per cubic foot of interior space.

[c]Input is not proportional to memory size.

[d]Heat gain per 10 cubic feet of interior space.

[e]Heat gain per gallon of capacity.

and should be considered for implementation with the following additions and comments. Large clinical laboratories may operate like a production laboratory and will resemble an open or team laboratory; Chapter 21, Open or Team Research Laboratory, should be consulted to understand unique requirements.

15.4.2 Egress

Because clinical laboratory activities range from simple to very complex and diverse, good zoning, and even segregation of activities, should be considered in large facilities. Otherwise, maintenance of adequate exit

routes and routes to fire extinguishers, deluge showers, and other emergency equipment may become difficult. Follow the guidelines in Chapters 1 and 2.

15.4.2.1 Access Control. It may be necessary to consider security access for such laboratories, or sections of main clinical laboratories such as blood bank, tissue typing, and microbiology laboratories.

15.4.3 Chemical Storage

Chemical storage facilities should be carefully located with consideration of exit access, firefighting, spill control, and laboratory operation exposures in mind. Storage within the laboratory should be provided only for small amounts of chemicals. This restriction should be maintained by careful laboratory management.

15.4.4 Fire Suppression

In general, the requirements of Chapter 1, Section 1.4.4.2.2 pertain to clinical laboratories. For the placement of hand-portable fire extinguishers in clinical laboratories, the following criterion should be considered. It may be more critical to get to a fire extinguisher than to be able to make a rapid exit. For this reason, 2A-40 BC dry chemical extinguishers, with their increased extinguishing capacity, compared to CO_2-type units, are considered the most appropriate for use in clinical laboratories. They should be placed in the back of the laboratory as well as at each exit door to enable personnel remote from the exit to get to a unit quickly and safely.

15.4.4.1 Sprinklers. Water-sprinkling systems provide excellent fire suppression for clinical laboratories. In general, semirecessed heads in ceiling tiles provide reasonable protection against accidental breakage of sprinkler heads and resulting water damage. Further protection against accidental release can be obtained by the use of reaction systems whereby two detector heads in parallel must trigger to open a solenoid valve that allows water to pass. For example, in a clinical laboratory with a preaction-type sprinkler system that must be activated by smoke as well as fire.

15.4.5 Codes and Standards

NFPA 99, Health Care Facility Code (NFPA, 2012), which covers laboratories in health-related institutions, should be consulted for additional regulatory requirements. (This standard is available at http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp?cookie%5Ftest=1) There are several quality standards employed in clinical laboratories. An example is ISO 15189 (2012), Accreditation for Clinical Laboratories.

15.4.6 Medical Waste

The waste from clinical laboratories may have come in contact with the body fluids of patients and is presumed to be infectious. Until recently, steam autoclaving of such waste before municipal waste disposal was considered adequate. With concern about HIV infection, all medical waste is considered to be infectious whether autoclaved or not. The EPA and other regulators prescribe strict guidelines on how these wastes must be handled and disposed of. A typical system begins with the collection of medical waste in double red bags. Red bags may be packed in cardboard boxes then shipped from the laboratory to a central location. At central collection facilities, boxes are treated in an approved fashion. EPA regulations have resulted in eliminating most medical waste incinerators in the United States. Many other medical waste treatment systems are available in the marketplace. A strictly enforced documentation is required to track the waste from source to ultimate destruction. See Chapter 27, Hazardous Chemical, Radioactive, and Biological Waste Handling Rooms, for more information on waste handling.

15.4.7 Emergency and Clean Electrical Power

Many new automated testing systems require "clean" electric power, that is, power free from electrical "noise." Chapter 1, Section 1.5.5 should be consulted for additional information on clean power. Local power conditioning devices are manufactured to isolate specific clinical and analytical instruments. This is a cost-effective approach for clinical laboratories that contain such systems.

Continuous operation of many of the automated testing devices is vital for patient care. Therefore, it is necessary that some equipment be on generator emergency power. Many may need to be placed on UPS.

Information technologies used in these clinical laboratories create their own issues and UPS is needed to provide reliability. If a UPS system is battery-based, they should be placed in appropriately designed locations. See Chapters 1 and2.It is important that ability to continuously test power systems. To achieve this results all clinical testing equipment is connected to emergency power, and if needed, to UPS systems. If not all clinical laboratory test equipment is connected, at least one of each type should be connected to emergency power, to ensure that during loss of normal power conditions, all

routine clinical tests can still be conducted and patient care is not compromised.

15.4.8 Wastewater

Wastewater from clinical laboratories may contain trace amounts of metals (lead, mercury, zinc, etc.), volatile organic compounds (formaldehyde, etc.), and other chemicals prohibited by the local wastewater authority. Chapter 1, Section 1.5.3.2 explains some issues that must be considered.

15.4.9 Other Utilities

Provide laboratory grade compressed air, vacuum, pure-water (RODI grade), CO_2, and other compressed gases as necessary.

As clinical tests become more computerized, extensive IT systems requirements also grow. Space must be allocated for these systems, such as server rooms. Expanded use of wireless technology should also be considered where data security is not a significant issue.

16

TEACHING LABORATORY

16.1 DESCRIPTION

16.1.1 Introduction

Teaching laboratories should be planned, designed, and constructed to provide safe working and learning environments for groups of students. Teaching laboratories can range from high school to graduate studies and training for adults. Because of the range of ages and expertise, extreme care must be taken to incorporate health and safety features that will minimize the potential for serious accidents. In many high school classes, the number of students may not exceed 30, whereas in some undergraduate college and university laboratories, the number may be larger. Graduate-level laboratory instruction is normally conducted in research laboratories, which are covered elsewhere in this book. Adult training laboratories are designed and used for specific professional continuing education programs and for professional certification testing that are required by corporations and government agencies for their laboratory workers. Teaching laboratories should be designed to demonstrate and encourage safe practices and operations: A disregard or ignorance of safety as a student will be carried over into the professional work that follows schooling. For example, laboratories designed for physics that involve electrical apparatus capable of providing serious electrical shock hazards or an ignition source potential should not be combined with chemical laboratories that use flammable liquids and gases.

The trend to more multi-interdisciplinary research may begin to spur a similar effort in teaching. This will emphasize the need to carefully review the activities to be performed and the equipment used in these teaching laboratories.

Experiments carried out in microscale chemistry teaching laboratories are similar to those performed in a typical general chemistry laboratory, except they are performed at 1/10th to 1/100th of the normal level of chemical volumes. This means that the quantities of hazardous materials that are used will be much less than in conventional chemical experiments. The introduction of microscale organic chemistry in instructional laboratories was first implemented in 1983 (Mayo, 1989). By 2009, over 2000 colleges and universities in the United States were conducting organic chemistry teaching laboratories at the microscale level (see www.microscale.org). In addition, the introduction of microscale inorganic chemistry teaching laboratories is underway. Although microscale techniques have not become widespread in some types of research and development laboratories, the potential exists.

The concept of the studio laboratory is to incorporate two work zones in a single space: a seated lecture zone either at tablet-arm chairs or at tables, where the didactic learning takes place; and an experimental zone, with benches, equipment or chemical processes, etc. This dual-purpose arrangement allows instructors to integrate lecture, discussion, and experimentation and demonstrations. It allows students to easily work in groups

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

for data analysis and discussion. Using studio laboratories, some universities have experienced significant efficiencies in scheduling experiment-based science courses, and increase in effective student learning experience.

16.1.2 Work Activities

Tasks performed in teaching laboratories will fall into two laboratory types: wet laboratories and dry laboratories. Wet laboratories employ bench experiments that use liquid, solid, and gaseous chemicals, microbiological agents, organic or inorganic specimens, heating devices, and, at times, open flames. The experiments may discharge both gaseous and liquid effluents. They are characteristic of traditional chemistry, biology, life sciences, earth and environmental sciences laboratories.

Dry laboratories use few liquid chemicals. They are characteristic of traditional physics, computer science, and mechanical and electrical engineering teaching laboratories. Experimentation involves the use of electrical components, light generators and optical instruments, mechanical devices, and microscopes. Dry labs will have very limited use of fuel gas. Water is primarily used for hand washing and cleanup activities.

The activities performed in a microscale chemistry laboratory are similar to those performed in a general chemistry laboratory and teaching laboratory except on a smaller scale (see Chapter 5). Activities performed in studio laboratories may be for any scientific or engineering discipline, and include lectures and audiovisual presentations.

16.1.3 Equipment and Materials Used

The materials and equipment found in teaching laboratories are determined by the subjects that are taught. A general chemistry teaching laboratory, for example, will tend to resemble a general chemistry research or analytical chemistry laboratory with respect to equipment and materials used, although a teaching laboratory will have its own unique features.

Teaching laboratories for physics, biology, geology, and other experimental sciences will also resemble their research counterparts with respect to equipment and materials. A primary difference is most teaching laboratories are used by more than one group of students during the academic year. For example, during a 12-hour day, laboratories may be occupied by different groups of students for up to 9 hours or more, according to the duration of scheduled laboratory sections. In periods between sections, materials from one class are generally cleaned up and stored, the benches are cleaned, and the area is set-up for the next class. Therefore, providing adequate secure storage facilities and class preparation areas is a particularly significant issue for teaching laboratories.

16.1.4 Exclusions

Teaching laboratories, as defined here, are not intended for use for specialized research activities or for conducting hydraulics, civil engineering, materials testing, mechanical engineering, or electronics work. The latter laboratory types have unique requirements and more closely resemble pilot plants or the engineering laboratories described in Chapters 8 and 9.

16.1.5 Special Requirements for Microscale Chemistry Laboratories

Because the chemical quantities required are 1/10th to 1/100th those used in conventional experiments, the glassware and associated equipment must be similarly reduced in size. However, the analytical equipment (e.g., chromatographs, spectrophotometers) remains unchanged. The activities performed in a microscale chemistry laboratory are similar to those performed in a general chemistry laboratory and teaching laboratory except on a smaller scale (see Chapter 5).

16.2 LABORATORY LAYOUT

16.2.1 Introduction

Teaching laboratories, wet or dry, usually require a maximum number of workstations in a minimum area. Despite the pressure to maximize use of all available space, benches should be so located that easy, multidirectional movement and egress are maintained. Ease of movement is needed for students getting to and from supply points or rooms, shared instruments, and fume hoods. In addition, instructors must be able to move about freely, to see all areas and students, and to provide quick response to emergency situations. Long peninsula bench arrangements do not easily permit such movement, but wall benches and island benches do. Island-type benches for teaching laboratories are recommended for classes of 12 or more students. Smaller classes do well working at benches arrayed around walls and at short peninsula benches 8–10 lft (2.4 m–3.0 m). Island benches function better for safe access when lengths are 12 lft (3.7 m) or less. Aisles around 3 ft (1 m) wide need to divide long rows of island benches to provide access for instructors to move quickly and safely between aisles and attend to students' questions and accidents—and potential problems. These short aisles reduce congestion for students. Continuous island or peninsula

benches 15 ft and longer are not recommended for teaching laboratories.

The distances discussed in Chapter 2, Section 2.2.2.2, Egress Safety Considerations, are the minimum recommended between benches and between benches and walls. The distance between benches where students must work back to back must not be less than 6 ft (1.8 m). Otherwise, safe circulation is not possible for students and instructors who carry chemicals, equipment, or other materials.

Experience shows that 32 ft^2 (3.0 m^2) of floor space per student is an absolute minimum for teaching laboratories. This minimum should only be considered when other aspects of the design allow ideal placement of fume hoods, adequate circulation when the room is fully occupied, and rapid and easy egress in case of emergency. Consideration must be given also to adequate areas for storage and cleanup. By the time floor space per student reaches 70 ft^2 (6.5 m^2), generally there is adequate room for design flexibility to accommodate varied teaching styles and course activities. The National Science Teacher Association (www.nsta.org) recommends minimum of 45 net square feet (4.2 m^2) per student. American Chemical Society (www.ACS.org) recommends minimums of 50 net ft^2 (4.65 m^2) per student for general chemistry teaching and 55 net ft^2 (5.1 m^2) per student for organic chemistry teaching laboratories.

16.2.2 Individual Laboratory Arrangements

In addition to adequate clearances and area requirements, laboratory layouts should be guided by the principle of hazard zoning. See Chapter 2, Section 2.2. Hazard zoning locates equipment and processes that pose greater risks for accidents and injury as far away from primary laboratory exits as feasible. As students move toward laboratory exits they should progressively experience less risk. For example, chemical hoods and other containment devices should be located away from exits and experiment write-up tables and instructors' desks can be located near exits.

Figure 16-1 shows an arrangement for a general chemistry teaching laboratory. This layout features fume hoods at the rear of the room arrayed side by side with shared benches between hoods. Each student works facing a hood. This allows instructors to see students working at the hoods, as well as to look directly into the work areas in the hoods and be able to quickly recognize when an obvious hazard is developing, such as a fire or runaway reaction. Good sight lines give alert instructors and students a small, but significant head start to react to an emergency in an appropriate manner. A disadvantage of the arrangement shown in Figure 16-1 is that students may use the aisle in front of the hoods to traverse the laboratory, producing sufficient traffic in front of fume hoods to compromise effective contaminated air capture. To reduce traffic in front of the hoods, commonly used instruments, supplies, and less-hazardous resources should be located at opposite ends of benches toward the instructor's demonstration table. This arrangement increases student circulation in the less-hazardous sector of the laboratory, another example of the hazard zoning concept discussed in Chapter 2.

An understanding of staffing practices is critical when deciding on the layout of chemistry or other types of teaching laboratories. For example, when there is a low student:instructor ratio, good laboratory visibility may be less difficult to arrange. In laboratories that do not require many fume hoods, or experimental setups that obstruct sight lines, there may be fewer constraints on laboratory designs. Teaching laboratories for disciplines that do not normally use hazardous or odoriferous chemicals may be arranged in other ways that are not used for chemistry teaching. See Figures 16.2A and B for several of these options. Primary objectives are to provide instructors with good sightlines and ease of movement throughout these laboratories. Laboratory tables may be used instead of benches. If it is desirable for tables to be movable, electric power and data outlets must be provided to tables in one of the following ways:

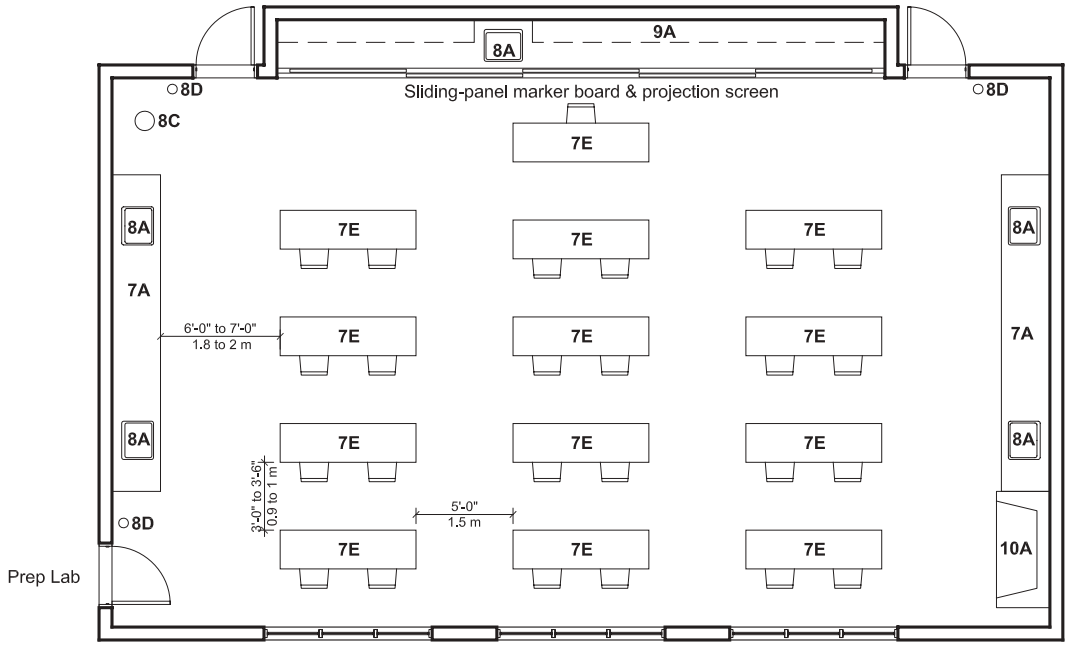
- Walls with outlets in a docking station
- Ceilings with overhead cord reels or utility carriers
- Floors with recessed, waterproof outlet boxes with covers, flush with the floor when closed

Studio-style teaching uses teams of two to six students who study and solve problems collaboratively. This method requires benches for small groups and more flexibility to set-up experiments. Some instructors include lecture or discussion zones within studio teaching laboratories.

Computers can be integrated into the course activities both at wet benches and in discussion areas of teaching laboratories. As miniaturization and wireless technologies progress, difficulties of safely locating expensive electronic devices near wet activities may diminish. For standard personal computers and laptop computers, surfaces above or separate from possible wet areas, and metal armatures, to which computers can be attached, all work well. They can be modified reagent shelves or writing surfaces that slide out from under the countertops.

16.2.2.1 Organic Chemistry Teaching Laboratories.

In organic chemistry teaching laboratories, where there



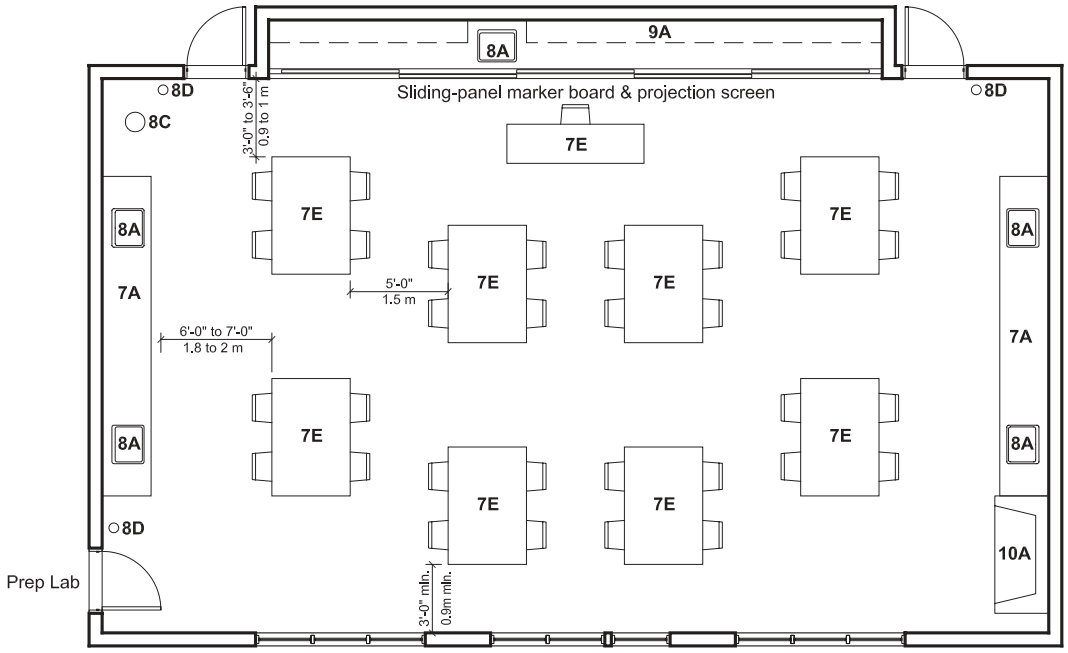
KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 16-1. General chemistry teaching laboratory layout.

may be a requirement for up to one fume hood per student, fume hood density becomes very high and designing a safe laboratory layout and following the principles of hazard zoning are more difficult. Examples of good design solutions are to intersperse fume hoods with individual student benches on a one-to-one basis or to have every two students share one larger fume hood. Either arrangement reduces the potential for traffic in front of each hood by limiting access to fewer students and an instructor. In addition, transfer of materials from bench to hood becomes very convenient and encourages students to use the hood. Benches separating chemical hoods side by side should be a minimum of 4 ft wide (1.22 m) to reduce air turbulence into hood sashes. Arrangements are highly discouraged where pairs of hoods are installed with normal 5-ft wide aisles between two or more face-to-face hoods. With only 5 feet separating open hood sashes, great incoming air turbulence occurs that can totally compromise performance of both chemical hoods. When students work back to back in this arrangement, their movement further disrupts smooth airflow.

Arrangements that distribute fume hoods throughout the laboratory tend to restrict good sight lines that cover the entire laboratory because the hood superstructures are so tall. When chemical hoods have superstructures with transparent glass or plastic panels on all sides, instructors and students are better able to observe safety problems occurring at other workstations or in another part of the laboratory, as shown in Figure 16-3. In more traditional laboratory arrangements, a clearer view of the entire laboratory is possible with standard types of chemical hoods. This arrangement takes considerable wall space to line up hoods with a minimum 4 ft



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6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

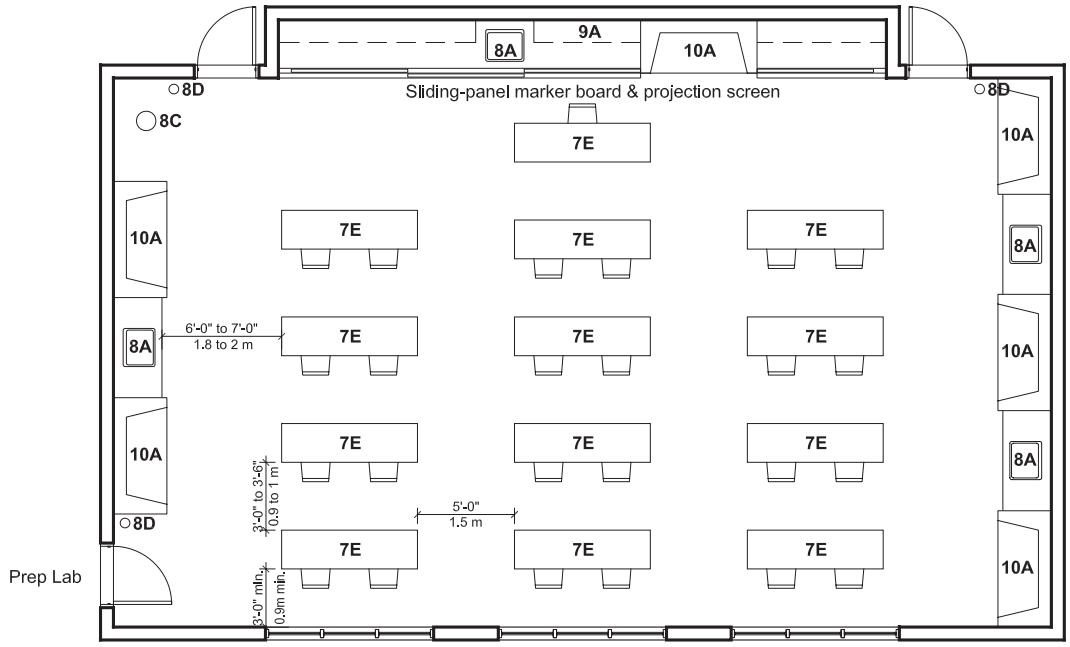
FIGURE 16-2A. General chemistry teaching laboratory layout, with 4-seat tables, one chemical hood.

(1.22 m) separation side-to-side and minimum 5-ft (1.5 m) aisle width from hood to bench, dimensions recommended in National Institutes of Health chemical hood guidelines (Memarzadeh, 2012). Windows can be located above benches that are positioned between chemical hoods.

Provide a zone in the lab or between the organic labs for shared analytical instruments. This is separately ventilated and positively pressured space relative to the flanking organic labs to protect the instruments. Shared instrument zones may be partially enclosed with walls or totally enclosed to provide better isolation of instruments from laboratory air. Providing wide windows in these walls improves safety because instructors can continue to view students from the instrument space.

16.2.2.2 Microscale Chemistry Teaching Laboratory Arrangement. The layout of a microscale chemistry laboratory resembles a general chemistry laboratory (Chapter 5) or a conventional teaching laboratory. All the items described in Chapter 5, Sections 5.1.2 and 5.2.2, and Chapter 16, Sections 16.1.2, and 16.2.2 should be reviewed, and those that are relevant should be implemented. The major changes will be in the furniture and ventilation requirements.

Because of the increased use of microchemistry analytical techniques, careful consideration should be given to individual student workstations. If standing benches are preferred, work surfaces should adjust in height from 34–40 in. (0.86–1 m) to safely accommodate tall and short students. Workstations may also be designed



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1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
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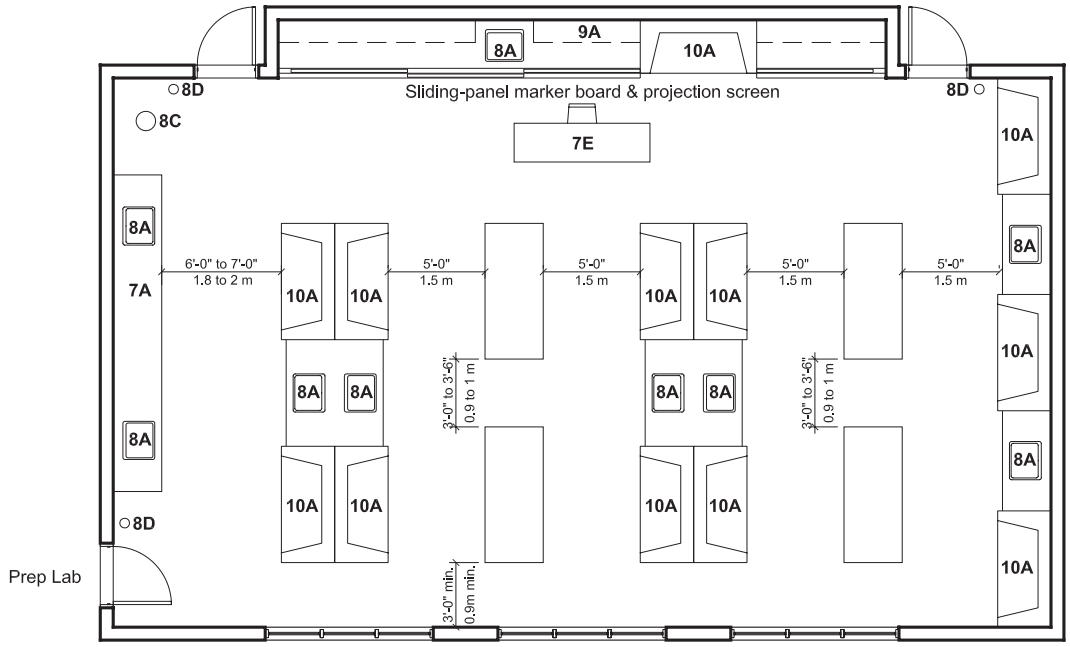
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 16-2B. General chemistry teaching laboratory layout, with 2-seat tables, six chemical hoods.

for students to be seated rather than standing because students require greater manual precision to manipulate equipment and materials. A seated position with both feet on the floor improves balance, postural stability, and manual control. In this case, the benches should be adjustable from 29–34 in. (0.75–0.82 m) in height and leg spaces must be provided by kneeholes in the benches so students can push chairs or stools up to countertops. When work benches are low, to permit work while seated, aisles should be wide enough for students seated back to back to push back their chairs and still leave room for instructors and other students to pass. A 7-ft (2.1 m) aisle width is recommended.

16.2.2.3 Studio Teaching Laboratory Arrangement. The didactic zone should not be surrounded with all the fume hoods. This arrangement is especially hazardous because (1) it could delay instructors from getting from one side of the lab to the other to respond to a student or to an accident, and (2) it might distract instructors from watching those students doing experimental activities.

16.2.2.4 Preparation Laboratory. Most experimental science teaching laboratories need support facilities, such as preparation laboratories. According to the size of the science program at the undergraduate level, each science discipline may need one or more preparation laboratories. Preparation laboratories provide counter space, equipment, and some storage for materials used in teaching laboratories. The layout of a preparation laboratory resembles a general chemistry laboratory



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
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7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 16-3. Organic chemistry teaching laboratory layout.

(Chapter 5). All the items described in Sections 5.1.2 and 5.2 should be reviewed, and those that are relevant should be implemented. The major changes will be in the furniture and ventilation requirements. Preparation laboratories often have hazardous or odoriferous chemicals even if students in adjacent teaching laboratories do not use them. Therefore, instructors and technicians may require use of one or more chemical hoods in preparation laboratories, according to the types and volume of preparations for one full days' laboratory use (see Section 16.3.1.1 below). Appropriate chemical storage units to hold one-week's volume of chemicals should be considered, unless a central chemical stockroom is conveniently close. Doors that connect directly into teaching laboratories are convenient and may be used for secondary egress, but preparation laboratories should also have primary exit doors that open directly into egress corridors. Preparation laboratories require security to protect contents from theft or vandalism.

16.2.3 Egress

There should be a minimum of two exits from each teaching laboratory and preparation laboratory, with each exit opening into separate fire-safe egress pathways, where possible. Where exits open into the same corridor, arrange these exits as far apart as possible. When teaching laboratories are large, additional exits may be required to be certain that the travel distance to an exit never exceeds 50 ft (15 m). All exit doors should swing in the direction of exit travel.

All of the remaining egress recommendations in Chapters 1 and 2 should be followed.

FIGURE 16-4. View of a safety station panel in a teaching laboratory, located under and to the left of the clock.

Safety equipment and emergency response equipment should be placed in "safety stations" at laboratory entries (see Fig. 16-4).

16.2.4 Laboratory Furniture

Teaching laboratories require very strong frames or supports and very durable and cleanable finishes. Students may use open drawers as stepladders to reach something out of reach on a shelf above the bench, so hardware used to mount drawers and cabinet doors and to open them needs to be extra-heavy duty to withstand students' use. Individual locks may be required on student-assigned storage units. Hardware can be built-in locks or simple hasps to accept combination locks that students' purchase. Due to excessive administration services required for keys and combinations, providing hasps reduces costs and improves security of students' laboratory equipment and materials.

Jurisdictions having authority or teaching institutions may adopt ADA requirements and require compliance in some or all of the teaching laboratories, where one ADA workstation and accessibility is provided. See Chapter 1, Section 2.2.2, and Chapter 2, Sections 2.1 and 2.5. ADA requirements must be defined in the programming phase so that designers plan for appropriate workstation configurations, chemical hoods, and safe laboratory egress for students with disabilities. Compliance to ADA affects bench heights and depths of countertops, reaching distance, knee-space dimensions and locations, types of sinks and protection of legs from hot pipes beneath sinks, among other layout, furniture, and emergency equipment access considerations. Aisle widths recommended here in Section 2.1 meet ADA requirements. Locations of ADA workstations should be as close to one laboratory exit as is feasible, while still providing excellent sight lines to instructors, chalkboards, projection screens, or other audiovisual equipment. Include provision of an ADA compliant emergency eyewash fountain at each ADA workstation next to laboratory sinks, if there is no centrally located ADA-compliant eyewash fountain. Provision of a chemical hood for a student in a wheelchair should be located close to the ADA workstation, but not be in the path of egress. Benches for shared instruments may require a section of the countertop to be lowered to an ADA-compliant height of 34 in. (86 cm), or the entire bench can be designed and installed at 34 in. (86 cm) height. Knee-spaces are also required for ADA compliance.

When designing chemistry labs, consider providing a "dry" zone on student benches for writing up experiments and/or group discussions. This dry zone can be slightly separated from wet activities by distance, by lowering the counter height, or providing separate tables close by.

16.3 HEATING, VENTILATING, AND AIR-CONDITIONING

The HVAC recommendations contained in Chapters 1 and 2 are generally applicable to teaching laboratories and should be considered for implementation. Additional comments regarding HVAC facilities for teaching laboratories follow.

Microscale laboratories usually require lower room ventilation rates than do standard macroscale chemical laboratories because the potential for contamination is substantially reduced. A rate between 0.5 and 1.0 cfm per square foot of floor area (0.018–0.035 $m^3/s/m^2$) or between 4 and 6 air changes per hour is generally adequate when fume hoods are not in operation in microscale teaching laboratories.

16.3.1 Chemical Fume Hoods and Other Local Exhaust Systems

Fume hoods should be located so that they are removed from the main entrances and exits and do not face exit routes or block them in the event of a fire, an explosion, or a violent reaction within the hood. Hoods should be located near the back or outer walls of the laboratory, near the least-traveled egress routes, but within easy access of the students (see Section 16.2.2). Chemical hoods can be ordered and installed to meet ADA requirements. These hoods have special features such as lower counter heights; sash heights; knee space for wheelchair access; electric power, gas, and water at accessible heights and reaching distances; and safety devices. ADA-compliant hoods may include small

FIGURE 16-5. View of slot exhaust device at teaching laboratory benches.

FIGURE 16-6. View of a pass-thru chemical fume hood.

chemical storage cabinets mounted beneath countertops with rollout platforms. These cabinets provide safe chemical access for disabled students and eliminate risks for students in wheelchairs while transporting chemicals from central distribution stations common in teaching laboratories.

At least one local exhaust device is desirable at each bench in wet laboratories to provide convenient locations where effluents from small fuming, smoking, or noxious experiments can be removed safely. We recommend one individual local exhaust device per student in organic chemistry teaching laboratories, but only one per four work sites for general chemistry teaching laboratories. Figure 16-5 provides an example of local exhaust hoods provided at each bench in a pathology teaching laboratory. Similar devices are effective to capture odors in zoology and comparative anatomy laboratories where preserved animals are dissected. To comply with the principle of hazard zoning (see Chapter 2), local exhaust facilities should be located on the bench nearest the most hazardous zone of the laboratory. Bench exhaust devices are not usually needed for physics and similar teaching laboratories. Consider installing at least one chemical fume hood in every teaching laboratory or adjacent preparation laboratory for solvent dispensing and dry activities that should not be conducted on an open bench.

16.3.1.1 Pass Through Chemical Fume Hoods. For heavy chemical use teaching laboratories where much preparation work must be conducted it may be desirable to have a pass-through fume hood (see Figure 16-6) that allows easy and safe transfer of materials from adjoining preparation laboratories into teaching laboratories (see Section 16.2.2.4). Pass-through hoods should meet all the requirements of Chapter 32, Section 31.2.

16.3.1.2 Local Exhaust Systems for Microscale Chemistry Laboratories. There will be fewer fume hoods needed in microscale teaching laboratories compared with the number required in conventional laboratories because the quantity of chemicals used and the size of the experimental equipment are reduced by 1/10th to 1/100th. This means that most experiments can be performed conveniently at a lab bench, and consideration should be given to the use of a modified downdraft bench or installation of slot exhaust ventilation along the rear of the laboratory bench in place of conventional laboratory hoods. The *Industrial Ventilation: A Manual of Recommended Practice for Design, 27th Edition* (American Conference of Governmental Industrial Hygienists [ACGIH], 2010) provides design guidance. To meet ADA requirements, one or more workstations will be installed at lower height, 32–34 in. (81–86 cm). Slot exhaust devices at ADA workstations must be lowered commensurately to work effectively.

16.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

The loss prevention, industrial hygiene, and personal safety recommendations contained in Chapters 1 and 2 are applicable to teaching laboratories and should be considered for implementation in addition to the recommendations that follow.

16.4.1 Emergency Showers

Emergency showers for large teaching laboratories should be placed inside the laboratory proper and so located that no more than 25 ft (7.6 m) of travel distance is required from any point. Showers should not be placed in front of chemical or flammable liquid storage cabinets or shelves or directly in front of fume hoods. Handles to activate emergency showers should be accessible to students in wheelchairs and comply fully with ADA, 1990 requirements. Additional requirements for emergency showers are given in Appendix A and the ANSI standard Z358.1, Emergency Eyewash and Shower Equipment (ANSI, 2009).

16.4.2 Emergency Eyewash

For laboratories using chemicals and containing four or more multistudent benches, an eyewash device should be located at each bench sink. It can be a handheld dual-head spray type. For laboratories with fewer than four benches, there should be at least one eyewash fountain per laboratory and it should be so located that no more than 3–4 seconds are required to reach it from the most remote workstation. In addition to the hand-held type eyewash device mentioned above, at least one tempered, ADA-compliant, full-face eyewash fountain should be located in each teaching laboratory. Additional information on eyewash fountains is given in Appendix B and in Section 2.4.1.7, and ANSI standard Z358.1-2009, Emergency Eyewash and Shower Equipment (ANSI, 2009).

16.4.3 Chemical Storage and Handling

No highly reactive or flammable chemicals should be stored in a teaching laboratory. An adjacent chemical storage room or a specially constructed and protected dispensing area should be provided for this purpose. In teaching laboratories, provisions should be made to shelve or otherwise hold only the amount of chemicals necessary for a day's or a single class's experiments. Construction details of safe chemical shelving and storage cabinets are covered in Chapter 2, Section 2.4.

Generally large quantities of flammable liquids are not stored in teaching laboratories. Where large quantities of flammable solvents are stored a modified fume hood as seen in Figures 16-7A and 16-7B can be used. The solvent dispensing stations are built into the hood along with a fire suppression system.

16.4.3.1 Microscale Chemistry Laboratories. Because the quantities of chemicals used are small, storage space and shelving needs can be reduced proportionally.

FIGURE 16-7A. Front view of chemical fume hood with solvent-dispensing device.

FIGURE 16-7B. Back view of chemical fume hood with solvent-dispensing device.

16.4.4 Hazardous Chemical Disposal

Central points for the collection and temporary storage of chemical waste should be provided in each laboratory. They should be remote from students at their work sites and not located in egress routes. Locations in or near fume hoods are recommended. Large waste storage areas are unnecessary because wastes should be removed at least daily.

16.4.5 Fire Extinguishers

Provisions should be made for locating fire extinguishers within each teaching laboratory. With island benches, one fire extinguisher should be located at each bench. The type of extinguisher is dependent on the use of the laboratory. A clean agent such as CO_2 is appropriate for chemical operations. Size 4A-40 BC or larger ABC-type dry chemical units should be located in the hall to be used as a backup.

16.5 SPECIAL REQUIREMENTS

16.5.1 Preparation Lab

There should be a room associated with each teaching laboratory or group of teaching laboratories that can be used for the preparation of experimental equipment and materials. If the teaching laboratories do not involve the use of chemicals or hazardous substances, no special facilities are needed. When chemicals are used, the following considerations are important.

Chemicals stored in the preparation room (when not stored in the areas referred to in Section 16.4.3) will be in the nature of bulk chemical storage. Approved storage cabinets should be provided (see Chapter 1, Section 1.4.7 and Chapter 2, Section 2.4.6) in adequate numbers to handle all flammable liquids. Provisions should be made to store all chemicals according to safe compatibility characteristics. The preparation room should have good general ventilation to dilute released materials below their hazard level—that is, explosivity in the case of flammables and toxicity in the case of toxic materials.

The preparation room should have a well-planned fire-suppression capability that includes fixed automatic fire-suppression facilities and hand-portable fire extinguishers of the ABC dry chemical type with ratings of 4A40 BC or better. Hand-portable extinguishers should be located strategically to ensure that a fire can be attacked quickly and kept from threatening the laboratory itself.

An arrangement such as a pass-through or counter area should be used to eliminate the need for students to enter the preparation room. Dutch doors are not recommended because required fire separation may be compromised. Pass-through openings may need to be protected by fire shutters to maintain required fire separation.

16.5.2 Security

The use of hazardous materials in a teaching laboratory may require the application of locks on material, storage containers, and laboratory doors. In some cases, teaching labs may be used by students in "off" hours for unsupervised student research. This should be evaluated for added access restrictions. See security considerations discussed in Chapter 1, Sections 1.5.4.1 and Chapter 2, Section 2.5.1.

17

GROSS ANATOMY LABORATORY

17.1 DESCRIPTION

17.1.1 Introduction

The gross anatomy laboratory is a group of spaces for the preparation, storage, and dissection of human cadavers and large animal carcasses (or portions thereof) for the purpose of teaching gross anatomy or for research. The space described in this section is the dissection room. Requirements for morgue facilities that support gross anatomy laboratories are explained in Chapter 20. Emphasis is given here to the gross anatomy teaching laboratory because of its special requirements beyond those of anatomy research. Requirements for general teaching laboratories are in Chapter 16. Relevant sections in Chapters 1 and 2 should be followed closely for gross anatomy research laboratories.

17.1.2 Work Activities

17.1.2.1 Dissection Laboratory. Gross anatomy is generally taught by lectures in conjunction with laboratory sessions. In the laboratory, students inspect and identify all tissues revealed by dissection. Dissections are usually done by students, but may be performed by anatomy instructors in the case of many allied health science courses. Activities include cutting, sawing, manipulation with fine sharp instruments, and cleaning up. During laboratory sessions, instructors may give demonstrations with physical models, computer-generated images, videos, and other visual aids. They may also use previously dissected specimens called *prosections*.

In typical medical and allied health services training, a single cadaver may be dissected by a group of four to six students during the entire course, which may be as short as 2 weeks or as long as an entire semester. In veterinary medicine training, preserved large animal carcasses are used. Students refer to their textbooks, adjacent to the dissection table, as they manipulate and view the cadaver or carcass. Students gather both visual and tactile information. Students must be able to inspect the specimen from all angles and at very close range, 1–12 in. (2.5–30.5 cm) away. Some schools require students to clean up the dissection laboratories after each class period; therefore, those laboratories require a number of large sinks.

Some medical schools, veterinary schools, and private foundations provide continuing education training for surgeons and veterinarians in advanced and new surgical techniques using unpreserved cadavers or large animal carcasses. Facilities for surgical and emergency medicine training may look similar to gross anatomy teaching laboratories, but will include cameras and other audiovisual equipment above each table.

17.1.2.2 Research Laboratory. The activities in research laboratories that use gross anatomical specimens may include cutting, mixing, mechanical or biochemical procedures, tissue culture, microscopy, and

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

tissue sample preparation, staining, and labeling with radioisotopes or other chemical labels. Research on the effects of bodily trauma caused by firearms or vehicles, for example, may use whole cadavers or carcasses in experiments, both chemically preserved and unpreserved specimens. Biomechanics researchers may use specific body parts from cadavers or carcasses. Researchers in surgical and emergency medicine also use cadavers and carcasses. Dissections are often performed on research specimens.

17.1.3 Equipment and Materials Used

17.1.3.1 Dissection Laboratory. The materials present in the gross anatomy dissection laboratory may include chemically preserved bodies, body parts, or fresh unpreserved anatomical specimens (human or animal), organic waste matter, and chemicals. Chemicals include glycerin, glycol, formalin (a solution containing formaldehyde), phenol (carbolic acid), soap, and water. Equipment, in addition to dissection instruments and surgical tools, may include saws, drills, and cleaning tools. Dissection tables may be mobile and nonventilated, or fixed with downdraft exhaust to capture unpleasant odors. Dissection tables designed for gross anatomy dissections have shallow basins beneath the top surface because there is some fluid leakage.

Teaching aids may include anatomical models, skeletons, charts, computers, and other audiovisual equipment; these require appropriate storage facilities.

The smell of formaldehyde, recognizable at concentrations lower than one part per million in air, will be ever present in gross anatomy teaching laboratories that use formalin solutions for cadaver or carcass preservation. To help reduce that odor and other unpleasant odors, all surfaces should be impermeable, sealed, and smooth. Work surfaces and floors should be easily cleanable because students may do the cleaning before they leave the laboratory. The recommended material for all sinks and furnishings in dissection laboratories is stainless steel. All metal joints of dissection tables, gurneys, sinks, countertops, and storage cabinets should be welded, ground smooth, and coved for thorough cleaning. Avoid wood and plastic materials in furnishings because they do not resist wet conditions; nonmetal furnishings and finishes absorb odors that will revolatilize for long periods.

Because service personnel must clean traps regularly, all floor and sink drains should have sediment and grease traps for capture of organic matter.

17.1.3.2 Research Laboratory. The materials present in research laboratories that use gross anatomical specimens are those listed above for dissection laboratories. In addition, all the chemicals, equipment, and instruments associated with general research laboratories may be present. In laboratories where research on major trauma is conducted, there may be large arrays of heavy equipment and special installations for experiments. Cadavers and carcasses, preserved or unpreserved, are tested in special apparatus constructed for those experiments, such as firing ranges or high-velocity, high-acceleration sleds on tracks fixed to floors. Overhead hoists may be used in these laboratories. These installations require review by structural engineers for strength of floors, walls, and ceilings for resistance to projectiles, impact loads, and weight capacity to support apparatus.

Trauma research laboratories also require standard gross anatomy dissection facilities and equipment. Surgical and emergency medicine research may require or specialized surgical tables and overhead, adjustable surgical light assemblies. These laboratories may require a morgue and cold storage facility for cadavers (see Chapter 20).

17.1.4 Exclusions

17.1.4.1 Dissection Laboratory. Gross anatomy dissection laboratories are not operating rooms or laboratories for experimentation with live animals (see Chapter 22, Animal Research Laboratory, Section 22.2.4). The environment in gross anatomy laboratories is not sterile. Dissection laboratories' electrical and ventilating systems are not designed for use in an atmosphere of flammable anesthetics. Bulk volumes of embalming chemicals should remain within morgue facilities, not in dissection laboratories (see Chapter 20, Morgue Facility, Section 20.1.3.2).

17.2 LABORATORY LAYOUT

17.2.1 Introduction

The public may regard the activities pursued in dissection laboratories with alarm, disgust, or morbid curiosity. To secure these areas from public access and view, as well as to contain odors, the location of the dissection laboratory should be carefully considered so as to provide for the following:

- Private passageway between morgue and dissection laboratories is desirable to reduce the risk of accidental contact with uninvolved students and staff members, or with the public.
- Windows are desirable, but other buildings should not overlook dissection laboratories. Alternatively

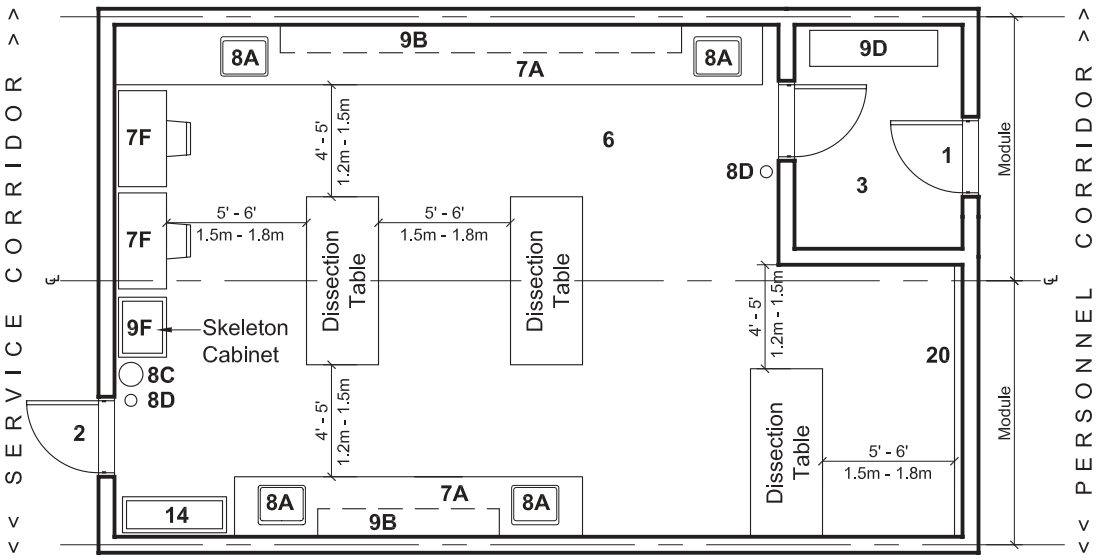
windows may be glazed with fretted or translucent glass, allowing no views inside dissection laboratories. One-way glass does not work because if laboratories are used after dark, interior lights expose the interior.

- Anteroom entries reduce the risk of passersby from looking directly into dissection laboratories (see Chapter 2, Section 2.2.2.3).

17.2.2 Individual Room Arrangements

17.2.2.1 Dissection Laboratory. A gross anatomy teaching laboratory consists of locker/shower rooms for men and women, dissection rooms, and storerooms. Keeping these functions together improves security and odor containment. Seminar rooms may also be adjacent to the gross anatomy laboratory suite for didactic instruction. See Figure 17-1 for an example of a small laboratory, and Figure 17-2 for a larger one. Gross anatomy laboratories generally do not have concerns for sterility or for biohazards; microorganisms do not flourish in properly prepared cadavers. However, where fresh cadavers, animal carcasses, or specimens thereof are investigated, universal microbiological precautions are maintained, including use of biosafety cabinets (see Chapter 32, Section 32.9). Appropriate personal protective gear must be provided and safe dissection techniques taught, practiced, and mastered. Dissection laboratories using chemically unpreserved specimens or bodies require special cleaning agents and sanitation procedures to reduce risk of transmission of infection for students and personnel (see the above Section 17.1.3.2).

Standard dissection tables are 78 in.–86 in. (198–218 cm) long and 27–32 in. (69–81 cm) wide for average height and weight human cadavers, with maximum



KEY

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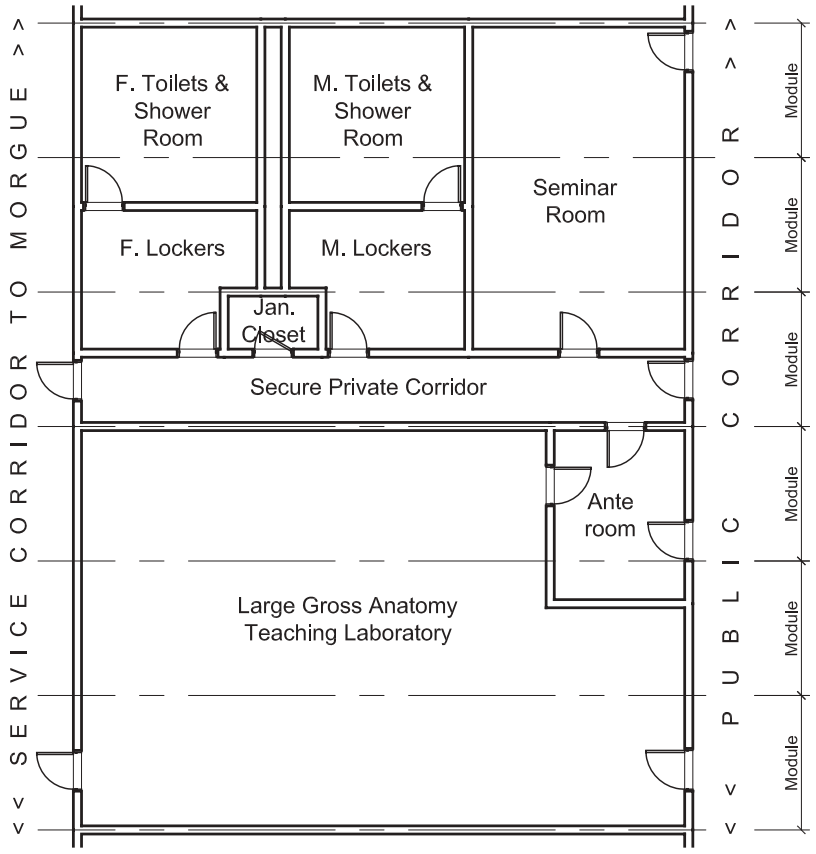
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 17-1. Small gross anatomy laboratory layout.



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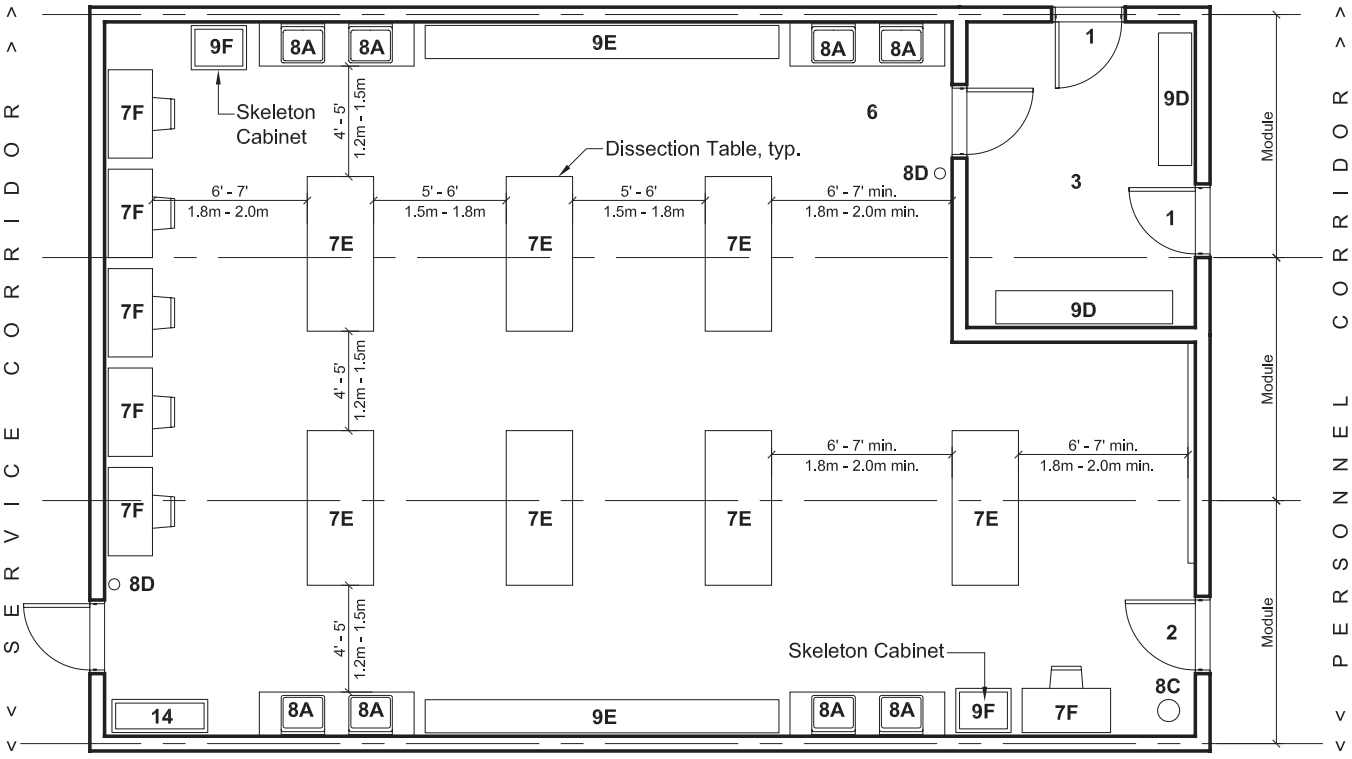
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 17-2A. Gross anatomy laboratory and support function suite layout.

weight capacity from 250–300 lbs (113–136 kgs). If obese or over normal-size cadavers are commonly used, wider or longer tables with greater weight capacity—over 300–600 lbs (136–271 kgs)—may be required. Because of ergonomic considerations for students and instructors, who are different heights, dissection tables or gurneys should be provided in a variety of heights or have height-adjustment capabilities. Tables are usually arranged with minimum clearances of 50–60 in. (127–152 cm) head to toe and 40–60 in. (101–1.52 cm) side to side to accommodate four students with their books and instruments working on cadavers of average size and weight. Students in wheelchairs require minimum 60 in. (1.5 m) clearances all around the table and a table with height adjustable to 30 in. (76 cm).

Provision of excellent lighting levels and fixtures with lamps of 5500 K and close to 100 color-rendering index can achieve nearly natural daylight spectrum



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7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 17-2B. Large gross anatomy laboratory layout.

that improves visual acuity and accurate color perception. Procedure lights with articulating arms and suspended from the ceiling are intense light sources that users can move to direct the beam to the area under examination.

Provision of ventilation for all dissection tables is critical to maintain formaldehyde fumes below exposure limits (see Chapter 20, Section 20.1.3.2). Manufactured downdraft dissection tables are very effective in reducing odors. Downdraft dissection tables with hinged covers decrease release of odors from specimens when the laboratory is not occupied.

Provision of large scrub sinks for hand washing and general cleanup is important. To support cleaning activity, consider providing one large sink for every six to eight students. Bowls of large sinks range from a minimum of 24 in. long, 18 in. front to back, and 10 in. deep ($60 \times 45 \times 25$ cm) to a more generous size of 36 in. long, 22 in. front to back, and 16 in. deep ($90 \times 55 \times 40$ cm). They should have a spray hose and two or more sets of faucets, according to the length of the sink.

Countertops and display cases can be arrayed along the perimeter of the room for storage and display of additional teaching materials. This leaves unobstructed views

from any vantage point. Skeletons require hangers or racks, but all should be stored in locked cabinets or storerooms to protect skeletons from theft. Blackboards, projection screens, and TV monitors should be positioned so that all students can see them from dissection tables.

17.2.2.2 Laboratory Anteroom. Entry anterooms provided between the public-access corridor and dissection laboratory discourage curiosity-seekers and accidental viewing of dissection activities, cadavers, and animal carcasses. Anterooms can be equipped with lockers for students and/or staff members to secure their outerwear and personal effects if separate locker/shower rooms are not provided for men and women (see Chapter 2, Section 2.2.2.3 and Figure 17-2A). Students and staff must not bring personal items into gross anatomy laboratories for their own safety within the lab and for the safety of their families and friends when they return home. Coat racks accommodate the separation of clean and soiled lab coat storage. All persons entering should put on a lab coat to keep organic matter or chemicals from soiling or contaminating their street clothes. Racks of shelves for other PPE required, such as eye protection, gloves, aprons, etc., should be stored in anterooms. Laboratory anterooms do not replace the need for personal shower facilities for men and women, where they can wash completely to remove unpleasant odors and splashes after working for several hours in a gross anatomy dissection laboratory.

17.2.2.3 Research Laboratory. The layout recommendations contained in Chapters 1 and 2, Section 2 are generally applicable to research laboratories that use gross anatomical specimens, and they should be followed closely. Anatomical research laboratories doing trauma and biomechanical experimentation use large and long arrays of heavy and/or moving equipment. Safe clearances and appropriate barriers around the equipment should be provided to protect personnel from injury. Because of these factors, gross anatomy research laboratories can be much larger than research laboratories of standard two-module size. Anatomical research laboratories used for developing surgical techniques and wound treatment may have several operating room and/or dissection tables in addition to standard arrays of laboratory benches and support equipment. Adequate clearances need to be provided around these tables as required for the number of people, procedures performed there, and ancillary equipment required. Clearances may reach 8–10 ft (2.4–3 m). Consideration should be made for location of gross anatomy research laboratories for proximity and convenience to a docking area that can be used for receiving of cadavers or animal carcasses and a secure pathway to laboratories and cold rooms in the morgue for storage (see Chapter 20, Section 20.1.2.3).

17.2.3 Walls, Ceilings, and Floors

Glazed ceramic tile or epoxy paint on plaster, concrete block, and water-resistant sheetrock are preferred wall finishes. Wall surfaces made of composite material panels with integral smooth enamel finish and constructed with sealed joints are an excellent alternative to standard construction methods and materials. Floors must be seamless, sealed, and cleanable and able to withstand harsh cleaning agents. When using epoxy or other monolithic flooring materials consider specifying non slip finishes to reduce the risk of falls because under normal conditions, floors will be wet.

For ceiling construction in large gross anatomy dissection teaching laboratories, acoustical dampening qualities may be more important than impermeability. Noise levels during class sessions can be unbearable in dissection laboratories where all surfaces are hard. Ceilings are best constructed in seamless, sealed, solid, and cleanable assemblies of plaster or sheetrock with water-resistant finishes. Painted plaster and sheetrock ceilings resist odor absorption better than permeable acoustical ceiling tiles and panels. Electric outlets and switches should be waterproof because of the need for frequent cleaning and wet conditions in these laboratories.

17.2.4 Egress

The egress recommendations specified in Chapter 2, Section 2.2.2.2 is generally applicable to gross anatomy laboratories and should be followed closely.

17.3 HEATING, VENTILATING, AND AIR-CONDITIONING

17.3.1 Introduction

The HVAC recommendations contained in Chapters 1 and 2, Section 3 are generally applicable to gross anatomy laboratories and should be followed closely. HVAC systems for gross anatomy laboratories are critical because they must provide a safe environment for those who work in a laboratory with potentially high concentrations of formaldehyde, phenol, and other volatile and toxic chemicals. The threshold limit value (ACGIH, 2012) of exposure to formaldehyde is limited to 0.3 ppm at all times. Installation of downdraft dissection tables with hinged covers is highly recommended for dissection teaching laboratories to contain odors and reduce concentration of formaldehyde fumes. The

basic intent is to maintain formaldehyde, phenol, and other chemical concentrations below objectionable and harmful levels. Odor control in the laboratory and surrounding areas is also critical; the odor threshold for formaldehyde is 1 ppm.

A minimum outside air change rate of 15–20 per hour is common for this laboratory and supporting functions but the actual amount will depend on how well the sources are controlled. If engineering controls, local exhaust devices, and downdraft dissection tables provide adequate fume containment, lower air change rates may be considered. It is best to introduce the supply air high in the room and to exhaust it from a low room location to draw the contaminated air below the work area and well below the breathing zone. Specially equipped fixed dissection tables with built-in downdraft exhaust can provide local capture of chemical fumes more effectively than general room exhaust points located near the floor.

Recirculation of air is not recommended. Certain chemicals, such as potassium permanganate, that have good absorption/adsorption properties for formaldehyde have been used in some cases to remove formaldehyde vapors from recirculated air. For such systems to be successful, large recirculation rates must be maintained and careful monitoring of the activity of the air-cleaning chemicals must be conducted on a continuing basis.

Local exhaust or capture hoods may not be feasible for gross anatomy teaching laboratories because students tend to work extremely close to the parts being dissected. Downdraft tables effectively draw supply air over the specimens, down and away from a user's breathing zone. Low room air exhaust grilles located on the perimeter walls contribute to reducing risks of excessive exposure to embalming fluid vapors. Nevertheless, local exhaust opportunities should be studied for each function to determine the feasibility of this method of vapor and odor control. Use of stainless steel ventilation ducts should be considered because of their corrosion resistance. The room should be at a negative pressure with respect to all public areas and other laboratories. No special treatment of exhaust air is needed, provided that room exhaust air can be discharged well above all surrounding buildings and terrain features.

17.3.2 Individual Room Requirements

17.3.2.1 Dissection Laboratory. In gross anatomy teaching laboratories, students work with cadavers or animal carcasses already prepared and preserved in embalming fluid, an aqueous solution of formaldehyde, methanol, ethanol, phenol, and glycerin. The extent of chemical exposure depends on the type of dissections made and the organ being studied. For example, levels of exposure are higher for dissections involving opening body cavities. The greatest exposure appears to be from the abdomen. Quantitative measurements substantiate this experience. Personal exposure concentrations can easily exceed OSHA's permissible exposure limits (PEL) when adequate ventilation is not provided (see Section 17.3.1 above). Exposure levels generally do not decrease with time because as cavities dry out, students wet cadavers with additional embalming fluid.

17.3.2.2 Research Laboratory. Mechanical engineers must review facility conditions to provide appropriate methods of ventilation to apparatus and to laboratories. In gross anatomy research laboratories, researchers will be dealing with cadavers or large animal carcasses already prepared and preserved in embalming fluid. Dissection activities may take place in anatomy research laboratories with unpreserved specimens stored under cold conditions.

17.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

The loss prevention, industrial hygiene, and personal safety recommendations contained in Chapters 1 and 2, Section 4 are generally applicable to gross anatomy laboratories and should be followed closely. Bone saws tend to spray bone fragments. Students and instructors should wear face shields to protect the eyes, nose, and mouth when using saws. Dissection instruments are sharp, so a sufficient number of secure storage cabinets or drawers will be needed for these instruments. Emergency eyewash fountains are highly recommended in gross anatomy dissection laboratories (see Chapter 2, Section 2.4.1.7).

Phenol splashes are very harmful to skin. Phenol must be scrubbed off with soap and water or by using an emergency deluge shower. Emergency deluge showers are highly recommended (see Chapter 2, Section 2.4.1.6). Bulk chemicals are stored in morgue facilities, but dissection laboratories should provide sufficient and appropriate chemical storage facilities for containers of preservatives and cleaning agents.

17.4.1 Fire Protection Systems

A standard NFPA 13-compliant automatic sprinkler system is highly recommended. See Figures 17-1 and 17-2B for locations of handheld fire extinguishers and Chapter 2, Section 2.4.1.2.

17.5 SECURITY

Confidential, highly flammable, toxic, or pathogenic materials that may require the application of material and/or laboratory lock-up are unlikely to be in dissecting laboratories. Security considerations discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1 may be required for research gross anatomy laboratories when sensitive material or specimens are present.

Equipment and moving apparatus may pose hazards to persons entering trauma and emergency medicine research laboratories; therefore appropriate access control systems and security measures should be provided.

18

PATHOLOGY LABORATORY

18.1 DESCRIPTION

18.1.1 Introduction

Pathology laboratory suites may be comprised of clinical, forensic, or research laboratories, as well as support areas that often include a clinical or forensic morgue and autopsy laboratory (see Chapters 19 and 20); organ storage; specimen and slide preparation laboratories; a microscopy laboratory for specimen and slide reading; possibly a photography laboratory (see Chapter 25, Imaging and Photographic Facilities); and a small conference room for review of autopsy materials by pathologists, physicians, or police officials. An example of a pathology suite with these support areas is shown in Figure 18-1. Pathology laboratory support areas are likely to be based within hospitals or medical examiners' facilities, and research laboratories can be at the same or at another location. This chapter will discuss the technical areas only.

18.1.2 Work Activities

18.1.2.1 Pathology Laboratory. Activities conducted in research, clinical, and forensic pathology laboratories involve the use of diseased and damaged tissues plus contaminated or infectious materials of living organisms. Operations include tissue cutting, dissection, chemical mixing, mechanical manipulation of organs and tissues, biochemical procedures of widely varying nature, microscopy, microbiological culturing, sample preparation, and staining.

18.1.2.2 Specimen Preparation Laboratory. Activities conducted in specimen preparation laboratories include performing gross dissections on body parts, preparing pickled, frozen, and freeze-dried organ and tissue samples for further processing. Organs and tissues may be of human or animal origin. High volumes of slide production indicate that a separate histology laboratory should be added to a pathology suite. See Section 18.1.2.3 below to determine if specimen preparation laboratories must accommodate histology.

18.1.2.3 Histology Laboratory. When the volume of microscopy specimens prepared in pathology laboratories is high, provision for histology laboratories, specifically designed for high-throughput slide preparation may be warranted. Activities conducted in histology laboratories include taking small volumes of tissues from the specimen preparation laboratory, thinly slicing, fixing them in chemical solutions, staining with a variety of dyes and radioactive chemical markers, and then mounting on slides for microscopic examination. Separation of histology activities from a general specimen preparation lab is a preferred arrangement because chemicals used for slide preparation may be toxic. Special local exhaust ventilation facilities are recommended for activities involving toxic chemicals and

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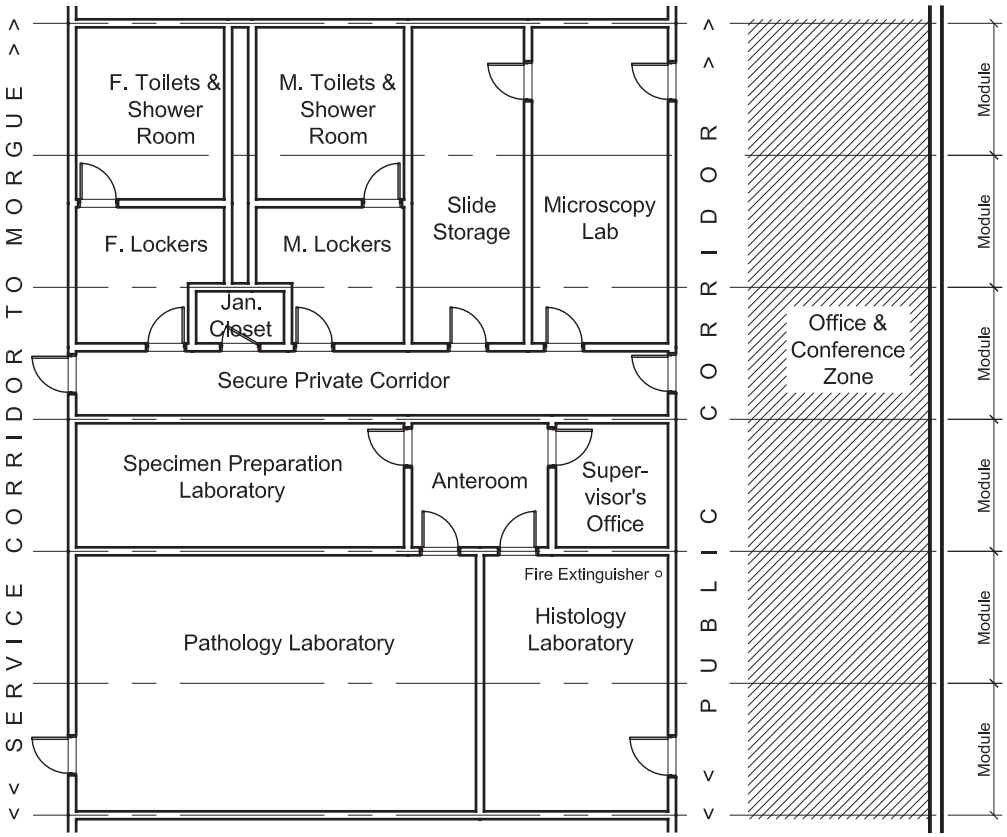


KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 18-1. Pathology laboratory and support function suite layout.

chemicals that are malodorous or irritants (see Chapter 20, Section 20.3.1. and Chapter 32, Section 32.10).

18.1.2.4 Organ Storage Room. For both clinical and forensic pathology work and research, entire organs are preserved and stored for future reference. Activities conducted in organ storage rooms include preserving organs and organ samples by perfusion or immersion in sinks, tanks, or jars of chemicals and by freeze-drying. Organs may be removed for gross visual study or to obtain additional specimens for slide preparation.

18.1.2.5 Slide Storage Room. Pathologists need access to thousands of microscope slides for current and recent cases associated with hospitals, forensics facilities, or research and educational institutions. These are stored centrally in slide storage rooms, where records are kept to keep track of the case and specimens preserved on

the slides. Vast numbers of microscope slides are stored for decades for pathology research, forensic, and educational purposes. These archival collections may be located offsite, with active cases stored in slide storage rooms close to the pathology laboratory.

18.1.3 Materials and Equipment Used

18.1.3.1 Pathology Laboratory. Clinical and research pathology laboratories may contain contaminated or infectious materials in addition to chemicals, equipment, and analytical instruments associated with a general research laboratory. All infectious materials shall be only opened and handled within biological safety cabinets. Chemical fume hoods may be required in pathology laboratories for some work and processes using hazardous chemicals. Forensic pathology laboratories contain similar chemicals, equipment and analytical instruments, but focus on special procedures for the collection of detailed evidence on cause of death for suspicious and wrongful death cases.

18.1.3.2 Specimen Preparation Laboratory. Equipment in specimen preparation laboratories may include gross dissection benches, tissue trimming workstations, chemical fume hoods, cryostats, and a lyophilizer. See Section 18.1.3.3 below for equipment to do histological preparation of specimens. In gross specimen examination (dissecting), considerable quantities of formaldehyde (formalin) are used in this area as a fixative (see Chapter 20, Section 20.1.3.2). When no separate organ storage area is available, laboratories may have circulating pumps for formalin or other chemical fixation liquids gravity fed into large sinks to perfuse organs.

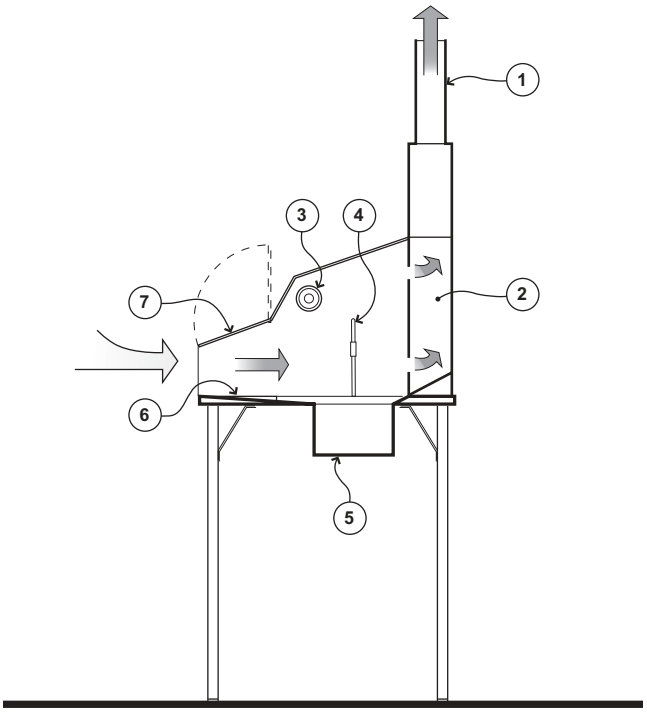
Contaminated materials and infectious organisms may be present. Tissues from patients should be handled in biological safety cabinets specially designed for these agents. See Chapter 14, Section 14.1.3 and Chapter 32, Section 32.9. Figure 18-2 shows tissue-trimming workstations designed for organ and tissue dissections. Staff must be trained to handle infectious specimens safely, according to approved microbiological techniques. All materials must be sterilized before disposal to destroy harmful biological agents in waste materials. However, once tissue specimens are fixed and preserved, they no longer pose an infectious hazard.

Chemicals include formaldehyde, formalin (a solution containing formaldehyde), phenol (carbolic acid), alcohol, paraffin, soap, and water. If specimen preparation laboratories include histology processes, see Section 18.1.3.3 for the other chemicals and chemical hazards that may be present.

18.1.3.3 Histology Laboratory. Equipment in histology laboratories is limited to tissue processing to produce microscope slides. Histology includes equipment to finely slice specimens such as cryostats, microtomes, and lyophilizers. Automated histology equipment includes tissue staining, glass cover slipping, and tissue embedding equipment. Without automation, these processes can be done manually.

The same universal precautions for handling infectious materials and sterilization, and use of toxic and flammable staining chemicals apply to histology laboratories, as in specimen preparation laboratories.

Various histological stains and fixatives, some of which are toxic and/or flammable, are found in histology laboratories. Automatic tissue processing uses alcohol, benzene, toluene, and xylene as drying and clearing agents in processing specimens (see Chapter 20, Section 20.1.31). Concentrations of some of these chemicals



KEY

1	Exhaust Duct
2	Negative Pressure Exhaust Plenum
3	Acrylic Tube with Removable Light Inside
4	Faucet
5	Double Chamber Sink
6	Flat Cutting Surface
7	Acrylic Face Shield
□	Clean Air
■	Contaminated Air

FIGURE 18-2. Section diagram of a ventilated tissue trimming station.

may have high explosion potential in histology and sample preparation laboratories. Local exhaust devices and ventilated workstations should be installed for procedures that are potentially hazardous, such as a slide preparation exhaust chamber which is designed to reduce exposure to xylene fumes.

18.1.3.4 Organ Storage Room. Chemicals used for organ storage include formalin, alcohol, xylene, phenol, soap, and water. The area will have a large sink with gravity feed or a circulating pump for formalin or other chemical fixatives. There will be heavy-duty industrial shelving to hold organ buckets and jars. If any specimens are preserved in alcohol in concentrations greater than 20%, they should be stored in UL-rated flammable liquid storage cabinets.

18.1.3.5 Slide Storage Room. Slide storage rooms provide space for millions of glass slides from completed medical and forensic cases or for research collections. Slide storage boxes or drawers are very heavy, generally 68 lbs (30 kgs) each. Slide cabinets with 14 drawers have the capacity for approximately 6,500 slides weighing over 472 lbs (214 kgs). Slide box storage requires industrial-type shelving or specially manufactured file cabinets to safely support the weight of many boxes or drawers.

18.2 LABORATORY LAYOUT

18.2.1 Introduction

The layout recommendations contained in Chapters 1 and 2, Section 2 are generally applicable to research and support laboratories that are used for pathology research; they should be followed closely. The location of pathology laboratories is not critical. Tissue samples from hospital operating rooms or from forensic and hospital autopsy laboratories can be transported safely and discretely in closed, sealed, and opaque containers to pathology laboratory suites. However, if highly infectious materials are frequently examined, consider locating the laboratory close to operating rooms or the morgue to reduce distances and logistics of transporting infectious specimens. These functions need to be located close and conveniently to each other to promote efficiency in hospital and research staff activities. An example of a pathology laboratory suite is shown in Figure 18-1.

18.2.2 Individual Room Arrangements

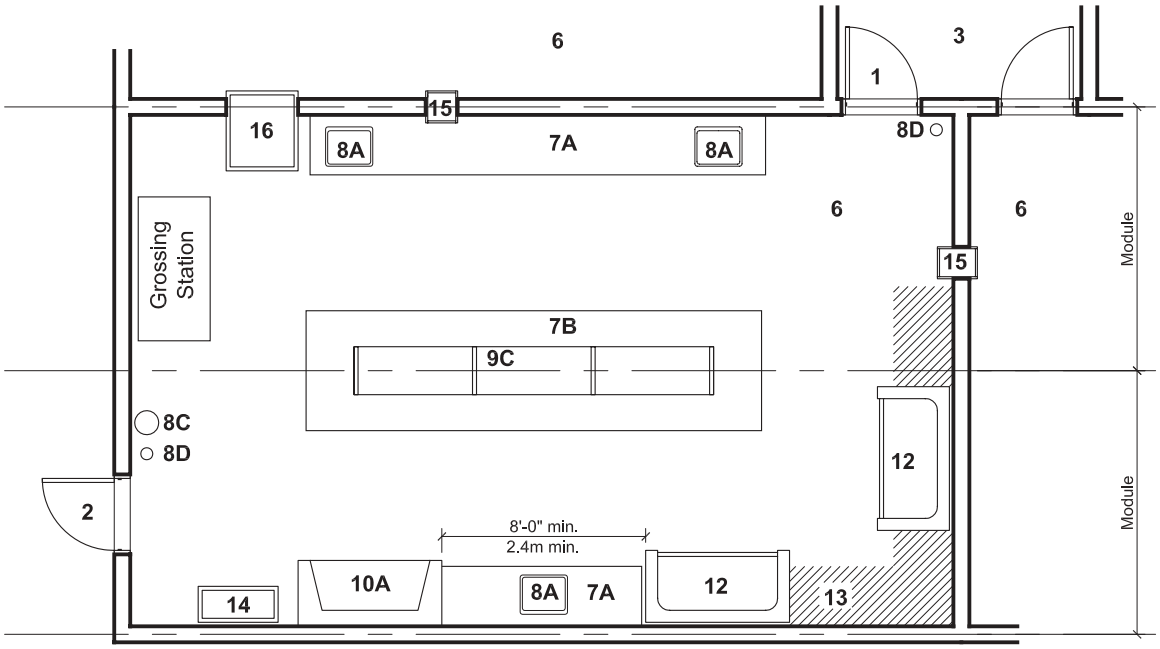
18.2.2.1 Pathology Laboratory. Pathology laboratories, like many research laboratories will have benches and a variety of movable equipment, a chemical fume hood, and a biological safety cabinet as illustrated in the example shown in Chapter 14, Figure 14-3B. When materials classified as Biohazard Level 2 and higher will be routinely used in pathology laboratories, all the protective measures cited in Chapter 14, Section 14.4 for biosafety laboratories should be considered for use. Figure 18-3 is an example of a layout for a pathology laboratory. Close and convenient access to autoclave or alternative sterilization facilities is highly recommended.

18.2.2.2 Specimen Preparation Laboratory. Size and layout of specimen preparation laboratories depend on the volume of tissue samples that must be processed daily and on the number of staff members who normally occupy these laboratories. Grossing stations and tissue trimming stations are activities done while seated on high stools and chairs**,** respectively. Where stations require workers to sit back-to-back, aisles should be **a** minimum of 6 ft (1.8 m) wide to allow safe access between seats. Chemical fume hoods should be located where laboratory traffic and other factors that can create air turbulence are avoided (Chapter 2, Section 2.2.5 and Chapter 32, Section 32.2.3).

When specimen preparation laboratories are also used for long-term storage of pickled samples, labs can become dangerously overcrowded and cluttered. Consideration should be given to providing separate sample storage areas with excellent ventilation or using cold rooms or freezers for storage, so that preparation laboratories can function more efficiently and safely. Separation of storage rooms is particularly recommended for large facilities that may have special tissue collections that require very long-term storage.

Preparation sinks and stainless steel work counters should be separated from storage shelves or racks by an aisle that is a minimum of 5 ft (1.5 m) wide to allow ease of movement without risk of staff members bumping into or knocking over specimen containers. Specimen preparation requires fine hand movements and handling of very small tissue slices. For ergonomic comfort and to improve fine motor control, sit-down benches perform better for staff members than high benches. A 5 ft (1.5 m) minimum aisle width should be maintained within work areas and exit pathways.

18.2.2.3 Histology Laboratory. Layouts of histology laboratories have many similarities to general chemistry laboratories (see Figure 18-2A). The primary difference is that benches are generally installed at seated height from 29–34 in. (74–86 cm); hence, adjustable-height benches would be appropriate here. Automated tissue fixing and staining stations should be installed in



KEY

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4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 18-3 Pathology laboratory layout.

protected locations, similar to desirable locations for chemical hoods (Chapter 2, Section 2.2.5). Cryostats, which slice frozen specimens, need to be located where laboratory airflows are at low velocity and low turbulence, so the extremely thin and lightweight slices are not captured in turbulent air and carried away, only to land on the floor. Microtomes are also adversely affected by turbulent airflows. Histology technicians also use microtomes at seated-height benches to slice specimens embedded in paraffin, so thin slices can float away in drafts and drop onto the floor, causing slip hazards (see Section 18.2.4). Laboratory sinks are required with emergency eyewash fountains in convenient location(s). Histology sinks are used to rinse off stains. Where there are many workers, providing a separate hand wash sink is recommended; it can be more easily cleaned.

18.2.2.4 Organ Storage Room. Materials handling considerations are paramount in this area. Large drums of chemicals plus heavy containers with organs will be moved in and out. Although storage capacity is the primary concern, adequate space for cart and chemical drum movement and storage should be provided. Aisle widths should be 5 ft (1.5 m) minimum. Large sinks used for filling containers should be located out of the primary circulation route and have sufficient staging area for temporary storage of stacks of empty containers.

18.2.2.5 Slide Storage Room. This room functions like a library, with slide cases instead of books. Here carts may be used to transport stacks of cases to the pathologists' microscopy laboratories; therefore, adequate room is needed to move in aisles. Additional structural strength may be required to support floors and columns. Average live loads for full slide cases in a room are over 90 PSF (440 kg/m^2). Standard laboratory floors have live load capacity ranges from 120–150 PSF (586–732 kg/m^2). Where high-density compact storage systems may be considered for this function to increase the volume of slides, the structural capacity of floors must be increased. Archival slide storage facilities may be located offsite from hospitals and medical examiners' primary locations.

18.2.3 Egress

The egress recommendations contained in Chapter 2, Section 2.2.2.2 are applicable to pathology laboratories and should be followed closely.

18.2.4 Walls, Ceilings, Floors

Glazed ceramic tile or epoxy paint on plaster, concrete block, or water-resistant sheetrock are preferred wall finishes. All surfaces should be impermeable, nonporous, and washable. Extending and sealing wall assemblies to the underside of the structure of floors above helps to control odors and improve directional airflow into pathology laboratories.

Flooring should be seamless consisting of a nonslip material with an integral cove base extending at least 4 in. (10 cm) up all walls. In histology and possibly in specimen preparation laboratories, tissue specimens may be embedded in paraffin and then sliced microscopically thin; paraffin flakes can float down to floors and cause these floors to become very slippery.

Ceilings should not have sound-attenuating materials if high concentrations of formaldehyde will be present. Ceilings constructed with solid, smooth surfaces and sealed to walls are highly recommended. Finishes should be washable. Light fixtures and other ceiling-mounted equipment should be sealed to ceiling surfaces to resist moisture penetration.

18.3 HEATING, VENTILATING, AND AIR-CONDITIONING

18.3.1 Introduction

Environmental control in pathology laboratories may be critical, depending on the nature of the facility. An important difference between community hospitals and large teaching hospitals is that more autopsies are performed in teaching hospitals. During an autopsy, organs and tissue samples will be removed for study and examination in pathology laboratories. Specimens are immediately frozen at very low temperature, freeze-dried, or preserved in a formaldehyde-based solution. The latter procedure can result in very high concentrations of formaldehyde in the area. Pathologists perform autopsies on patients who die with a serious communicable or infectious disease. This presents a need to control infection hazards from specimens brought from autopsy into pathology laboratories. In some hospitals, there will be separate areas with strict access control and special facilities designated for this service, such as described in Chapter 14, Section 14.3. HVAC systems must deal with each of these environmental control issues.

18.3.2 System Description

The information contained in Chapter 20, Section 20.3.1 also applies to hospital, research, and forensic pathology laboratories.

18.3.3 Local Exhaust Systems

Local exhaust ventilation hoods or capture hoods are strongly recommended for hospital and forensic pathology facilities where large quantities of formaldehyde, a carcinogen, and other toxic chemicals are used in open trays for transfer of tissues. Local capture hoods placed at work level are effective for controlling formaldehyde exposure (see Chapter 16, Figure 16-5B). Care must be taken in positioning such hoods to prevent obstructing the procedure, or causing disruptive air turbulence. Good locations for local exhaust facilities are at sinks, tissue processors, and staining workstations. Stainless steel ducts are recommended for corrosion control.

18.3.4 Supply Air Systems

Supply air requirements will be similar to those for most other laboratories. Odor control is critical. High air-exchange rates, low-level exhaust inlets, and negative pressure relative to surrounding areas are additional requirements. Air-conditioning is highly desirable.

18.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

The loss prevention, industrial hygiene, and personal safety recommendations provided in Chapters 1 and 2, Section 4 are generally applicable to pathology laboratories and

should be followed closely. Refer to Chapter 14, Biosafety Laboratory, for additional relevant safety information on the use of hazardous biological materials.

18.5 SPECIAL REQUIREMENTS

18.5.1 Waste Fluids

Disinfection of waste fluids from these facilities should be considered. A safety engineer, industrial hygienist, or infection control authority should be consulted for assistance with system selection (see Chapter 2, Section 2.4.5).

18.5.2 Security

The sensitive nature of operations and the materials used in pathology laboratories may require the use of security equipment. Comprehensive security systems are required in forensic pathology facilities. See security considerations discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1.

19

AUTOPSY LABORATORY

19.1 DESCRIPTION

19.1.1 Introduction

Autopsy laboratories are designed for dissecting human cadavers to determine the cause of death. Some hospitals and most medical examiner (M.E.) facilities have autopsy laboratories. Spaces described in this section include autopsy laboratories, special autopsy laboratories (SAL), forensic dental and anthropology laboratories, and observation rooms. Guidelines in Chapters 1 and 2, where applicable, should be followed closely for autopsy laboratories. Some guidelines in Chapter 14, Biosafety Laboratories, should be followed closely for SALs.

19.1.2 Work Activities

19.1.2.1 Autopsy Laboratory. Medical examiners and hospital-based medical pathologists investigate cause of death in persons who die while hospitalized or die elsewhere from disease, accidents, criminal actions, or unknown causes. Autopsy is a legal requirement in many jurisdictions for persons who die of unknown, accidental, or suspicious causes or from certain infectious diseases. Otherwise, permission of the family or next of kin is required before an autopsy can be performed. Using gross and microscopic inspection, as well as toxicology, molecular, and biochemical testing methods, board-certified pathologists legally determine the cause of death and the condition of all organ systems.

Pathologists, assisted by trained technicians, may x-ray, photograph, and visually inspect deceased persons carefully before dissection. In forensic cases, technicians take fingerprints and dental impressions from unidentified deceased persons to help in identification. During dissection, the body and its parts are measured, weighed, and sectioned for further gross and microscopic examination conducted in pathology laboratories, which are discussed in Chapter 18. Cleaning autopsy laboratories is an important daily activity.

Medical pathologists present autopsy results to clinicians for review, confirmation of diagnosis and treatment, and discussion. These results are then reported to family members. Autopsies provide valuable data on the effects of disease and injuries on the human body, as well as on the effectiveness of treatment. When deceased persons' identities are unknown, after autopsy bodies may be stored in the morgue until identified or as required by law.

19.1.2.2 Special Autopsy Laboratory (SAL***).*** Work activities in special autopsy laboratories are the same as in standard autopsy laboratories, as is their function, the determination of the cause of death. If Biosafety Level 3 infectious agents are suspected in the death of decedents, autopsies will be performed in a SAL.

19.1.2.3 Forensic Dental and Anthropology Laboratories. Medical examiners' facilities may include laboratories to conduct specialized investigations on

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unidentified decedents using dental and physical anthropology methods. Primary work activities include cleaning bones and teeth by removing soft tissues; x-ray examination of teeth and bones; and measurement, photography, and comparison with anatomical standards.

19.1.2.4 Observation Room. In teaching hospitals, autopsy laboratories should allow small groups of physicians and/or medical students to observe autopsies without getting in the way of pathologists and technicians. Similarly, M.E. facilities must allow law enforcement personnel and pathology students to observe autopsies.

In small hospitals, where there is no family viewing room (see Chapter 20, Section 20.1.3.5), police officers may escort family members to observation rooms to view the body prior to the autopsy to make a positive identification of the deceased.

19.1.3 Equipment and Materials Used

19.1.3.1 Autopsy Laboratory. Autopsy laboratories contain autopsy tables, additional counter surfaces for organ dissections and specimen harvesting, scales, x-ray view boxes (if films are required) or large computer monitors for x-ray displays, sharp instrument cabinets, bone saws, electric drills, local exhaust facilities, voice and video recording equipment, tissue cleansing sinks, hand-washing sinks, and cleaning equipment. Autopsy tables' range from simple movable tables with special features and fixed tables with integral plumbing to ventilated downdraft tables with integral plumbing. Unlike tables designed for gross anatomy activities, autopsy tables require deeper basins and higher rims to contain bodily fluids released during dissection.

Materials' handling equipment may include gurneys, which are mobile stainless steel tables for transporting bodies. High-quality wheels make gurneys easy to move and turn when loaded. Heavy-duty gurneys, rated for loads of 500–600 pounds (227–272 kg), are needed to transport obese decedents.

Excellent lighting is required in autopsy laboratories. In addition to normal ceiling light fixtures, examination and large multihead procedure lights are recommended. Fixtures on articulated arms allow pathologists and technicians to direct the illumination as needed, but the fixture supports must be securely attached to structural members above ceilings. Lamps of 5500 K and close to 100 color-rendering index can achieve a nearly natural daylight spectrum that improves the visual acuity and accurate color perception required for these laboratories.

Hospital pathologists and M.E.s follow the concept of universal precaution: Patients' bodies are considered infectious unless proven otherwise. Therefore, autopsies are done with personal protective gear (special gloves, face masks or respirators, safety glasses or face shields) and space must be provided for their storage.

Autoclaves to sterilize contaminated equipment, tools, and infected materials should be installed within or very near autopsy laboratories. Autopsy laboratories may also have ultracold or liquid nitrogen freezers to immediately preserve tissues, plus other refrigerators for storing donated organs and tissues. Small, low-volume autopsy laboratories may use freestanding body refrigeration units inside the autopsy laboratory, instead of using morgue facilities (see Chapter 20). Autopsy facilities may also require separate sterile operating rooms, dedicated to organ harvesting for transplant use, that need to be located outside, but immediately adjacent to the autopsy laboratories.

Chemicals used in autopsy laboratories include soap, water, alcohol, and decontamination agents, such as chlorine- or phenol-containing solutions. Bulk quantities of these chemicals should remain outside of autopsy laboratories and in appropriate, safe chemical storage facilities (see Chapter 1, Section 1.4.7 and Chapter 28, Section 28.1.3.1).

19.1.3.2 Special Autopsy Laboratory (*SAL*). SALs use much the same materials and equipment as found in standard autopsy laboratories. The primary difference is that bodies in SALs are suspected of harboring acute infectious disease, with Biosafety Level 2 and Level 3 agents (see Chapter 14, Sections 14.1.1, 14.1.2, and 14.2. These Biosafety measures are used to reduce the risk from aerosolization of infectious bodily fluids released when body cavities are opened. Moreover, bodies in a state of advanced decomposition are processed in SALs to better contain foul odors. Pathologists and technicians wear respirators (NIOSH N-95) and other special PPE.

When pathologists and technicians require maximum protection from exposure to infectious aerosols, custom-designed autopsy tables, equipped with full-length, removable, transparent covers that have multiple glove ports, may be considered for use in SALs. Air removed from autopsy tables and covers should pass through HEPA filters in independent SAL exhaust systems.

It is highly recommended that autoclaves are two-door models with through-the-wall installation, and equipped with secure, effective, properly installed bioseals on the contaminated side of the unit. Autoclave valves, controls and pumps should be located outside SALs, to allow ease of maintenance (see Chapter 14, Sections 14.1.3 and 14.2.4).

19.1.2.3 Forensic Dental and Anthropology Laboratories. Forensic dental and/or anthropology laborato-

ries have equipment commonly found in gross anatomy dissection laboratories, such as gurneys, dissection tables, scales, microscopes, and cutting tools. Dental x-ray units are used to investigate fractures and internal structures of teeth and bones. In addition, there is equipment and apparatus to remove soft tissues from bones and teeth and clean them. This may be a large, commercial pressure cooker or a stove and a large pot. An effective alternative method is to use carrion beetles to clean bones. Locate a large box in a secure area outside the building, such as in a shed, to contain the beetles and the stench. Forensic dental and anthropology laboratories may contain vaults to hold skeletal remains of decedents until their identities are determined or cases are completed.

19.1.2.4 Observation Room. Autopsy laboratory observation rooms may contain chairs and writing counters for official and invited observers. Audiovisual equipment may include closed-circuit televisions and audio communication equipment between the autopsy lab and observation room. Lighting fixtures within observation rooms should be on dimmers to improve visibility toward brightly lit autopsy tables.

19.1.4 Exclusions

Educational and research institution morgues serving gross anatomy laboratories are not equipped properly and should not be used to perform clinical or forensic autopsies. Autopsy rooms should be restricted from public access, including family members of decedents (see Section 20.1.3.5). Access should be restricted to authorized, trained medical pathologists, forensic science professionals, and pathology technicians and trainees.

19.2 LABORATORY LAYOUT

19.2.1 Introduction

The public may regard the activities pursued in autopsy laboratories with alarm, disgust, or morbid curiosity, as they do for gross anatomy laboratories. To secure autopsy facilities from public access and view, as well as to ensure odor containment, autopsy laboratories should provide

- Private passageway between the receiving area and the cold storage room(s)
- Private passageway between the morgue and the autopsy laboratory (see Chapter 20, Section 20.2.1)
- Windows not overlooked by other buildings, or with glazing that obscures all views into autopsy facilities under all lighting conditions. Mirrored glass is not recommended because it does not work under nighttime conditions.
- Controlled, secure access on all entrances and exits from these facilities
- No entry from a main public corridor. Anterooms and other entry configurations should be designed to prevent views into these areas, contain odors, and support security measures (see Chapter 2, Section 2.2.2.3).

The layout recommendations contained in Chapter 2, Section 2.2 are generally applicable to autopsy laboratories and should be followed closely.

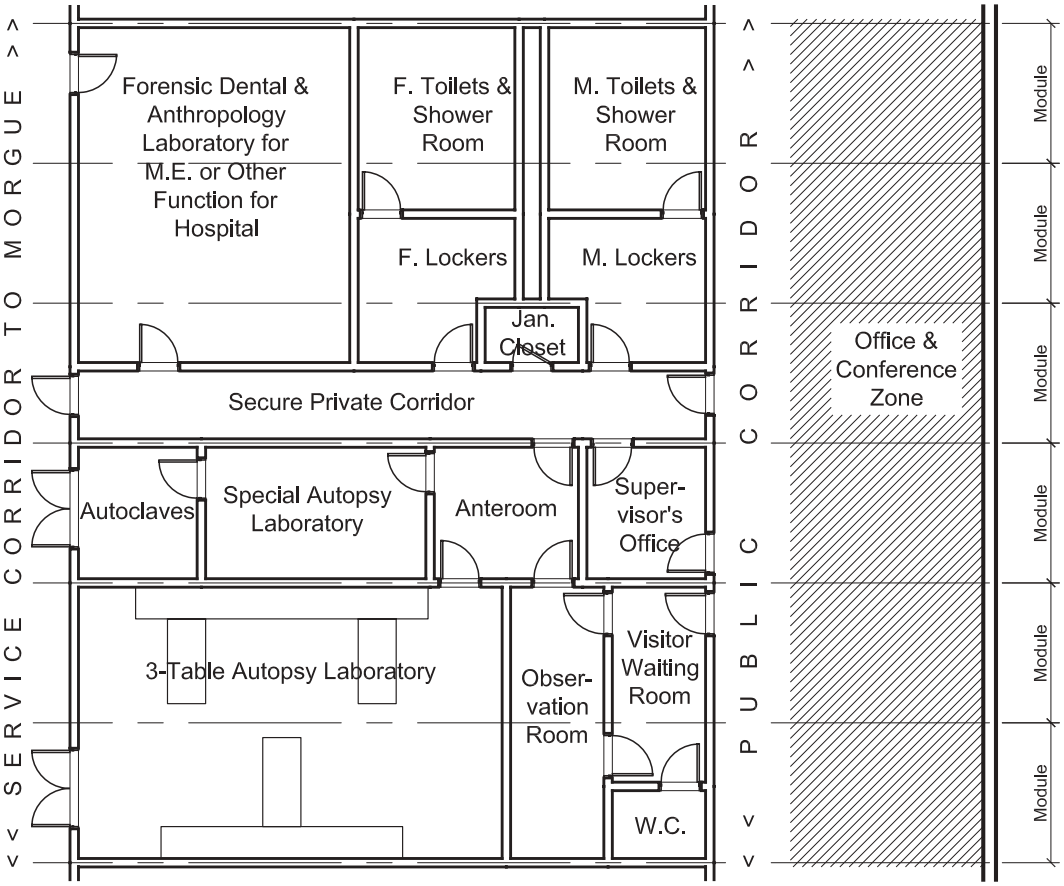
19.2.2 Individual Room Arrangements

19.2.2.1 Autopsy Laboratory. The layout and size of autopsy laboratories for hospitals and for M.E.s depend on the projected average and peak number of autopsies that will be performed each day and the number of pathologists and staff to manage the workload. In many hospitals the caseload has decreased significantly in recent decades, to the point that major medical centers may perform only a few autopsies each week. Many physicians do not recommend autopsies out of concern for malpractice suits. Family members, who are not encouraged to give their permission for autopsy procedures, are unlikely to request it. In hospitals where the number of procedures is low, a single space with one autopsy table may be adequate and require approximately 400 ft^2 (37 m^2). One-table autopsy laboratories may also need space to install a freestanding body refrigerator, instead of constructing separate cold rooms or a morgue. Autopsy laboratories with a refrigerator require approximately 500 ft^2 (46 m^2). A sample three-table autopsy suite is shown in Figure 19-1A, with an enlarged layout plan of the autopsy laboratory in Figure 19-1B.

However, both local jurisdictions having authority and hospital policies may require construction of a special autopsy laboratory in addition to a standard autopsy laboratory for acute infectious disease cases (see Figure 19-1C and Chapter 14, Section 14.2.1).

In contrast to reduction in hospitals, the number of autopsies M.E.s perform in many jurisdictions has risen because of increased dependence on forensic sciences for criminal investigations, prosecutions, and for identification of unknown bodies. These standard autopsy laboratories can be very large spaces with up to 20 tables.

The layout of autopsy laboratories needs to provide excellent-quality light and ventilation to autopsy tables,



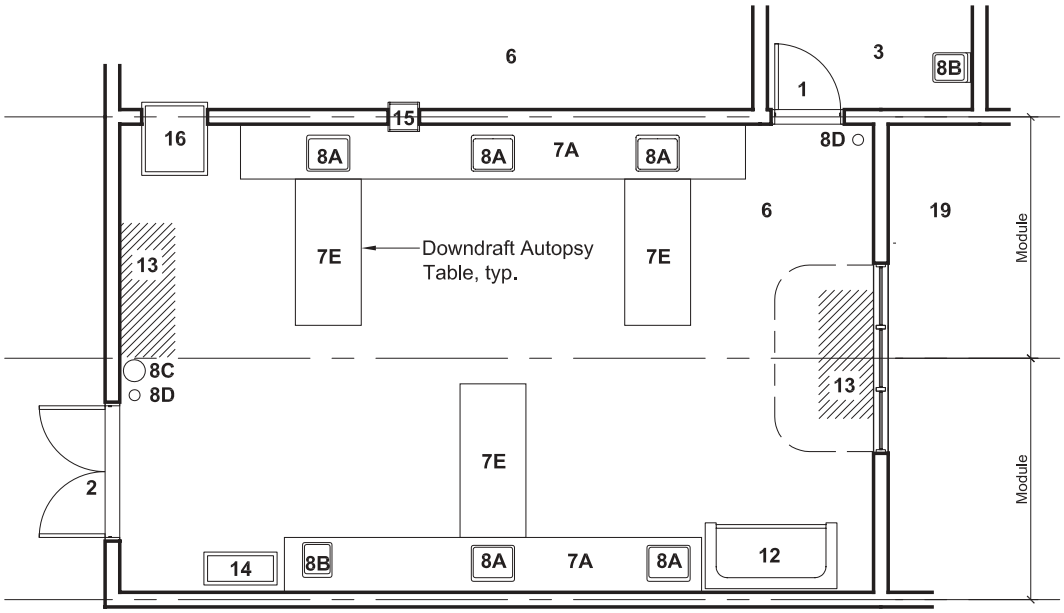
KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
2	Emergency Exit	8B	Hand Wash Sink	11	Glove Box
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 19-1A. Small autopsy laboratory and support functions suite layout.

bone saws, and tissue preparation sinks. Fixed autopsy tables in the center of single-table workstations allow pathologists and technicians to move with ease all around the table. When gurneys are used instead of fixed tables, head-wall bench and sink arrangements, whereby gurneys are latched to sink rims so that body fluids drain by gravity into the sink, work well also (see Figure 19-1B for an example of this table/sink layout).

In larger autopsy laboratories with many autopsy stations, tables can be installed in either linear or cluster arrangements (see Figure 19-2). Fixed downdraft tables should be arranged to optimize containment airflow. There should be sufficient space for at least one spare gurney to remain in autopsy laboratories without interfering with personnel circulation. Another consideration is the area required for a bariatric autopsy table



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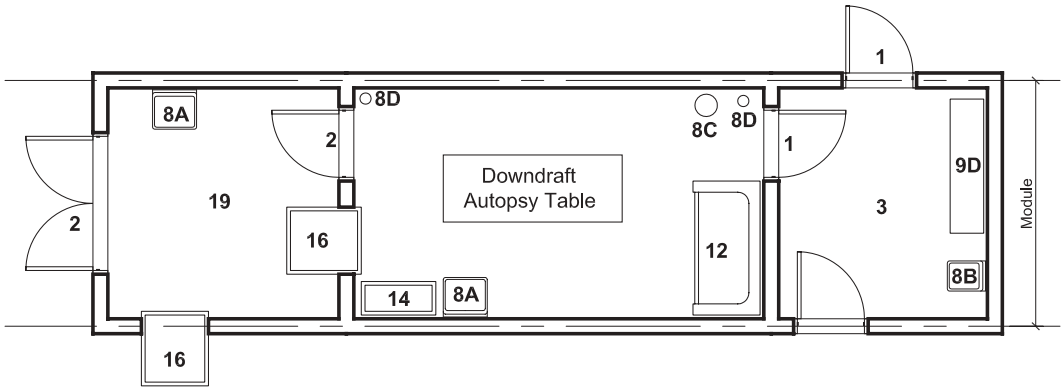
3	Anteroom	8C	Emergncy EW & SS	12	Biosafety Cabinet
4	Clothes Changing Room	8D	Fire Extinguisher	13	Equipment Zone
5	Decon Shower Room	9A	Wall Shelves	14	Haz-Waste Container
6	Laboratory	9B	Wall Cabinets	15	Pass-thru Chamber
7A	Wall Bench	9C	Reagent Shelves	16	Autoclave (pass-thru)
7B	Island Bench	9D	Rack for PPE	17	Personnel Lockers
7C	Mobile Bench	9E	Personnel Lockers	18	Personnel Shower
7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 19-1B. Autopsy laboratory—three tables.

to hold bodies weighing 300 lbs (136 kg) or more, and the need for extra work area around the table. A minimum area of 15 × 15 ft (4.5 × 4.5 m), not including an L-extension to the table for dissections provides adequate clearances.

Bone saws may be located in separate small booths or in alcoves adjacent to autopsy tables; local exhaust ventilation is recommended to contain spray of bone and tissue particles. Preparation and clean-up sinks (also with local exhaust ventilation hoods), x-ray viewing boxes, and instrument and storage cabinets can be arrayed conveniently along laboratory walls. Refrigerators and freezers used for temporary tissue sample storage are located convenient to autopsy stations. Floor-mounted equipment and storage units should have sufficient space maintained so that floors can be easily and thoroughly scrubbed. Hose bibs may be mounted on walls or hose reels mounted from the ceiling may be used for cleaning. Each autopsy table should have a large floor drain, ≥12 in. diameter (≥30 cm), where the grate is flush with the floor surface and located where it will not trip workers, but efficiently capture fluids or water used to clean the floor. Special traps with removable wire baskets are required here to capture tissue.

19.2.2.2 Special Autopsy Laboratory (SAL). Layouts of SAL facilities are similar to standard autopsy laboratories. SALs are dedicated facilities for cases suspected of involving Biosafety Level-2 or 3 infectious agents or for bodies that are decomposed. The primary difference is additional provision of an entry anteroom for gowning and an exit anteroom with personnel shower and locker/changing areas (see Figure 19-1C). SAL facilities may have less area because SALs normally have only one to three autopsy tables, rarely more, except for M.E. facilities serving jurisdictions with high



KEY

1	Primary Entry/Exit	8A	Lab Sink	10B	Radioisotope Hood
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7D	Split Bench	9F	Floor Mounted Shelving Unit	19	Lab Support Room
7E	Lab Table	10A	Chemical Fume Hood	20	Vented Gas Cabinet

FIGURE 19-1C. Special autopsy laboratory—one table.

populations. Under normal conditions, cases requiring the use of SALs are far fewer than for standard autopsy laboratories. Small amounts of tissue or organ specimens may have to be transferred to other pathology laboratories for culturing processes to identify suspected infectious agents. Sealed specimen containers can leave SALs through ventilated and sealed pass-through boxes or through dunk tanks (see Chapter 14, Section 14.2.4 and Figures 14-3 and 14-4).

It is highly recommended that SALs have doors to anterooms that connect directly to freezer facilities dedicated to storage of potentially infectious and/or decomposed bodies before removal (see Chapter 2, Section 2.2.2.3 and Chapter 20, Section 20.2.2.2). Providing individual body freezer(s) located within SAL facilities are an alternative.

19.2.2.3 Forensic Dental and Anthropology Laboratory. These laboratories will have features similar to pathology laboratories, with benches, sinks, BSCs, and equipment areas, including a dental x-ray unit. A chemical fume hood may be needed. Large, mobile stainless steel laboratory tables are helpful for laying out skeletons and other reference materials. There may be area required for a stove that will hold large, commercial pots, or a commercial pressure-cooker. If carrion (dermestidae) beetles are used for cleaning bones, the box holding them and the body should be located exterior to the laboratory in a garage, an open-air shed if ambient temperatures stay above freezing, or another secure location with good natural or mechanical ventilation with some temperature control.

Provision of anterooms to enter these laboratories from personnel corridors is highly recommended. Forensic dentists, anthropologists, and technicians should be able to enter their laboratories without passing through the autopsy laboratory. Because access to autopsy laboratories is tightly controlled, anterooms provide an efficient and convenient safety precaution for these specialists. To allow for transfer of the body or specimens after the autopsy has been performed, there should be a secure connecting door between the forensic dental and anthropology laboratory and the autopsy laboratory. This transfer entry must have an anteroom of sufficient size to accommodate a gurney with a body especially if the autopsy laboratory is designed and operated at BSL-3.

19.2.2.4 Observation Room. In teaching hospitals, autopsy laboratories should be of adequate size and

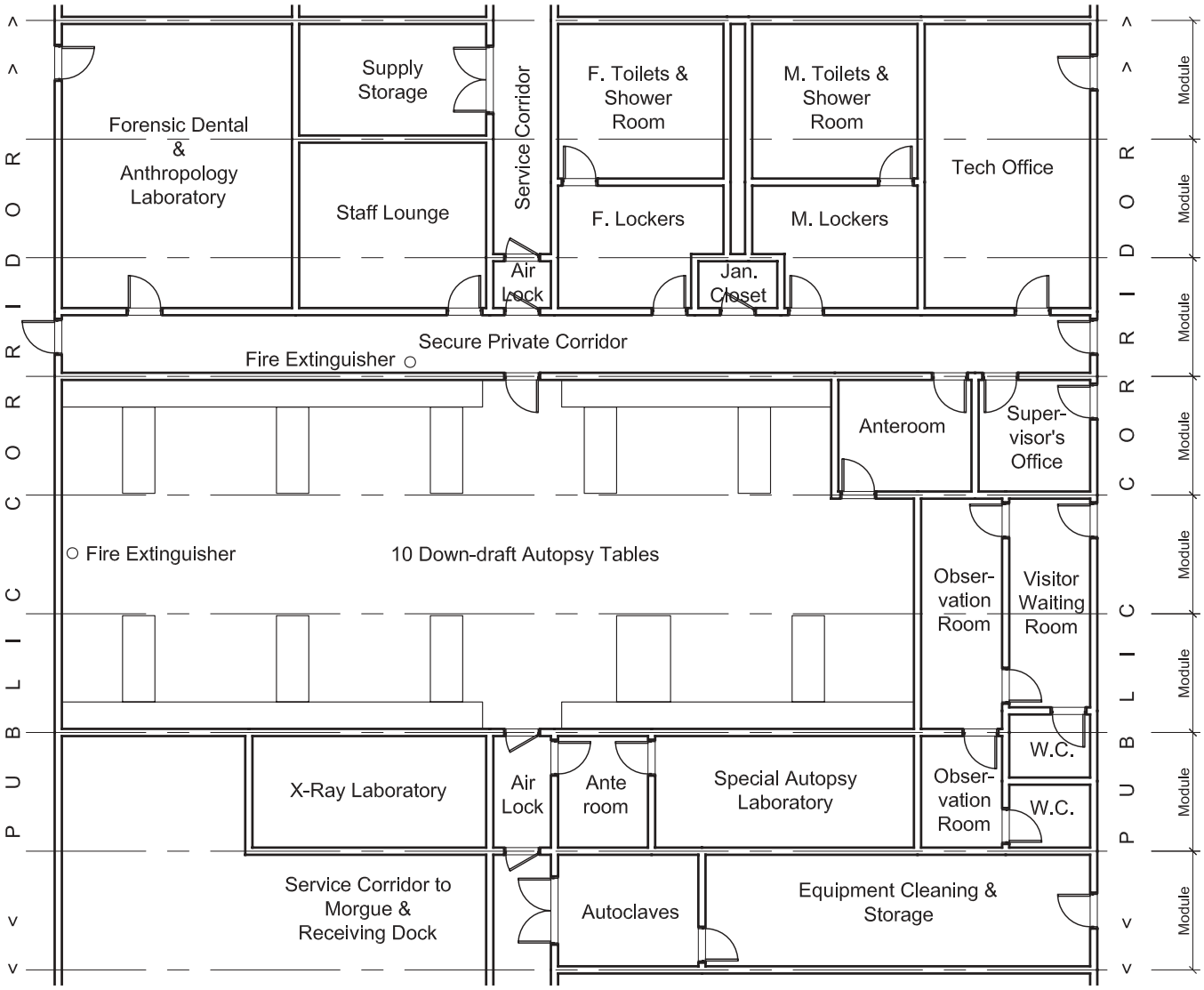


FIGURE 19-2. Large autopsy laboratory and support functions suite layout.

arrangement to allow small groups of physicians and/or medical students to observe autopsies without interfering with pathologists and technicians. Medical examiners' facilities have similar needs for law-enforcement personnel and pathology trainees to observe autopsies.

Observation rooms for authorized witnesses and trainees can be designed to serve one or several autopsy tables and workstations. With observers behind glass walls, pathologists do not have to worry about contamination of bodies, evidence, or for the safety of the observers. See Figures 19-1A and 19-2A for examples of locations and access to observation rooms. A toilet facility adjacent to an observation room is helpful.

A two-way intercom system allows observers to ask questions and hear pathologists' answers. Output from high-definition video cameras installed above one or more autopsy tables can be wired to televisions or monitors in observation rooms, offices, or even conference rooms. Video cameras often provide observers with better close-up images of procedures in real time. Video recordings of procedures are useful as well for training. It is necessary to check with the pathology department and with hospital or M.E. administrators to learn their particular educational requirements for the autopsy laboratory.

As in standard autopsy laboratories, observation facilities may be required for SALs. Observation areas need to be separated, sealed, and provide views into SALs through double-glazed laminated glass windows (see Figure 19-2A). Every precaution should be taken to protect the zone surrounding SAL facilities from risk of exposure to contamination or infectious agents.

19.2.3 Egress

The egress recommendations contained in Chapter 1, Section 1.3.1 and Chapter 2, Section 2.2.2 are generally applicable to autopsy laboratories and gross anatomy morgues and should be followed closely. There should be two exits from autopsy laboratories. One of the exits can be strictly for emergency situations. Security systems should be provided at both exits.

19.2.4 Floors, Ceilings, and Walls

All surfaces should be impermeable and washable so that autopsy laboratories can be cleaned properly and decontaminated. Floors must be seamless, sealed, and cleanable with the ability to withstand harsh cleaning agents. When using troweled epoxy or other monolithic materials consider specifying nonslip finishes to reduce risk of falls because under normal conditions the floors will be wet.

Install flooring material in integral cove bases extending a minimum of 8 in. (20 cm) up each wall. A wainscot height of 30 in. (76 cm) is recommended. These higher than typical base heights protect wall finishes from water splashed by cleaning hoses, mops, and motorized floor-cleaning machines. All drains should have sediment strainers and grease traps so that organic matter can be cleaned out daily.

Walls should extend and be sealed to the underside of the structure of the floor or roof above. Walls should be waterproof, seamless, and smooth. Glazed ceramic tile, epoxy paint on plaster, concrete block, or water-resistant sheetrock are preferred wall finishes. Wall surfaces made of composite material panels with integral smooth enamel finish and constructed with joints that can be totally sealed are excellent alternatives to standard construction methods and materials. All storage cabinets or cupboards should be stainless steel with welded and polished joints.

Plaster or concrete ceilings can also be painted with epoxy. Suspended ceilings may be a lay-in type of metal pan. High volumes of formalin-containing chemicals are not generally found in high concentrations in autopsy laboratories, so sound-attenuating material may be used above metal pan ceilings. Ceilings can also be made of composite material panels with integral smooth enamel finish and constructed with joints that can be totally sealed. Composite panel and plaster ceiling systems must be securely supported to the structure of the floor or roof above to reduce deflection that could split seals in joints to other panels and to joints with walls.

Because of the presence of moisture from frequent cleaning procedures and splashing from water hoses, light fixtures, wall outlets, and switches should be waterproof. In BSL-3 containment autopsy laboratories, all penetrations in walls, ceilings, and floors should be sealed sufficiently to allow for successful vapor or gaseous decontamination (see Chapter 14, Section 14.5.4).

19.3 HEATING, VENTILATING, AND AIR-CONDITIONING

19.3.1 Introduction

The HVAC recommendations contained in Chapters 1 and 2, Section 3 are generally applicable to autopsy laboratories and should be followed closely. Control of odors from organic decay within autopsy laboratories and surrounding areas is critical.

Use of stainless steel ventilation ducts should be considered because of their corrosion resistance. These laboratories should be maintained at a negative pressure with respect to all public areas and adjacent occupancies. Observation rooms should be pressurized positively relative to autopsy laboratories, but negative to public areas. No special treatment of autopsy laboratory exhaust air is needed provided that the exhaust air can be discharged well above all surrounding buildings and terrain features, so foul odors will not become reentrained.

19.3.2 Individual Room Requirements

19.3.2.1 Autopsy Laboratory. A minimum outside air change rate of 15–20 per hour is recommended for autopsy laboratories. If downdraft autopsy tables and adequate local exhaust devices are installed to effectively capture fumes and odors at the source, consideration can be given to lowering the outside air change rate. This can be determined through engineering analysis and engineering control methods. It is best to introduce the supply air high in the laboratory and to exhaust it from low wall locations to draw contaminated air below the work area and well below occupants' breathing zone. Specially equipped fixed autopsy tables with built-in downdraft exhaust can provide local capture of fumes and decay odors more effectively than general room exhaust points located near the floor.

Recirculation of air is not recommended for autopsy laboratories. Local exhaust and capture hoods may be feasible for head-wall installations just above sinks in autopsy laboratories. General exhaust grilles can be installed in zones beneath sinks and countertops at head-walls.

19.3.2.2 Special Autopsy Laboratory (SAL). For containment autopsy laboratories that are dedicated to

cases of infectious diseases and decomposed corpses, stainless steel should be used for ducts, air outlets, and all other equipment and facilities for ease of cleaning and to reduce corrosion. SALs must be at a negative pressure with respect to all surroundings. No recirculation of air is permitted. HEPA filters in the exhaust air system are required for BSL-3 autopsy laboratories. It is strongly recommended that HEPA filters also be placed in the supply air system.

It is also necessary to provide facilities for paraformaldehyde or hydrogen peroxide vapor decontamination of the entire laboratory by adding airtight shutoff dampers in supply and exhaust ducts. Doors must have gaskets; all penetrations in walls, floors, and ceilings must be sealed. All of the precautions and safety regulations described for biosafety laboratories should be observed when handling bodies with suspected infectious disease (see Chapter 14, Section 14.3).

19.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

The loss prevention, industrial hygiene, and personal safety recommendations contained in Chapters 1 and 2, Section 4 are generally applicable to autopsy laboratories and should be followed closely. Ergonomic and materials handling considerations are particularly important in autopsy laboratories.

19.4.1 Personal Protective Equipment

Policies for hospital and M.E. facilities may require personnel working in autopsy laboratories to wear respirators when cases involve infectious diseases or suspicion of infection. NIOSH-approved N-95 respirators are recommended because infectious aerosols are often released when abdominal and thoracic cavities are opened during autopsy procedures. Use of respirators in standard autopsy laboratories is common in regions where there is a high incidence of pulmonary tuberculosis and hantavirus in the population. Respirators may also be required for use during epidemics involving severe respiratory infections.

19.4.2 Security

Autopsy laboratories require controlled access, security procedures, and devices to prevent intrusion by curiosity-seekers or others intent upon illegal activities, such as theft or vandalism. In addition, containment of possible biological hazards is a priority, particularly for SALs. Security and surveillance systems should be provided specifically for SAL facilities.

Medical examiner facilities are a particular focus for illegal intrusions to disrupt investigations, destroy evidence, or steal bodies. Secure locks and biometric access control devices are recommended for M.E. autopsy facilities.

20

MORGUE FACILITY

20.1 DESCRIPTION

20.1.1 Introduction

A morgue facility is a group of spaces for the preparation and storage of cadavers. A separate and specific type of morgue is used for preserving bodies to be used in gross anatomy teaching laboratories, and for conducting anatomical research on cadavers or on animal carcasses. Spaces described in this chapter are located in hospitals, medical and veterinary schools, coroners' and medical examiners' facilities: cold rooms, family viewing rooms, morgue embalming facilities, receiving and loading areas, and x-ray laboratories. Guidelines in Chapters 1 and 2 should be followed closely for morgue facilities, as should the strategies related to morgue facilities in Chapters 17, 18, and 19, Gross Anatomy Laboratory, Pathology Laboratory, and Autopsy Laboratory, respectively. Similarly, the recommendations in Chapter 14, Biosafety Laboratory, Section 14.2 should be followed.

20.1.2 Work Activities

20.1.2.1 Morgue for Hospitals and Medical Examiners' Facilities. The term morgue described here refers to the central room into which all the receiving and storage facilities connect, as shown in Figure 20-1A. This is the area to which bodies are transported for initial examination and documentation before being transferred to storage or directly to the autopsy suite. Activities include entering data of the deceased person, if known, placing a toe-tag on the body, weighing it, and transporting the body.

20.1.2.2 Cold Rooms for Hospitals and Medical Examiners' Facilities. In hospital morgues and medical examiners' (M.E.) facilities, bodies normally remain in cold room storage briefly before autopsies are performed, after which bodies are promptly released to morticians for funeral preparation.

20.1.2.3 Morgue for Gross Anatomy Laboratories. Medical research and teaching institutions receive anatomical gifts from individuals who have arranged for donation of their bodies after death. Deceased persons are brought to morgue receiving areas by hospital personnel, funeral directors, or by family members. Donated bodies are embalmed, a process that chemically preserves all tissues so that bodies can remain unrefrigerated for some time without deteriorating. Preserved cadavers or untreated bodies may be returned to cold rooms for short-term storage or to freezers for long-term storage. After dissection or other use, all of the decedent's remains are returned to the morgue cold room for release to family members or to a funeral home for burial.

Veterinary school morgues receive animal carcasses upon order from suppliers and require little long-term storage facilities. Cold room for short-term storage may

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

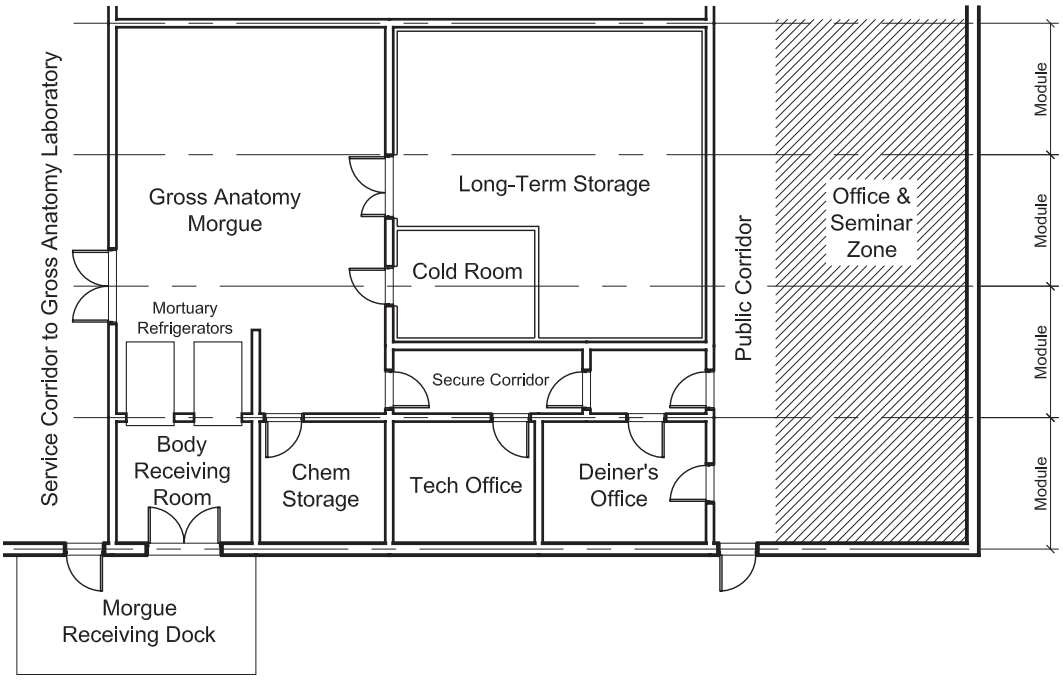


FIGURE 20-1A. Morgue laboratory suite layout, serving a hospital or medical examiner facility.

be needed. The veterinary school gross anatomy laboratory manager can offer the storage requirements to the laboratory design team.

20.1.2.4 Receiving and Loading Facilities. Morgue technicians transfer bodies onto or from gurneys. Single or multiple bodies are loaded into or removed from vehicles such as ambulances, M.E. and coroner vans, and hearses. Convenient, close access to parking zones and driveways are required for these vehicles. This area may also be used to clean gurneys. Veterinary school morgues may use forklift trucks, hoists, or other materials' handling devices to transport large animal carcasses into veterinary morgues.

20.1.2.5 X-Ray Laboratory. Pathologists take x-rays to investigate the age and gender of unidentified bodies, the condition of bones, whether bones are broken, and to determine some causes of death. X-rays of gun wounds can reveal shot pellets, bullets, and bullet fragments. Forensic dentists take x-rays to investigate and identify bodies from teeth and surrounding bone characteristics. Dental x-rays may also be taken in forensic dental and anthropology laboratories as part of M.E. facilities serving large populations.

20.1.2.6 Viewing Room in Hospitals and Medical Examiners' Facilities. Family members may view the deceased person or identify the decedent's body before removal. Separate viewing rooms close to morgue cold rooms are desirable. Persons who come to view the deceased may have mobility difficulties or visual handicaps, so viewing rooms should be designed with sensitivity to such needs. Video transmission from cameras in autopsy laboratories into viewing rooms is an alternative method to show the body to family members.

Cultural traditions of various ethnic groups also affect the design of viewing rooms. For example, some cultural and religious practices require family members to wash and prepare the decedent's body prior to autopsy.

20.1.3 Equipment and Materials Used

20.1.3.1 Morgue for Hospitals and Medical Examiners. Besides computer and communications equipment, including standard and bar code printers, primary equipment in the central morgue area is gurneys holding bodies. A floor scale for weighing bodies may be located here (or in the Receiving and Transport Room). General gurney storage, and washing facilities, may be located outside the immediate morgue area. Morgues require cleaning equipment and materials to clean up messes that may include bodily fluids. A hose bib and large floor drain are useful for cleaning. A hand-wash sink is highly recommended.

20.1.3.2 Cold Rooms for Hospitals and Medical Examiners. Equipment used in these cold rooms includes gurneys, mobile cadaver-lift equipment that may be motorized or manual, and cadaver storage tray/rack systems. Gurneys are wheeled stainless steel tables used to move human bodies. Gurneys in morgues may be equipped with washable, lightweight plastic trays to contain bodily fluids. To safely move cadavers to and from shelves within cold rooms and onto gurneys, mobile cadaver-lift devices are used. These may be hydraulic, with electric motors, or employ manual hoist mechanisms.

Several systems of racks are manufactured to efficiently store cadavers. Wall-mounted cantilevered brackets hold body trays. Cold room walls must be reinforced to support the weight of wall-mounted brackets and loaded trays. Other rack systems are floor mounted and have vertical frames upon which brackets are fastened to hold trays. When unloaded, these frames can be moved and rearranged, as required. Grossly obese cadavers require wide, heavy-duty racks and support trays for storage.

20.1.3.3 Morgue for Gross Anatomy Laboratory. This type of morgue contains standard mortuary equipment for the removal of blood, body cleansing, and perfusion of the bodies with liquid chemical preservatives. Excellent lighting is required. Chemicals used include glycerin, glycol, formaldehyde solution (formalin), phenol (carbolic acid), soap, and water. The List of Carcinogens (National Institutes of Health, 2009) cites formaldehyde as a known carcinogen. Formalin, commonly used to preserve cadavers, has approximately 4.0% formaldehyde, 2% methyl alcohol, over 90% water, and sometimes a very small percentage of buffering chemicals. The OSHA 29 CFR 1910.1048 airborne exposure limits are permissible exposure limit (PEL) = 0.75 ppm, and short-term exposure limit (STEL) = 2 ppm (OSHA Part 1910, subpart Z; 2012). It is desirable that formaldehyde exposures be monitored regularly using tube detector instruments. See Section 20.4 below for more personal safety information on these chemicals. Other preservative solutions are available that do not contain any formaldehyde.

Pathologic and infectious materials may be present, and technical personnel must be trained to recognize and safely handle these specimens. Saws and other cutting instruments are used to collect body parts for preservation and separate storage. There are large scales for weighing specimens. Refrigerators may be found here. Morgues use materials-handling equipment, such as carts, gurneys, and forklift trucks. It is important to provide sufficient area (not in corridors) to park these devices. Permeable supplies that absorb odors, such as those made of paper or fabric should be stored in a separate room if possible. Bulk embalming chemicals should be kept in a separate storeroom. Premixed embalming fluids can be purchased if volumes are kept low.

20.1.3.4 Receiving and Loading. Receiving areas of hospital and M.E. facilities need little equipment except access to telecommunications devices and computer data ports, space for gurneys, and a floor scale. Receiving areas for medical school morgues supporting gross anatomy laboratories require direct access to cold storage rooms or individual refrigerated vaults to secure and store body donations. For a gurney washing station in the receiving and loading zone, a hose bib with hot and cold water and a large floor drain are required.

For veterinary schools or large animal diagnostic service facilities, a receiving dock or dedicated parking area to accommodate a large truck or van is needed. Farmers and ranchers may bring in several cattle or horse carcasses if there has been an outbreak of disease in their herds. To off-load large animals from trucks, an overhead hoist rated for a 2-ton minimum (1,184 kg) is also needed.

20.1.3.5 X-Ray Laboratory. Medical examiners' morgue facilities need x-ray laboratories or safe, secure access to whole-body C-arm x-ray units and to dental x-ray units immediately adjacent to autopsy laboratories. Other imaging equipment, such as computed tomography computed tomography (CT) or ultrasound, may be required. Hospitals may use digitized x-rays or film. In some hospitals and in all M.E. facilities, small darkrooms should be available and convenient to x-ray laboratories to develop x-ray films. Films are still required as evidence in many jurisdictions. Chapter 24 contains information on photographic darkrooms and automated x-ray developing equipment.

20.1.3.6 Viewing Room in Hospitals and Medical Examiners' Facilities. Family viewing rooms require a hand wash sink for personal hygiene. If ritual body washing is permitted, another large sink is required to fill containers with water and to rinse cloths used to wash the body. The infection control officer should be consulted on requirements for installation of dispensers for alcohol-based hand-cleaning fluid and other infection control requirements. Ritual washing/viewing rooms are equipped with a large central table or fixed platform where the body is placed and family members have access to all sides. Raised edges of the table contain water that is poured and wiped on the body. A drain in the table or platform is not usually required, but may be provided for ease of cleaning. Grief counselors

should be consulted to learn how rituals are performed and to understand which utilities and facility features are required.

20.1.4 Exclusions

Educational and research institution morgues serving gross anatomy laboratories should not be used to support clinical and forensic autopsies. Morgue facilities should be restricted from public access.

20.2 LABORATORY LAYOUT

20.2.1 Introduction

The layout recommendations contained in Chapter 2, Section 2.2.2, are generally applicable to morgue facilities and should be followed closely. To secure morgue facilities from public access and view, as well as to ensure odor containment, the morgue facilities should be carefully located to provide

- Convenient access to a secure loading dock area and receiving room
- Private passageway between the receiving room and the morgue or cold storage

  Private passageway between the morgue and dissection laboratories or the autopsy laboratory
- Windows not overlooked by other buildings, or with window glazing that obscures all views into morgue and autopsy facilities, under all lighting conditions. Mirrored glass is not recommended because it does not work in nighttime conditions. Access should be controlled for all entries and exits from these facilities.
- No direct entry from a main corridor. Anterooms and other entry configurations should be designed to prevent views into the morgue area (see Chapter 2, Section 2.2.2.3).

20.2.2 Individual Room Arrangements

20.2.2.1 Morgue for Hospitals and Medical Examiners. Figures 20-1A and 20-1B show a modestly sized central morgue area that has the capacity for one or two gurneys at any one time. After a body is delivered to the morgue, this room has sufficient area for a morgue technician to briefly examine the body, generate the documentation, then to move the loaded gurney into the Cold or the Freezer Rooms or directly to the Autopsy Laboratory. Discharge out of the morgue proceeds in the opposite order. According to the average volume of cases the hospital or M.E. processes per day, and the number of staff members who work on receiving and release of bodies, the central morgue area will be sized accordingly. If a M.E. or coroner regularly experiences influx of many cases at a time, the morgue may be generously sized, to relieve congestion.

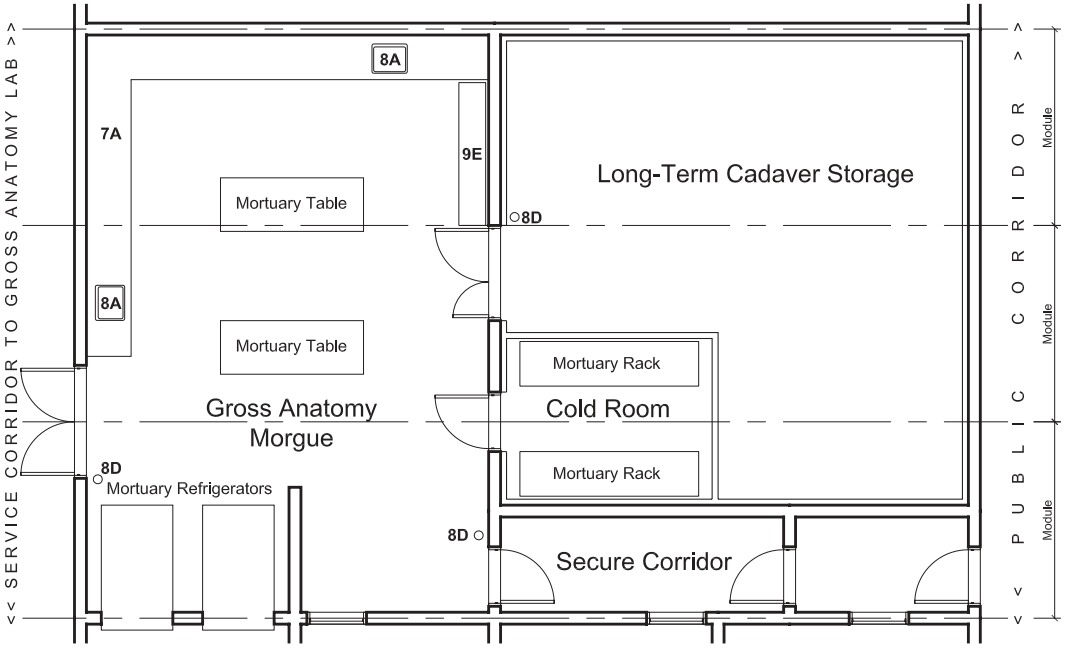


FIGURE 20-1B. Morgue laboratory layout, serving a gross anatomy facility.

20.2.2.2 Cold Room for Hospitals and Medical Examiners. Layouts of cold rooms and freezer rooms, maintained at 39.2°F (4°C) and 24.8°F (-4°C), respectively, for body storage, are based on the required storage capacity. If the volume is very low, for example, just two to four bodies, freestanding refrigeration units may be sufficient. For more than four bodies, cold room capacity for storage systems and efficient arrangement of racks should be provided.

Aisles should be a minimum of 5 ft wide for transport on gurneys and manual transfer of bodies onto trays. Some motorized cadaver-lift equipment and hoists may require even wider aisles for the equipment to move, turn, and operate effectively. Consider providing sufficient free floor area to accommodate one or more gurneys for spare capacity. Doorways should provide ample clearance for moving gurneys and cadaver-lifts. Consider installation of double doors at the main entry of the cold room. Persons can open just one door to enter conveniently, reducing loss of cold air. With both doors open, equipment can easily be moved in and out. All cold room doors should be equipped with emergency exit hardware, so persons cannot be trapped inside.

If a cold room is required for bodies going to special autopsy laboratories (SALs), it should be separate from standard cold rooms. Consider providing an airlock or anteroom on the receiving area side to the cold room door. This anteroom can be negatively pressurized and provide extra containment of odors and infection control. After autopsies in SALs are completed, remains are normally immediately placed in freezer rooms or in free-standing freezers. Layout considerations for freezer rooms are similar to those for standard cold room body storage.

20.2.2.3 Morgue for Gross Anatomy Laboratory. The layout and sizes of morgues for research and medical education institutions depend on the projected quantity of bodies (anatomical gifts), the number of staff, and whether the institution has a permanent anatomical collection or museum (see Figures 20-2A and B).

Morgue facilities that support gross anatomy laboratories may consist of receiving rooms, materials and chemical storerooms (see Chapter 1, Section 1.4.7 and Chapter 28, Section 28.2.2.), pickling rooms, cold rooms, freezer rooms, cadaver preparation laboratories (see Chapter 18, Section 18.2.2.2.), and locker rooms. Veterinary school morgue facilities are similar. This chapter focuses on human cadaver preparation laboratories.

Preparation laboratories must accommodate the number of gurneys needed to transport donations held in the receiving area and to safely maneuver them from one procedure area to the next when heavily loaded. Embalmed bodies are moved temporarily to racks in ambient temperature storage areas immediately adja-

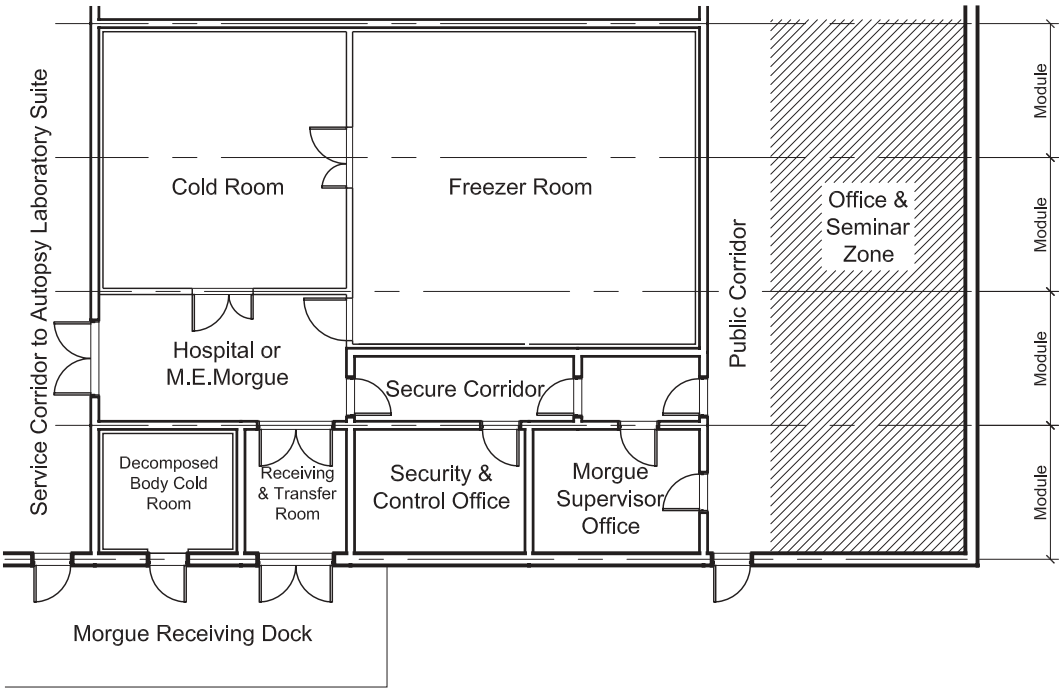


FIGURE 20-2A. Morgue laboratory suite layout, serving a hospital or medical examiner facility.

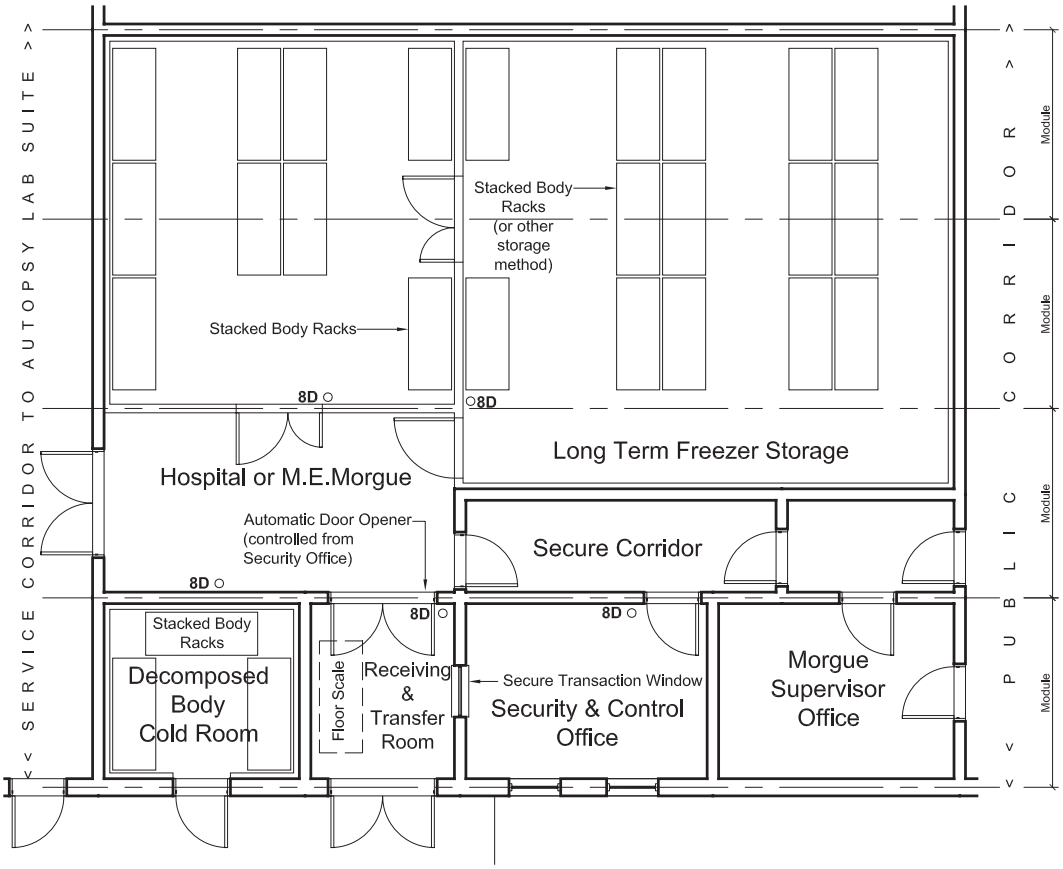


FIGURE 20-2B. Morgue laboratory layout, serving a hospital or medical examiner facility.

cent to the preparation area for fixing of chemicals in the tissues. Racks and aisles should be arranged and spaced adequately so that the staff can safely move prepared bodies into cold rooms or freezer rooms adjacent to the morgue. Cold rooms can have horizontal or vertical cadaver storage systems. Every area in the morgue should be sized to facilitate transport of very heavy, stiff specimens with body-lifts, hoists, or other devices.

Support areas for materials and chemical storage, sample preparation, and staff locker and shower facilities should be immediately adjacent to the morgue laboratory. These functions are kept together so that formaldehyde and decomposition odors can be contained (see Chapter 17, Section 17.2.2.1).

20.2.2.4 Receiving and Loading. The location of morgues in hospitals and M.E. facilities is important for both improved efficiency and for security. The area for receiving bodies for autopsy and for removing bodies by mortician transporters should be covered and secured. Receiving and loading docks should not be shared with other receiving, materials handling, or trash-removal activities. It is desirable that morgue receiving and loading be located out of sight of all other activities, even if vehicular access is shared with other hospital, M.E., or coroner or functions. If cold storage rooms are not adjacent to the receiving and loading area, a short, private corridor or a controlled access, keycard operated elevator should connect them directly, without passage through any public areas. Providing a gurney wash-down area in the receiving/loading zone is very helpful. Space for staging soiled and cleaned gurneys while they dry is also required.

To hold decomposed bodies or those suspected of serious infectious disease, separate cold storage rooms should be located directly in the receiving area. For transport of patients who die within hospitals, personnel must use corridors used by the public and access-controlled elevators used by hospital staff members. Covered gurneys are used to discretely transport bodies.

In medical education morgues where families donate bodies of family members, there should be a covered receiving area and enclosed room that contains a

mortuary-type refrigerator with multiple chambers. Cold storage equipment should be large enough to hold the number of body donations normally made over long holiday weekends. Being able to place the body of a family member in a refrigerated chamber reduces both stress on families and disagreeable odors. Access from this room to the morgue should be indicated with signs and restricted by locking doors. Refrigerators or cold boxes that can be opened from both sides permit discreet transfer of body donations directly into the morgue or the secured passageway leading to the morgue. Where possible, receiving rooms should be adjacent to and on the same level as the morgue. Alternatively, key-operated elevators can connect receiving rooms to morgue facilities that are on different levels. Similar private circulation is desirable between morgues and gross anatomy dissection laboratories to reduce the chance of accidental contact with uninvolved students and staff or with the public.

Veterinary schools and veterinary diagnostic services require receiving docks with sufficient area to accommodate large farm trucks (see Section 20.1.3.4).

20.2.2.5 X-Ray Laboratory. X-ray laboratories require a separate small area, shielded from x-rays for the operator to stand. C-arm x-ray units require special nonmetallic tables supporting bodies to be filmed. X-ray units mounted on ceilings generally have fixed tables beneath. There must be sufficient area for transport gurneys to move easily and park, especially when bodies must be transferred onto fixed tables or special gurneys. If films are required, x-ray laboratories need access to x-ray developing equipment and ample, secure storage for x-ray films. Digital x-ray documentation is not allowed as evidence in some judicial systems. X-ray viewing boxes need to be mounted on walls.

Some M.E. facilities may have other imaging modalities associated with autopsy suites, such as computer tomography (CT) and positron emission tomography (PET) equipment. Each of these requires a separate room with adequate area for moving gurneys in and out as well as for operating and servicing the equipment. Control rooms for these imaging modalities should be outside the imaging room.

20.2.2.6 Viewing Room in Hospitals and Medical Examiners' Facilities. Grief counselors for hospital or medical examiners can advise designers on the average and peak numbers of family members who participate in religious and cultural rituals that will take place in viewing rooms. Body tables are generally placed in the center of viewing rooms, and one bench with a large sink is along one wall. This arrangement allows open area along at least three walls for participants to sit or stand during the ritual. Two doors are suggested for viewing rooms. Technicians use one door to bring in the body from the restricted access morgue facility, and family members use the other door to enter from a public access area. Doors must close and lock automatically, preventing unauthorized entry into morgue zones.

20.2.3 Egress

The egress recommendations contained in Chapters 1 and 2, Sections 2 are generally applicable to morgues that service autopsy facilities and gross anatomy laboratories and they should be followed closely. There should be two exits from morgue preparation areas. Exits from cold and freezer body storage rooms should be designed with the egress requirements contained in Chapters 1, 2, and 11, Section 2 firmly in mind. All doors in environmentally controlled rooms should have hardware to operate from both sides, so no one can be trapped inside.

20.2.4 Floors, Ceilings, and Walls

All surfaces should be impermeable and washable with bleach or other disinfecting solution. Floors must be seamless, sealed, and able to withstand harsh cleaning agents. In gross anatomy morgues, x-ray laboratories, or receiving and loading facilities where epoxy or other monolithic materials are used, consider specifying nonslip finishes because under normal conditions, floors will be wet.

Install flooring material with integral and continuous cove bases extending a minimum of 8 in. (20 cm) up each wall. A wainscot height of 30 in. (75 cm) is recommended in gross anatomy morgues, but not required in cold rooms, family viewing rooms, or x-ray laboratories. This base height protects wall finishes from splashing by cleaning hoses, mops, and motorized floor-cleaning machines. All drains should have sediment strainers and grease traps. These allow organic matter to be cleaned out, keeping traps and pipes from clogging and meeting medical waste disposal regulations in the jurisdiction having authority.

Walls in all types of morgues, x-ray laboratories, and receiving and loading facilities should extend and be sealed to the underside of the structure above. Moreover, they should be waterproof, seamless, and smooth. Walls in CT scanning rooms and other advance imaging modalities may require shielding. A health physicist should be consulted for shielding requirements. Glazed ceramic tile, epoxy paint on plaster, concrete block, and water-resistant sheetrock are preferred wall finishes. Wall surfaces made of composite material panels with

integral smooth enamel finish and constructed with sealed joints are an excellent alternative to standard construction methods and materials for gross anatomy morgues. Insulated metal panels are commonly used for cold room walls, ceilings, and floors. All storage cabinets or cupboards should be stainless steel, with full-seam welded and polished joints.

Plaster or concrete ceilings can also be painted with epoxy to resist absorption of the formalin-containing chemicals that are generally found in high concentrations in gross anatomy morgues. Ceilings in CT scanning rooms and other imaging modalities may require shielding. Consult with a health physicist to determine the requirements. Because of the presence of moisture from frequent cleaning procedures, all light fixtures, wall outlets, and switches should be waterproof.

20.3 HEATING, VENTILATING, AND AIR-CONDITIONING

20.3.1 Introduction

HVAC systems for morgues supporting gross anatomy laboratories are critical: They must provide a safe environment for those who must work with potentially high volumes of formaldehyde, phenol, and other toxic chemicals.

HVAC recommendations contained in Chapters 1 and 2, Section 3 are generally applicable to morgues for gross anatomy laboratories and should be followed closely. Control of odors from organic decay within morgues, and surrounding areas is essential. For gross anatomy specimen preparation morgues, the basic intent is to keep air concentrations of formaldehyde, phenol, and other chemicals below objectionable odor levels. The odor threshold for formaldehyde is 1 ppm.

A minimum outside air change rate of 15–20 per hour is recommended for morgues. If downdraft embalming tables and adequate local exhaust devices are installed to capture fumes and odors at the source, consideration can be given to lowering the outside air change rate. When morgue facilities are unoccupied, ventilation rates may be reduced. Outside air exchange rates can be determined through engineering analysis and by using engineering control methods. It is best to introduce the supply air high in the laboratory and to exhaust it from low wall locations, thus drawing contaminated air below the work area and well below the workers' breathing zone. Embalming tables with built-in downdraft exhaust ventilation can provide local capture of chemical fumes and decay odors more effectively than general room exhaust points located near the floor.

Recirculation of air is not recommended for morgue facilities. Local exhaust and capture hoods may be feasible for head-wall installation just above the sink in embalming areas of cadaver preparation laboratories. General exhaust grilles can be installed in zones beneath countertops to draw fumes down and away from the breathing zone.

These laboratories and rooms should be maintained at a negative pressure with respect to all public areas and adjacent occupancies. Stainless steel ventilation ducts should be considered because of their corrosion resistance. No special treatment of exhaust air is needed, provided that the exhaust air can be discharged well above all surrounding buildings and terrain features.

20.3.2 Individual Room Requirements

20.3.2.1 Cold Room for Hospitals and Medical Examiners Facilities. Cold rooms for cadaver storage must maintain a regulated range of temperature and humidity conditions. However, due to odors of decomposition and decay, minimal ventilation is still required. Walk-in freezer rooms generally experience fewer odors because bodily decay processes are slowed at freezing temperatures. No ventilation is required for walk-in freezer rooms.

20.3.2.2 Morgue for Gross Anatomy Laboratory. Cadavers may be prepared before they are brought to the morgue or receiving area. However, many are prepared in the morgue serving gross anatomy laboratories. The embalming process consumes substantial amounts of formaldehyde-containing solution. Exposure levels are necessarily higher when embalming occurs in the morgue.

Automatic mixing systems feeding into closed, vented vessels should be used to prepare large volumes of embalming fluid. Small quantities can be prepared in a laboratory fume hood or ventilated enclosure. Bulk storage of embalming chemicals should be located in storage areas that are very well ventilated, with 10–15 outside air exchanges.

20.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

The loss prevention, industrial hygiene, and personal safety recommendations contained in Chapters 1 and 2, Section 4 are generally applicable to morgue facilities and should be followed closely. Ergonomic and materials handling considerations are particularly important in morgue facilities.

20.4.1 Personal Protective Equipment

Policies in hospital and M.E. facilities may require personnel working in receiving facilities to wear NIOSH-approved N-95 respirators.

20.4.2 Security

Morgue facilities require controlled access, security procedures, and equipment to prevent intrusion by curiosity-seekers or others intent upon illegal activities, such as theft or vandalism. In addition, containment of possible biological hazards is a priority. M.E. facilities are particularly targets for illegal intrusions attempting to disrupt investigations, destroy evidence, and/or steal bodies. Secure locks and biometric access control devices are recommended for hospitals' and M.E. morgue facilities. Universities and institutions that have morgues supporting gross anatomy laboratories also need a well-considered level of security to prevent theft and vandalism, as well as to contain biological contamination. Video surveillance and alarm systems are recommended for all receiving and loading facilities involving the transfer of bodies.

21

OPEN OR TEAM RESEARCH LABORATORY

21.1 DESCRIPTION

21.1.1 Introduction

An open laboratory sometimes called a team research laboratory may occupy a single unpartitioned space larger than the average size of a two- to four-module laboratory. It is not defined by the specific activities conducted within, but rather by its large size. The term "team laboratory," as used here, is not interchangeable with the designation "laboratory unit." A laboratory unit, according to NFPA, is identified as an aggregation of laboratory-use spaces defined by the rating of fire separation between the individual spaces within the unit, as well as between the unit and abutting spaces. A team laboratory may also be a laboratory unit, but it need not be. The distinguishing feature of this laboratory type is the interdisciplinary nature of the activities conducted therein. This may include chemistry, biology, engineering, physics, and other disciplines. However, multiple disciplines are not a prerequisite. This type of laboratory is defined by size and number of occupants. As a guideline for the purposes of planning, an open laboratory would have more than eight occupants and be greater than 1000 ft^2 (93 m^2). The large size of a team laboratory often poses unique problems in layout, HVAC, and loss prevention.

21.1.2 Work Activities

Activities conducted in a team research laboratory include any or all of those carried on in general chemistry, analytical chemistry, physics, clean room, controlled environment, engineering, biology, and biosafety laboratories (Levels 1 and 2 only).

21.1.3 Materials and Equipment Used

Equipment used in the team research laboratory may include any of the items listed as characteristic of the several laboratory types listed in Part II. Small quantities of highly toxic materials may be used, but this adds additional challenges for controlling exposures and security. The biggest complaint in open laboratories is the "borrowing" of materials or equipment that are not returned.

21.1.4 Exclusions

Activities, processes, materials, and equipment specifically associated with high toxicity, high hazard, and biosafety laboratories above a trivial level are not usually conducted in a team research laboratory because the named laboratories require environmental containment or security measures that are difficult to achieve in the more open setting of a team laboratory. These would include Select Agents and the Chemicals of Interest regulated by the Department of Homeland Security. The reader is referred to Chapters 14 and 23 for discussion of the containment type laboratories.

In addition, teaching laboratories (Chapter 16) and contract laboratories (those that routinely process large

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

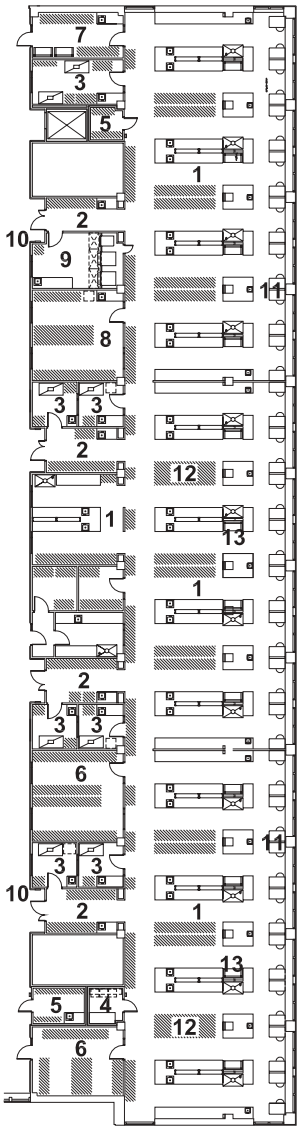
numbers of analytical samples) are not considered an open laboratory as discussed in this chapter.

21.2 LABORATORY LAYOUT

21.2.1 Introduction

The recommendations in Chapter 1 and 2, Section 2 and apply generally to team research laboratories. The management of spills and other types of release accidents involving hazardous materials is much more difficult in the large open area of a team laboratory (Figure 21-1) than in a room of average size because there is no simple means of containing hazardous vapors, gases, fumes, or smoke. In addition, more people potentially may be affected. An incident in one area of the laboratory may not be noticed in time for safeguards to be taken by persons in other parts of the laboratory. In a large open area, there is increased risk of flame spread. For this reason, the fire protective rating of walls around a team research laboratory should conform to requirements of NFPA 45 (NFPA, 2011) and local building and fire codes.

There are several advantages to team laboratories, and some have an indirect bearing on safety. Team laboratories promote interaction among researchers. Because boundaries between them are not "built-in," team members are more likely to encounter one another in the open environment and to share ideas as well as equipment. Institutions gain a great deal of flexibility with team laboratories because they can modulate and shift facilities assignments with changes in funding, research focus, or personnel. After the initial shock of not having walls around their "turf," researchers tend to respond in a more cooperative and sometimes more considerate manner in the use of the common space. Incompatible tastes in music as well as space temperature seem to generate the most problems in team laboratories. Noise can reach truly unpleasant and disruptive levels because of the operation of certain types of scientific equipment and ventilation systems. Large team laboratories are less expensive to construct compared to multiple smaller, but enclosed laboratories. See Table 21-1 for factors to consider when deciding on the design of a team laboratory.



KEY

1	Wet Lab	8	Major Equipment Room
2	Biosafety Vestibule	9	Autoclave Room
3	Cell Culture Lab	10	Corridor
4	Controlled Temperature	11	Computer Station
5	Cold Room	12	Equipment Zone
6	Freezer	13	Mobile Bench
7	Fine Instrument Room		

FIGURE 21-1. Team laboratory layout occupying an entire floor.

21.2.1.1 Entire-Floor Laboratory. A team laboratory that occupies an entire floor of a building and is not divided by walls or access-egress corridors requires special planning. The space must be organized with a pattern of circulation that is easily perceived by occupants and visitors. Space allocation within the team laboratory may vary from 60 to 200 NSF per person. This may be less than allowed in the standard laboratory module discussed in Chapters 1 and 2. This is because of the large overall space and the many common features shared by occupants. It is important that the laboratory layout be sufficiently logical and simple that all personnel know where they are within the laboratory at all times and know how to get out, even when vision is

TABLE 21-1. Issues to Consider when Choosing an Open Lab

Issue	Comments
Egress	Difficult to maintain
Safety Equipment	Placement critical
Fume Hoods	Placement critical
Chemical Storage	Locate to minimize travel and provide adequate space
Waste Storage	Locate to minimize travel and provide adequate space
Housekeeping	Protocols required due to variety of activities and materials
Shared Equipment	Up to 50% savings on less duplication of equipment, but potential for more abuse and less preventive maintenance
Shared Space	Easier to share, but must have guidelines to be effective, fair
Directional Airflow	More difficult to maintain
Ergonomics	Less opening and closing doors, but increased potential to run into people
Thermal Comfort	More difficult to control
Hazmat Spills	More difficult to contain and more people affected
Communication	Fosters more communication, but may create more noise and disruption
Flexibility	Provides more flexibility
Space Utilization	More efficient use of space
Privacy	Less privacy
Confidentiality	Less confidentiality
Energy Consumption	Potential for less
Traffic	High traffic zones have potential for more accidents
Noise	Radios, etc. cannot be played. Equipment noise is high
Security	Not appropriate for highly regulated hazardous materials
Construction Costs	Less
Operational Costs	Less
Culture	May require significant changes
Effect on Productivity	Unknown
Effect on Wellness	Unknown
PPE	All lab personnel have to wear

impaired by darkness, smoke, or chemical irritants. Exotic geometries are inappropriate for team laboratories, and odd layouts containing long culs-de-sac or dead-end aisles can be outright dangerous. They should be avoided in team laboratories. Island benches with adequate aisles on all sides are preferred. A rectangular grid is recommended for circulation because of its familiarity to all by sight or touch; with no visual clues, people are literally able to feel their way out. Groups can exit safely when the major aisles between benches and equipment are wider than standard aisles. This arrangement is recommended for all team research laboratories. In addition, special patterns in the flooring material (such as a bright or textured stripe leading in the direction of the exit), along with illuminated directional signs mounted close to the floor, are immensely helpful in evacuating a large team laboratory in a visually obscured or dark environment.

21.2.1.2 Utility Distribution. Utility outlets should be aligned with the circulation grid so that all arrangements of fixed and movable benches and equipment will maintain the minimum recommended aisle and egress passageway widths. Sinks should be evenly distributed so that all personnel are within 10-s travel time to an emergency eyewash station and to a sink for washing spilled materials out of eyes and off limited parts of body extremities as well as for hand washing.

Overhead distribution of utilities allows for easier access and more flexibility and is particularly suited for open laboratories.

21.2.1.3 Hazard Zoning. Because there may be a great variety of activities occurring simultaneously within a team research laboratory, well-defined zones for particular activities should be established early in the planning phase to reduce conflicts and promote safety. As discussed in Chapter 2, zones of activities of increasing hazard should be located farther away from primary egress aisles when possible. Zones can be determined by observing the following characteristics:

1. Areas containing fixed benches will have a range of relatively predictable activities that can be

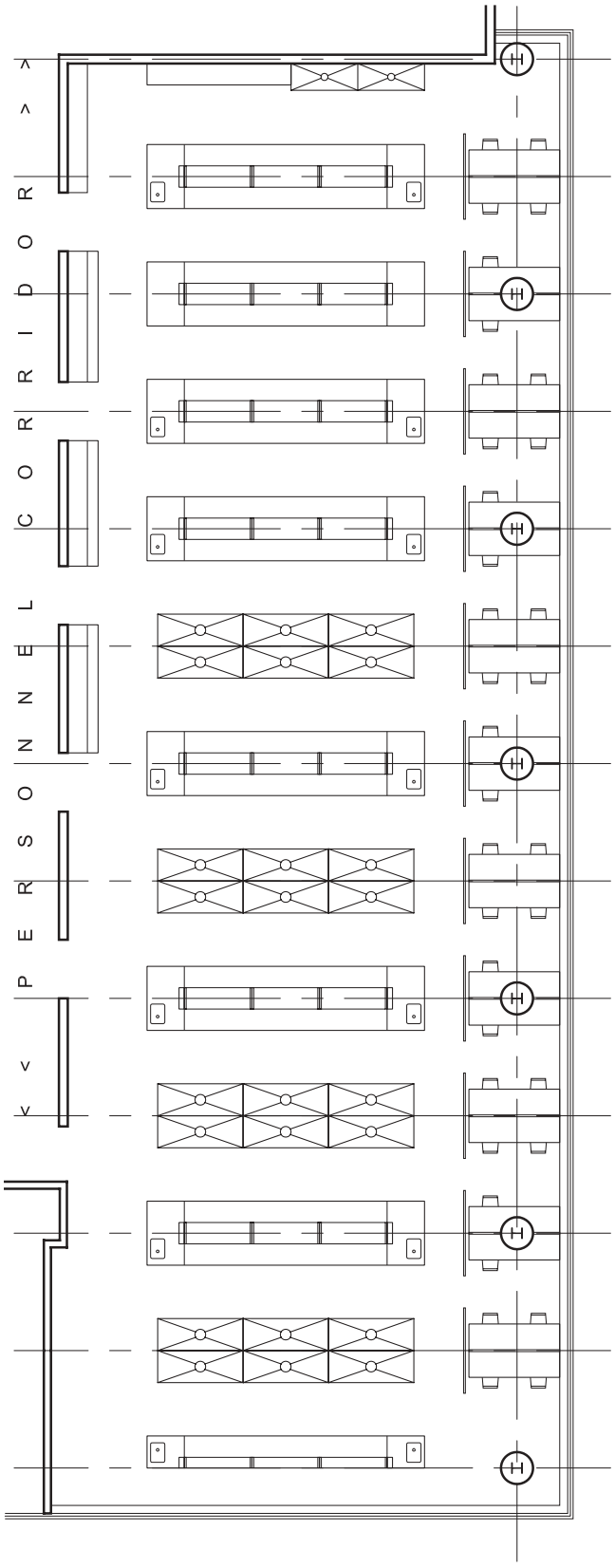


FIGURE 21-2. Team laboratory, detailed layout.

assessed for potential hazards. In contrast, open floor areas containing movable benches and large, nonpermanent equipment setups may be less predictable with regard to safety. Consideration should be given to providing a designated open floor area as a more hazardous zone and providing another area as a relatively safe zone.

2. Sterile processes are difficult to protect within a team laboratory unless the total laboratory is operated as a clean room. If this is not possible, sterile processes should be conducted within a full environmental enclosure or some other protective means in an area of the team laboratory that is zoned for and strictly maintained for clean activities. Chapter 23 contains a discussion of cleanroom laboratories. Nonsterile processes may not have more than normal cleanliness requirements.
3. Team laboratories may require special exclusion areas for containment of hazardous processes, equipment, or materials storage. In addition, they may need special exhaust air requirements to service processes or equipment that produce excessive heat, unpleasant odors, vapors, gases, or fumes, as well as acoustic controls to isolate equipment or processes that produce excessive or unpleasant noise.
4. Location and use of compressed gases must be carefully considered and should not impede egress. Space will need to be allocated for storage and use. Transportation of cylinders within the laboratory should be minimized.
5. Consider a central storage and dispensing section for chemicals.

21.2.2 Personnel Entry and Egress

The recommendations in Chapter 2, Section 2.2.1 apply generally to team research laboratories. Multiple egress doors will be needed based on size. When laboratories are larger than four standard modules, the distance to the nearest exit should not exceed 50 ft (15 m). Dead-end conditions should not exceed 20 ft (6 m). Applicable building and fire codes for occupancy and egress requirements must be observed.

Egress signage should also be in accordance with local and national standards. A special effort should be made to provide supplementary egress signs and visual guides for exit from large team research laboratories. This is particularly important when there are many exits. Exit signs should be visible from all areas and should be kept clear of pipes, ducts, light fixtures, and similar sight obstructions.

21.3 HEATING, VENTILATING, AND AIR-CONDITIONING

The recommendations in Chapter 2, Section 2.3 apply generally to team research laboratories.

21.3.1 Exhaust Air Systems

21.3.1.1 Fume Hoods. Large team research laboratories often require many chemical fume hoods. When they are grouped together, a lot of air must be exhausted from a relatively limited area, causing undesirable drafts and turbulence in the air flow patterns that frequently disrupt chemical hood performance. Side-by-side chemical fume hoods have been shown to perform poorly compared to fume hoods that have at least 4 ft (1.2 m) between them. The use of auxiliary air chemical fume hoods, especially when they are placed in alcoves, may be considered. When correctly installed and used, they reduce air current velocity and turbulence in the laboratory and also reduce the total amount of conditioned building supply air that must be exhausted to the outside. See Chapter 32 for more information on fume hoods. Even with conventional fume hoods, a good air distribution system will eliminate most problems associated with high-volume air exchange. The alcoves containing fume hoods should be considered high-hazard zones and placed away from the main egress aisles. They should be designed to aid a low-turbulence flow of laboratory air to the face of the fume hood. In addition, the location of chemical fume hoods must be carefully planned relative to all other local exhaust systems to avoid deflecting or reducing the effective capture velocities of some or all of these devices. There is a tendency to use variable-air-volume systems for fume hoods in team laboratories as well as occupancy sensors and other devices to reduce air flow. Careful evaluation of overall ventilation requirements of team laboratories should be conducted. When the ventilation air volume and rate required to maintain a desired air change level in the laboratory due to heating and cooling requirements are greater than the total air volume and rate from the fume hoods, a variable-air-volume system is not justified. Installation of a full-sized "ring" exhaust duct allows future flexibility.

21.3.1.2 Local Exhaust Air Systems. Recommendations contained in Chapter 2, Section 2.3 apply generally to team research laboratories. The distance between a particular bench top and the nearest fume hood may be significant in a large team laboratory. Ability to exhaust equipment locally is very useful.

21.3.1.3 General Room Air Exhaust Systems. Recommendations contained in Chapter 2, Section 2.3.4.1 apply generally to team research laboratories. An even distribution of exhaust grilles is important to reduce the spread of odors and fumes throughout large team research laboratories.

21.3.2 Supply Air Systems

Recommendations contained in Chapter 2, Section 2.3.3.1 apply generally to team research laboratories. An adequate volume and even distribution of supply air are especially important in large team research laboratories to provide for many exhaust air systems in a draft-free manner. There are two methods of introducing conditioned air to reduce drafts. One is to use perforated round or oval ducts that can deliver large volumes of air at far lower velocities over a much larger area than standard diffusers can. Perforated ducts must be hung within the space, not above a suspended ceiling. The tops of these ducts do not collect dust because air sweeps out of perforations on top. Another choice is to introduce conditioned air above ceilings and let it enter the room via perforated ceiling panels. Care must be taken to ensure that the supply plenum is clean and free from dust, duct insulation fibers, or other contaminants. Standard diffusers installed into lay-in ceiling systems or surface-mounted on ceiling structures should have directional vanes so that high-velocity airflows can be better controlled and smooth, even mixing with room air can be achieved.

21.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

The recommendations contained in Chapters 1 and 2, Section 4 apply generally to team research laboratories.

21.4.1 Emergency Showers

The recommendations contained in Chapter 2, Section 2.4.1.4 apply generally to team research laboratories. The emergency showers in team research laboratories that cover an entire floor should be located within the laboratory rather than in the corridors to ensure that there will be no more than 27 ft (9 m) of travel from any point to a shower (ANSI Z358.1, 2009). The showers should be arranged so that splashing and water runoff will not endanger laboratory equipment, benches, or electrical panels. Appendix A contains additional information on emergency showers.

21.4.2 Emergency Eyewash Facilities

The recommendations contained in Chapter 2, Section 2.4.1.5 apply generally to team research laboratories. There should be one emergency eyewash station for every two module equivalents, distributed evenly at sinks throughout the team laboratory. In addition, there should be at least one eyewash facility of the full-face type with water tempered in accordance with recommendations in Appendix B.

21.4.3 Hand-Portable Fire Extinguishers

The recommendations contained in Chapter 1, Section 1.4.4.2.2 apply generally to team research laboratories. In addition, large-capacity, multipurpose fire extinguishers may be needed within the laboratory. This should be determined with the aid of fire protection and safety specialists based on the anticipated uses of the laboratory.

21.4.4 Fire Alarm Systems

It is important that fire alarms be easily heard and seen throughout large team laboratories. Manual fire alarm boxes should be located at least within 200 ft (60 m) of each other (NFPA 101, 2012). Care should be given to selecting fire zones and zones of refuge. In many laboratory facilities with frequent false fire alarms, researchers tend to build up insensitivity to alarms that could be very dangerous should a real fire occur. A good public address system can be very helpful for giving building occupants critical information under emergency conditions. The International Building Code (IBC, 2012) requires public address systems in buildings over 70 ft (21 m) high; many fire departments also require them. Consideration should be given to including a public address system in team laboratories.

21.5 SPECIAL CONSIDERATIONS

21.5.1 Renovations

In large open team laboratories that will remain occupied during renovations, the area of active construction must be carefully separated from the remainder by good partitioning. Otherwise, unwanted dust and other contaminants may adversely affect occupants and experiments in occupied areas. All safety equipment must always be available to personnel on the occupied side. All recommendations contained in Part I, Section B apply to team laboratories.

21.5.2 Security

Team research laboratory operations may involve proprietary or hazardous materials that require security control. There may be special cases when valuable cell lines or other materials may need separate secure areas. Drawers may need to be lockable. Equipment may also need to be locked or otherwise secured (see security considerations discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1).

22

ANIMAL RESEARCH LABORATORY

22.1 DESCRIPTION

22.1.1 Introduction

The design of large research facilities for housing and caring for major laboratory animal colonies, especially when provisions must be made for accommodating many different species in the same facility, is a complex task that should not be undertaken without the active advice and assistance of veterinarians and scientists experienced in animal research, and managers experienced in operating comprehensive animal facilities. Stringent regulations covering all aspects of animal care and animal research practices have been established. The Animal Welfare Act (Title 9 CFR, Subchapter A, Parts 1, 2, and 3; CFR, 2000) invests the U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) with responsibility for issuing and enforcing regulations relating to all aspects of laboratory animal use and welfare. The most widely used document is the *Guide for the Care and Use of Laboratory Animals*, current edition published by the National Research Council (NRC, 2010). It covers all aspects of the care and use of laboratory animals, including institutional policies for monitoring animals and providing professional care. The guide is written as a performance specification, with few prescriptive recommendations. In addition, the National Institutes of Health's *Design Requirements Manual for Biomedical Laboratories and Animal Research Facilities* (NIH, 2012) offers extensive, detailed, thorough information, and current recommendations for design of animal laboratories. This important NIH document compliments the approach of the NRC *Guide* (NRC, 2012) and is very helpful to designers interpreting the *Guide's* performance specifications. For research calling for the use of animals to qualify for funding by U.S. agencies, animal facilities must conform to the NRC standards and be accredited by the Association for Assessment and Accreditation of Laboratory Animal Care (AAALAC). The AAALAC reviews and accredits entire animal research programs including care and use policies, animal environment, housing and management, veterinary medical care, and facilities. It is extremely important, therefore, that research facilities intended for animal housing and animal research be initially designed to meet the highest foreseeable standards. Anything less is likely to result in rapid obsolescence and to risk serious interference with future research programs.

There is frequently a need for the provision of animal facilities of modest size, 5,000 ft^2 (464 m^2), to medium size, approximately 15,000 ft^2 (1,390 m^2) or less, that are restricted to the housing of modest numbers, less than 50,000 mice, or a few similar species of standard research animals (e.g., only small rodents). The animal laboratories described in this chapter are confined to modest- and medium-scale purposes for teaching and research; the information that is contained here should not be extrapolated to cover design of large-sized facilities. The animal laboratories described here are suitable for the

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

housing and care of the most-used small research animals, principally rodents (mice, rats, gerbils, and guinea pigs). They are not designed for large animals, by ARS definition any animal larger than a guinea pig, or nonhuman primates.

Conventional animal laboratories provide security, humane care, and healthy environments for the animals plus facilities for research and animal care personnel within animal laboratories. Precautions are taken to admit only healthy, disease-free animals and to maintain them in a state of good health. No attempt is made to free them of normal animal microflora. On the other hand, barrier-type animal laboratories, as the name indicates, are designed to receive and maintain animals free of all, or certain classes of microflora, such as virus-free and transgenic mice. Other classes of animal laboratories have greater infection controls than the conventional, but less than barrier animal laboratories, to fit individual requirements of the research performed. Additionally, there are classes of animal biosafety laboratories that are equipped to safely handle animals purposely or adventitiously infected with animal and human pathogens. *Biosafety in Microbiological and Biomedical Laboratories* (5th ed.; BMBL; CDC/NIH, 2009) provides guidelines for containment facilities to hold these animals as does *Design Requirements Manual for Biomedical Laboratory and Animal Research* (NIH, 2012).

This chapter will begin with the smallest unit for design consideration, the cage and cage rack systems, followed by animal holding room requirements. The next level is design of animal laboratory facilities. Animal laboratories must be responsive to maintaining animals in health and comfort and provide safe workplaces for research and animal care staff. Facility types include (1) small, single-corridor, general-use rodent facilities, for example for supplying college teaching laboratories; (2) general-use double-corridor small animal laboratories; and (3) barrier facilities for immune-compromised strains and for transgenic mice. In addition, conditions required to house and handle infectious animals of various levels of hazard in animal biosafety laboratories are reviewed. Finally, design parameters and criteria for some individual rooms in animal laboratories will be described: animal receiving, quarantine, animal holding, procedure rooms, cage washing and sterilization, sterile surgery, necropsy laboratory, receiving, and shipping dock facilities.

22.1.2 Work Activities

The activities performed in a small animal laboratories include routine good animal care of a maintenance and preventive nature; animal breeding for genetics studies; animal experimentation involving administration of drugs, chemicals, and biological agents by inhalation, ingestion, injection, skin application, and surgical procedures; behavioral, pharmacokinetic, and metabolic studies requiring use of special equipment and/or round the clock monitoring of physiological effects; routine pathology preparations and examinations; and highly detailed record keeping. Much of the daily laboratory routine is occupied with animal care duties such as receiving and storing supplies, food preparation and distribution, changing animal bedding, washing cages and room surfaces, inspecting animals for illness, registering deaths, and disposing of animal carcasses and other wastes.

Direct experimentation with animals may take place inside animal laboratories when adequate facilities for such work have been provided. There is evidence that some species of small animals are disturbed by the smell of blood and sensitive to sounds made by animals that undergo treatment within holding rooms. In this case, it is desirable that treatments take place in procedure rooms within the animal laboratory. Procedure rooms should be adjacent or close to holding rooms for convenience of researchers and animal care takers. If the Institutional Animal Care and Use Committee (IACUC, the governing group of researchers and veterinarians) permits removal of animals from an animal laboratory for scientific and surgical procedures, animals are generally returned to the animal laboratory daily for housing and routine care. Certain experimental and surgical procedures are not normally performed in animal holding rooms. There may be circumstances when an IACUC will permit animals to stay in research laboratories and be cared for by research staff rather than returned daily. When animals will be exposed to hazardous substances or subjected to dangerous procedures, facilities for conducting such work should be made an integral part of animal laboratories to avoid unnecessary spread of toxic substances and exposure of personnel who are not directly involved.

22.1.3 Equipment and Materials Used

At a minimum, animal laboratories contain cages and cage racks for housing the animals, cage washing and sterilizing machines, a steam sterilizer for surgical supplies, food preparation equipment such as scales, dry feed mixers, vegetable slicers, and refrigerators. Technical equipment includes microscopes, surgical and necropsy tables, sinks, a freezer for storage of dead animals, and workbenches for holding a variety of scientific instruments used to measure animal responses and examine animal tissues. Chemical fume hoods may be required in necropsy laboratories or in procedure rooms to use for perfusions and other hazardous chemical pro-

FIGURE 22-1. View of ventilated animal cage changing station.

cesses. There may also be items usually found in biological laboratories such as high-speed blenders, sonicators, and lyophilizers. Biosafety cabinets (BSCs), described in Chapter 32, Section 32.9, are found in animal facilities in which hazardous microbiological procedures are performed and where animals are infected with contagious agents that affect human or rodent health. Commercially available mobile cage-changing stations can be brought close to cage racks to minimize exposure of animals during transfers, when correctly designed and used, this type of exhaust-ventilated cage-changing equipment can reduce occupational exposure to dust and animal allergens. It is shown in Figure 22-1.

Animal laboratories contain animal food and bedding materials in bulk quantities. These materials must be kept in clean, vermin-proof storage facilities. Only small amounts of veterinary drugs, laboratory chemicals, and bottled gases are needed in most modest small animal laboratories, but substantial quantities of sanitizing and disinfecting materials may be stored and used.

22.1.4 Exclusions

Conventional small animal laboratories are not suitable for work with highly infectious biological agents, with more than very small quantities of toxic chemicals, or for housing large or dangerous animals. Large animals commonly used in research, as defined by U.S. Department of Agriculture Agricultural Research Service (ARS), include rabbits, ferrets, fowl, nonhuman primates, dogs, cats, and large farm animals such as sheep, goats, horses, cattle, and pigs. Design and construction of large animal holding and research facilities, which necessarily involve larger spaces, are topics beyond the scope of this book, but are regulated by the ARS, which provides design guidelines in *Facilities Design Standards* 242.1M-ARS (ARS, 2002). Fish, amphibians, and invertebrate species also require specialized facilities for breeding and holding. Each of these conditions calls for highly specialized facilities not covered in this chapter.

For protection of the animals housed in animal laboratories and for safeguarding the integrity of experiments underway, storage of volatile, flammable, and explosive materials in animal laboratories should be strictly prohibited. When use of such materials will be needed in an animal laboratory, they should be stored outside in suitable facilities and only daily amounts brought into the animal areas.

22.2 LABORATORY LAYOUT

22.2.1 Introduction

Good animal laboratory design includes an efficient layout of facilities for ease of operations plus selection of materials of construction that make it possible to maintain excellent sanitary conditions. Whatever else may have to be omitted from animal research laboratories for reasons of inadequate space and insufficient budgets, no compromise should be made in provisions for maintaining excellent sanitation throughout the facility.

Animal facilities can potentially be in any part of a laboratory building. However, under all circumstances, security for research animals is of utmost importance in selecting location of animal laboratories. For this reason and for light cycle control, animal holding rooms do not have windows. Some facility managers prefer top floor locations directly beneath ventilation equipment to ventilate animal research laboratories with greater ease and shorter duct runs. Other managers prefer basement or other low-level locations relatively near loading docks to make waste removal and materials handling much easier. There are advantages and disadvantages of each location. When animal laboratories are above grade level, a minimum of one dedicated service elevator to transport animals, supplies, and animal waste is needed. Two dedicated service elevators are desirable to separate clean supplies and animals from waste, soiled, and potentially contaminated materials. When animal laboratories are on or below grade level, dedicated exhaust risers pass through the full height of buildings to roof-mounted ventilation equipment. Flooding can be disastrous in basement-level animal laboratories. Precautions to reduce the risk of flooding must be investigated and installed, such as adding bulkheads at entries and curbs

at tops of exterior exit stairs to animal laboratories. These precautions can help to hold off flooding until all the animals can be moved out of harm's way. In regions and specific locations where severe flooding conditions regularly occur, basement locations for animal laboratories are not recommended. Both roof-level and below-grade locations are more expensive to construct and to maintain, well above standard research laboratories costs and expense.

Another major consideration in locating animal facilities is noise and vibration. Many small rodent species are very sensitive to noise and vibrations produced by equipment in building mechanical, pump, and fan rooms as well as by elevator machinery. Even noise generated outside buildings, such as by subway trains, heavy industrial processes, or blasting for foundations and construction nearby can disrupt breeding and cause abnormal destructive behaviors. Excessive noise within animals' range of hearing can produce adverse health effects and lethal aggressive behavior toward cage occupants. These sounds may be well outside human hearing range, so specifications for equipment to monitor acoustical factors on a regular basis should be included in design documents. There is some concern about the effect of high-voltage transformer vaults and building electrical rooms proximate to animal laboratories and the effects of electromagnetic forces (EMF) on animal health. These health issues and others such as facility security, flexibility, and expansion potential should be discussed with the veterinarians and facility managers when the design team examines options to locate animal laboratories.

22.2.2 Ventilated Caging Systems

Many factors in addition to new laws and regulations have focused greater attention on protective animal cages; they include (a) research interest in long-term chronic studies of toxic substances and aging factors that require maintaining animals to old age in sterile environments, (b) the greatly increased cost of specially produced animals, and (c) a need to protect animal care personnel from infections and allergies. The general methods used for these purposes include (1) housing one or only a few animals in small transparent plastic cage boxes that have lids, which prevent animals' escape; (2) sealing cages against cross-contamination sources by physical barriers, or by lids equipped with high-efficiency particulate filters (micro-isolators); (3) providing positive ventilation to each individual cage at carefully controlled rates from a source of filtered supply air that has passed through HEPA filter(s) having a minimum efficiency of 99.99% for the most penetrable aerodynamic particle size (i.e., 0.1 mm); (4) self-contained cage racks that provide tempered, humidified, and decontaminated supply air to individual cages and provide positive means to exhaust the contaminated air from each cage into the dedicated general exhaust system for animal laboratories; and (5) the use of a Class II BSC or similar device for cage changing. Section 22.3.3 below provides more information on the supporting HVAC systems installation required.

In addition to providing effective isolation within each cage unit, use of positive cage ventilation ensures steady removal of the ammonia generated in bedding from rodent urine. This is said to reduce cage-changing frequency, which is labor saving and reduces disturbances to the animals from frequent handling. There are reported difficulties present in the operation of ventilated rack systems due to high-velocity air blown into cages. Animals become chilled and adverse to drafty conditions; they try to protect themselves behind barriers in the cages or beneath layers of bedding materials. There are pros and cons to each system. Because manufacturers regularly make improvements in their cage and rack systems, the burden of making decisions based on up-to-date information must involve veterinarians and facilities managers, in addition to the design team.

The NRC's *Guide for Care and Use of Laboratory Animals* (NRC, 2010) provides guidelines on the number of animals allowed in each cage by the area of cage, species, and weight of each animal, as shown in Table 22-1.

In addition, the number of animals allowed in each holding room is related to the net area of that room to prevent overcrowding. For example, if a typical holding room area is designed at 323 NSF (30 NSM), different numbers of animals will be permitted according to the species and weight of the animals. The representative animal census for 323-NSF rooms is shown in Table 22-2. Another method is to calculate the area required for a specific number of animals in each species. For example, Table 22-3 shows the net area required to house 1,000 animals of various small animal species.

There are exceptions to these guidelines as in the case of fully ventilated cages within compact storage rack systems. Figure 22-2 illustrates a self-contained cage rack with individual plastic cages, each connected through internal piping to a filtered air supply unit and a filtered air exhaust unit. Animal holding rooms can use a compact storage system for racks. It features wall-mounted or overhead support rails that allow racks to shift laterally. This conserves net area by allowing generally more than double the number of two-sided racks per holding room. Aisle spaces normally required between racks are all not required in compact storage systems.

TABLE 22-1. Cage Size by Animal and Weight

Animal	Weight in Grams		Floor Area per Animal in.^{2}	Floor Area per Animal cm^2	Height in in.	Height in cm
	Low	High			(cage floor to cage top)	
Mouse	<10		6	38.7	5	12.7
	10	15	8	51.6	5	12.7
	15	25	12	77.4	5	12.7
		>25	>15	>96.8	5	12.7
Rat	<100		17	109.7	7	17.8
	100	200	23	148.4	7	17.8
	200	300	29	187.1	7	17.8
	300	400	40	258.0	7	17.8
	400	500	60	387.0	7	17.8
		>500	>70	>451.5	7	17.8
Hamster	<60		10	64.5	6	15.2
	60	80	13	83.9	6	15.2
	80	100	16	103.2	6	15.2
		>100	>19	>122.6	6	15.2
Guinea Pig	<350		60	387.0	7	17.8
		>350	>101	>651.5	7	17.8

TABLE 22-2. Estimate of Number of Cages in Holding Room, 323 NSF (30 SM), by Animal and Weight

Animal	Weight in Grams		Floor Area per Animal in.^{2}	Max Animals Allowed in 323 NSF (30 NSM)	Max No. Animals per Cage	Approx No. of Cages
	Low	High				
Mouse	<10		6	7,752	8	969
	10	15	8	5,814	7	831
	15	25	12	3,876	6	646
		>25	>15	3,101	5	620
Rat	<100		17	2,736	2	1,368
	100	200	23	2,022	2	1,011
	200	300	29	1,604	2	802
	300	400	40	1,163	2	581
	400	500	60	775	1	775
		>500	>70	664	1	664
Hamster	<60		10	4,651	4	1,163
	60	80	13	3,578	4	894
	80	100	16	2,907	5	581
		>100	>19	2,448	5	490
Guinea Pig	<350		60	775	2	388
		>350	>101	461	2	231

Figure 22-1 depicts a mobile cage change station that maintains the animals in a filtered air envelope during cage changing and provides some protection to the animal handler. Use of Class II BSCs for cage changing provide the same degree of protection for the animals and provide more effective protection for animal handlers.

The use of self-contained isolator cages and racks serviced in mobile cage change stations reduces the size and complexity of animal laboratories for users of small numbers of rodents in laboratory settings. In addition to providing absolute particulate filtration of all the air withdrawn from the cage, it is possible to add a gas-adsorbent stage to remove ammonia and animal-associated odors. It has been stated that the availability of a self-contained cage isolator exhaust air purification unit makes it possible to locate cages as free-standing equipment in any laboratory or auxiliary room

TABLE 22-3. Floor Area Required to Hold 1,000 Animals, by Animal and Weight

Animal	Weight in Grams		Floor Area per Animal $in.^2$	Floor Area 1,000 Animals ft^2	Floor Area per Animal cm^2	Floor Area 1,000 Animals m^2	Approx No. of Cages
	Low	High					
Mouse	<10		6	41.7	38.7	387.0	167
	10	15	8	55.6	51.6	516.0	167
	15	25	12	83.3	77.4	774.0	200
		>25	>15	104.2	96.8	967.5	200
Rat	<100		17	118.1	109.7	1,096.5	7
	100	200	23	159.7	148.4	1,483.5	7
	200	300	29	201.4	187.1	1,870.5	7
	300	400	40	277.8	258.0	2,580.0	7
	400	500	60	416.7	387.0	3,870.0	7
		>500	>70	486.1	451.5	4,515.0	7
Hamster	<60		10	69.4	64.5	645.0	6
	60	80	13	90.3	83.9	838.5	6
	80	100	16	111.1	103.2	1,032.0	6
		>100	>19	131.9	122.6	1,225.5	6
Guinea Pig	<350		60	416.7	387.0	3,870.0	7
		>350	>101	701.4	651.5	6,514.5	7

FIGURE 22-2. View of ventilated cage rack.

even without provision of a dedicated air exhaust facility. Nevertheless, animals should remain in dedicated animal care facilities in which they can receive adequate services (e.g., watering, feeding, cage changing) from trained animal care staff.

For a research or teaching program that only needs to maintain a limited number of small animals for prolonged periods, the self-contained cage isolator system of animal housing can be adapted to less than ideal existing conditions and still comply with animal care regulations. For safeguarding large numbers of clean animals for long periods under ideal conditions, isolator housings represent advancement in good animal care and preservation.

22.2.3 Small Animal Holding Rooms

Animal holding rooms for small research rodents have common features: a hand-wash sink, ventilation system, lighting fixtures, and an enclosure comprised of floor, walls, and ceiling constructed of sturdy materials and sealed surfaces. No windows are required or recommended in small animal holding rooms. Small viewing windows in holding room doors are acceptable. These small windows may be covered on the corridor side of the window to reduce leakage of corridor light into holding rooms if required for research protocols and for the health of the animals. Standard sizes of animal holding rooms will vary based on the number of rodents, type and size of caging and rack system(s) used typically, and any other equipment that must be used in the room. Equipment that may be found in holding rooms includes BSCs, experimental apparatus used for particular research protocols, and a mobile cage changing station that may be moved out when cage cleaning is completed.

Main aisles within animal holding rooms must be a minimum of 5 ft (1.5 m) wide or the width of the largest rack. Other aisles should be a minimum of 3 ft (1 m) wide to allow animal handlers to safely squat, reach, and remove cages at bottoms of racks. For rooms with large two-sided cage racks, aisle widths may need to increase.

Clear corridor width outside animal holding rooms is recommended at 7 ft (2.1 m) wide minimum to allow workers to turn and move racks in and out of holding rooms in modest and medium-size animal laboratories. The *Guide* (NRC, 2010) recommends widths of 6 and 8 ft (1.8 and 2.4 m). The *NIH Design Requirements Manual* (NIH, 2012) recommends wider corridors in larger facilities.

22.2.3.1 Conventional Small-Animal Holding Rooms. In conventional small animal holding rooms, there are no subdivisions or barriers between racks. When veterinarians and user committees decide upon the cage and rack system(s) that will be purchased, animal laboratory designers can provide options on arrangements of racks in holding rooms. The *NIH Design Requirements Manual* (NIH, 2012) provides examples of several common layouts.

Critical factors that affect animal holding room layout are locations of structural columns and exhaust devices. Structural columns that protrude into holding rooms effectively reduce the usable size of rooms because they can be obstructions to efficient rack arrangements.

Exhaust devices in animal holding rooms are normally located low on walls and close to floors to optimize ventilation in rooms using conventional cage racks. If ducts and exhaust grilles protrude from walls, they also reduce the usable area of holding rooms.

Small animal holding rooms do not require floor drains, but hand-wash sinks should be located near holding room entries to remind researchers and caretakers to wash their hands upon entering and exiting. Providing mop hooks in each room is also useful. If animal laboratories have automatic watering systems, pipes will be mounted on walls against which racks will be located and mechanically connected to racks when in use. Watering system shut-off valves should be provided in convenient, visible locations in corridors. Lighting controls are automated to provide daily light cycles required for the species of animals housed and to meet NRC and AAALAC standards. However, researchers and caretakers, who need to work within animal holding rooms for short periods, may use light override switches. HVAC controls are also automated to monitor and control temperatures, humidity levels, and air volumes required for each species, as per NRC and AAALAC standards. In addition, automated HVAC controls monitor and control pressure differences between individual holding rooms and animal laboratory corridors; this could be positive or negative according to biosafety and exclusion requirements for research protocols. Pressurization considerations are described in Section 22.3 below.

22.2.3.2 Small Animal Cubicle Rooms. In small animal cubicle rooms, single- or two-sided cage racks are totally enclosed in chambers that are supplied with independent ventilation air systems, lighting, and environmental controls. Rooms that hold cubicle chambers can be designed to have the same area or a larger area than conventional holding rooms, but generally fewer animals can be housed in cubicle rooms of the same area. A cubicle room gives researchers the option to use as few as one rack of animals, which is functionally isolated from all other animals in that room. The long side of each rack faces the front of the cubicle chamber so that animal caretakers and researchers can visually check the animals without entering the chamber. Cubicle chambers may be manufactured units selected for the convenience of demounting, moving and rearranging them, or cubicles may be constructed by traditional construction methods using conventional materials, such as concrete masonry units. Cubicle chambers may be arranged in back-to-back rows or along walls of rooms. Access is from central aisles to each individual cubicle chamber door. These doors may be wide sliding-glass doors similar to those used in residential construction, glass panel overhead doors similar to garage doors, or they may be conventional hinged double doors. All cubicle chamber door openings must be sufficiently wide to easily maneuver one rack in and out.

Cubicle rooms generally have one BSC to service animals in all of the cubicle chambers, for inspection of animals, cage changing, and minor procedures. BSCs installed within cubicle rooms support protocols to reduce cross-contamination. Cubicle rooms require hand-washing sinks in the room, but not in each cubicle chamber. Other utility considerations and ventilation requirements are similar in cubicles as in conventional holding rooms, as described below in Section 22.2.5. The primary difference is that cubicle chambers are individually pressure controlled.

22.2.4 Common Elements of Animal Laboratory Layouts

The minimum facilities required for small research and teaching laboratories that use modest numbers of small animals use the following room types. They are discussed in more detail in Section 22.2.7, Individual Rooms.

1. *New animal reception and quarantine area.* These are usually closed rooms isolated from the main animal quarters and described in Sections 22.2.7.1, 22.2.7.6, 22.3.2.1, and 22.3.2.6.
2. *Animal holding rooms.* These are rooms in which cleared animals undergoing or awaiting

experimentation are housed, fed, and cleaned. Sections 22.2.3 and 22.3.2 provide details of this type of room.

3. *Procedure rooms.* These are rooms in which animals receive routine husbandry treatment, and undergo simple procedures according to research protocols as described in Sections 22.2.7.2 and 22.3.2.2.
4. *Sanitation facilities.* Designated "dirty areas" are used to collect and dispose of animal wastes and soiled bedding and to wash cages, cage racks, and water bottles. "Clean areas" are where washed cages, racks, water bottles, and equipment are sterilized and filled with clean or sterilized bedding, water, etc. Steam sterilizers are needed when dealing with highly infectious rodent and human pathogens, but otherwise, commercial disposal facilities can be utilized. Chapter 27, Hazardous Chemical, Radioactive, and Biological Waste Handling Rooms, Section 27.1.2.3 provides information on the design of temporary storage of biological waste.
5. *Personnel facilities.* These facilities include lockers, showers, toilets, and break rooms to serve animal husbandry and veterinary care workers.
6. *Storage rooms (internal).* These contain vermin-proof bins for animal feed, clean bedding, veterinary and other animal care supplies and equipment as required for behavioral, pharmacokinetic, and metabolic studies.
7. *Experimental surgery suite and/or necropsy laboratory.* Sections 22.2.7.4, 22.2.7.5, 22.3.2.4, and 22.3.2.5 provide details. When the size of the facility permits, the necropsy laboratory should be isolated from the treatment and research study laboratories. Tissue preparation and pathology facilities can be provided external to animal laboratories when space is limited. These laboratories are described in Chapter 19, Sections 19.1.2.2 and 19.1.2.3.
8. *Freezer.* A freezer holds carcasses before disposal and excised tissues before and after examination. Consult with local jurisdictions having authority on legal disposal methods. Chapter 27, Section 27.1.2.3 focusses on hazardous biological waste facilities.
9. *Storage room (external).* This facility holds animal waste for disposal or composting.
10. *Receiving/shipping dock space.* These spaces are separated from other general building receiving dock functions. They are outside the secure perimeter of animal laboratories, but only serve animal laboratories and are described here in Sections 22.2.7.6 and 22.3.2.6.
11. *Housekeeping rooms.* This room, or multiple rooms according to the size of the animal laboratory, stores essential cleaning materials, cleaning equipment (manual and motorized), chemicals, and supplies for maintaining cleanliness of all the surfaces in the facility.

22.2.5 Small Animal Laboratory

A feature specific to animal laboratories is the provision of designated "clean" and "dirty" areas. Animal laboratories may use circulation patterns that discourage passage of personnel and equipment from the dirty side to the clean side without first passing through a sanitation station. The objective is to avoid introducing infection to animal colonies or spreading infection. On the other hand, risk of spread of infection may be reduced by use of protocols and procedures developed by veterinarians and the animal care committee (IACUC) to control researchers' and animal caretakers' behaviors, as well as care and use of the facility. Providing isolated quarantine facilities also reduces risk of spread of infection.

Because of the need to bring large, 48–71 in. long and 20–35 in. depth (122–180 cm and 51–89 cm) cage racks with heights ranging from 59–79 in. (152–200 cm) cage racks regularly to a central cage cleaning facility, most corridors in the animal laboratory should be wide, 7 ft minimum clear width (2.15 m), to accommodate such traffic. All doors must be a minimum width of 42 in. and minimum clear height beneath automatic door closer of 80 in. (107 × 201 cm). Even though cage racks are on wheels, they are heavy, from 300–900 lbs (136–408 kgs) each. Animal caretakers work hard to maneuver racks out of doorways and to control movement around corners, up and down ramps, and on sloped floors. Therefore, animal laboratory corridor walls require cleanable guardrails or other protection from moving racks, which otherwise gouge walls and chip paint and other wall finishes. However, guardrails can functionally reduce corridor widths by 4–7 in. (10–18 cm), so slightly wider than recommended 7 ft minimum corridor widths are better.

Animal laboratories should be further isolated from surrounding building functions by maintaining them under negative air pressure relative to connecting corridors and adjacent rooms to prevent spread of animal-generated odors outside the animal quarters. The recommendations contained in Chapters 1 and 2, Section 3 are generally applicable to animal research laboratories except as supplemented or modified in the following paragraphs and specifically by Section 22.3.

22.2.5.1. Minimum Small Animal Laboratory. A typical layout for a minimum small animal laboratory using a single-corridor, double-loaded system has receiving and quarantine rooms that can be reached from the outside without entering any other part of the animal laboratory. A single, central corridor serves distribution of both clean and dirty materials. The minimum-size small animal laboratory is a suite of several rooms isolated from the remainder of the building by exit doors, preferably in pairs that provide pressurized anterooms between doors and out of traffic paths. As described in Chapter 2, Section 2.2.2.3, anterooms can also store daily supplies of PPE for persons to put on before entering, if there is not a separate locker and changing room for animal laboratory staff and researchers. A minimum-sized small animal laboratory will have several holding rooms, one procedure room, storage rooms for food and bedding, and a housekeeping room. Cage washing and sanitation equipment and a staging area must be provided in this suite. Cage washing can be done manually, but that requires large deep sinks. Minimum sized laboratories may use cage-washing facilities that are available elsewhere, but the remote facility must have spare capacity to serve the daily load generated in minimum animal laboratories. Likewise, surgery, necropsy, quarantine, central supplies and storage, receiving and loading facilities, and other support services may be provided remotely.

22.2.5.2 Two-Corridor Animal Laboratory. The important features of a two-corridor system are (1) corridors are confined to directional movement of personnel, animals, and equipment—always from "clean" to "dirty"; and (2) there are two doors to each animal holding room—one for entry, one for egress.

The size, proposed use, and location of these animal laboratories will determine if sterile surgery suites, necropsy laboratories, separate shipping and receiving facilities, should be included, or whether these support services can be provided remotely.

In small animal laboratories, the operational rigidity imposed by the two-corridor system can become an obstacle to efficiency and speed. Nevertheless, breeding colonies and long-term experiments (such as bioassays for carcinogenicity and pharmacokinetics) that call for the animals to live out a time approaching a normal life span require the ultimate in animal protection, and the two-corridor system is designed for such purposes. Entries and exits should include anterooms between two doors on both clean and dirty corridors. Any interconnections between clean and dirty corridors should also include two-door anterooms, described in Chapter 2, Section 2.2.2.3.

Because of the design rigidities imposed by two-corridor system layouts for animal laboratories, identification of a need for such a facility must be made very early in the design process. There is no consensus that improvements in animal health and longevity alone are sufficiently obvious to justify using two-corridor concepts, except for facilities dedicated to breeding programs. This decision needs to be made by veterinarians in charge in consultation with their committees of research users.

22.2.5.3 Barrier Small Animal Laboratory. This is an example of a combined confinement and exclusion facility inasmuch as it must prevent the entry of untreated air from the exterior to avoid infecting the animals. At the same time, it must prevent escape of animal-generated odors and dust into occupied areas external to the barrier facility. These contradictory objectives are achieved with the use of two-door anterooms between areas inside the laboratory as well as between the laboratory and the exterior, described in Chapter 2, Section 2.2.2.3. It also requires careful adjustment of airflow direction to maintain flow from animal holding rooms into interior corridors plus airflow from outside the facility into the same or other inside corridors. All corridor air is withdrawn from the laboratory suites. The basic airflow system maintains internal connecting corridors negative to animal holding rooms as well as to all areas exterior to barrier animal laboratories.

Precautions must also be taken to prevent all materials and people entering barrier animal facilities from introducing any contagions or dirt that put animals at risk for disease. All materials entering are sterilized either through two-door, through-the-wall autoclaves or by irradiation, which is currently only available for animal feed and bedding.

Before entering barrier animal laboratories, at minimum, all people must fully cover their normal clothing, shoes, hair, and beards with protective garments and coverings. Strict policies governing barrier animal laboratories may require persons entering to disrobe, removing all street clothing and shoes, and gown in prescribed animal laboratory garments and PPE. Often air showers are used to rid fully gowned persons of any lint, dust, hair, and skin particles as another precaution before entering.

Barrier animal laboratories are used typically for biomedical research using immunocompromised strains of inbred mice and transgenic mice (often referred to as "knockout mice"). These mice are expensive to produce or purchase (some cost thousands of dollars each) and are costly to maintain. In addition, one must take account of research staff time and equipment, making

it a critical and costly undertaking that calls for redundancy of essential facilities, electrical and utility emergency services, plus a high level of staff training and job satisfaction.

Figure 22-3 is a floor plan of an existing barrier animal laboratory housing transgenic mice. Entry into locked facilities is via a card-key or other computer-based security system that identifies and passes authorized employees and research visitors inside, as well as making a permanent record of entry and exit times. In addition to security, the system enhances accountability for adhering to the rules that maintain the barrier system. Entry is through an anteroom into a clothing change and shower room: one for men, one for women. This is followed by a second anteroom passage into the corridor connecting animal holding and procedure rooms. The second anteroom may be an air shower chamber.

Everything that enters the barrier, including food, water, bedding, and washed cages and cage racks passes through two-door pass-through steam sterilizer(s) or is otherwise decontaminated prior to entry. Inside the barrier are animal holding rooms, procedure rooms (many with BSCs), and breeding and transgenic mouse production areas. If research done in this facility requires access to a sterile surgery, it may be located within the barrier, but its use will be under strict protocols. Just outside the barrier, but connected to it through anterooms, is a dirty area for receipt of soiled cages, cage racks, and wastes from inside the barrier. An integral part of the laboratory, but external to the barrier, are animal quarantine, receiving, and holding rooms; cage washing and sterilization; storage for feed, bedding, and cleaning supplies; administrative offices; and required facilities for the comfort and convenience of the staff. These common services and facilities may be shared with adjacent conventional animal laboratories.

22.2.5.4 Small Animal Biosafety Laboratory. Although current interest in design of animal laboratory facilities is focused on construction or renovation of special environments for virus-free mice (an exclusion facility), there is a continuing need for animal laboratories equipped for work with pathogenic agents (a containment facility). Chapter 14 reviews essential requirements for the design of biosafety laboratories. In that chapter, the CDC/NIH publication, *Biosafety in Microbiological and Biomedical Laboratories* (HHS, 2009), is cited as an authoritative source for information on the hazard rating of biological agents and the characteristics of laboratories qualified to handle these agents safely. This publication contains animal laboratory classifications based on the hazard level of the agents that will be present. It uses the same four-level scale based on the risk of the agents that will be used. Inasmuch as it will be necessary for biological containment animal facilities to include biosafety laboratories (described in Chapter 14) as an adjunct, it is advisable to coordinate planning and operations for both in the programming and early in the design process.

The CDC/NIH publication (HHS, 2009) makes it clear that "laboratory animal facilities are simply a special type of laboratory" and that the recommended four levels of biosafety facilities, practices, and operational requirements that apply to nonanimal-containing biosafety laboratories are equally applicable to their animal-containing counterparts.

Animal Biosafety Level-1 (ABSL-1) requirements do not go beyond normal good practices for a laboratory animal colony. Animal Biosafety Level-2 (ABSL-2), in addition to normal good practice requirements, calls for the use of BSCs or comparable containment devices when conducting procedures that have a high potential for creating aerosols.

Animal Biosafety Level-3 (ABSL-3) facilities call for the installation of locked doors, controlled access, two-door entry anterooms, two-door pass-through autoclaves for transferring equipment and wastes out of animal laboratories, and inward-opening, self-closing doors into animal rooms. Once-through, nonrecirculated mechanical ventilation systems, dedicated solely to containment animal and research laboratory suites, should be provided. Flow of clean conditioned air should go from clean areas to potentially contaminated areas. HEPA filtration of exhaust air may be needed based on site considerations and the nature of the agent(s) manipulated. Each service connection of a vacuum line should be equipped with a liquid disinfectant trap and a HEPA filter. All procedures that have risk of generating aerosols are conducted in BSCs. This is particularly important in necropsy laboratories when bodies of dead, infected animals are opened for examination. When indicated by a risk assessment or required by institutional policy or by regulation, personnel showers must be provided for persons exiting ABSL-3 laboratories.

Animal Biosafety Level 4 (ABSL-4) is ". . . suitable for addressing dangerous or exotic agents that pose high risk of life threatening disease, aerosol transmission, or related agents with unknown risk of transmission" (HHS 2009). ABSL-4 builds upon the standard practices, procedures, containment equipment, and facility requirements of ABSL-3. Procedures must be developed locally to address specific operations of a Class III cabinet line (HHS, 2009). ABSL-4 facilities are likely to be included within a BSL-4 laboratory and to share all of the special requirements prescribed for this class of high-containment laboratory.

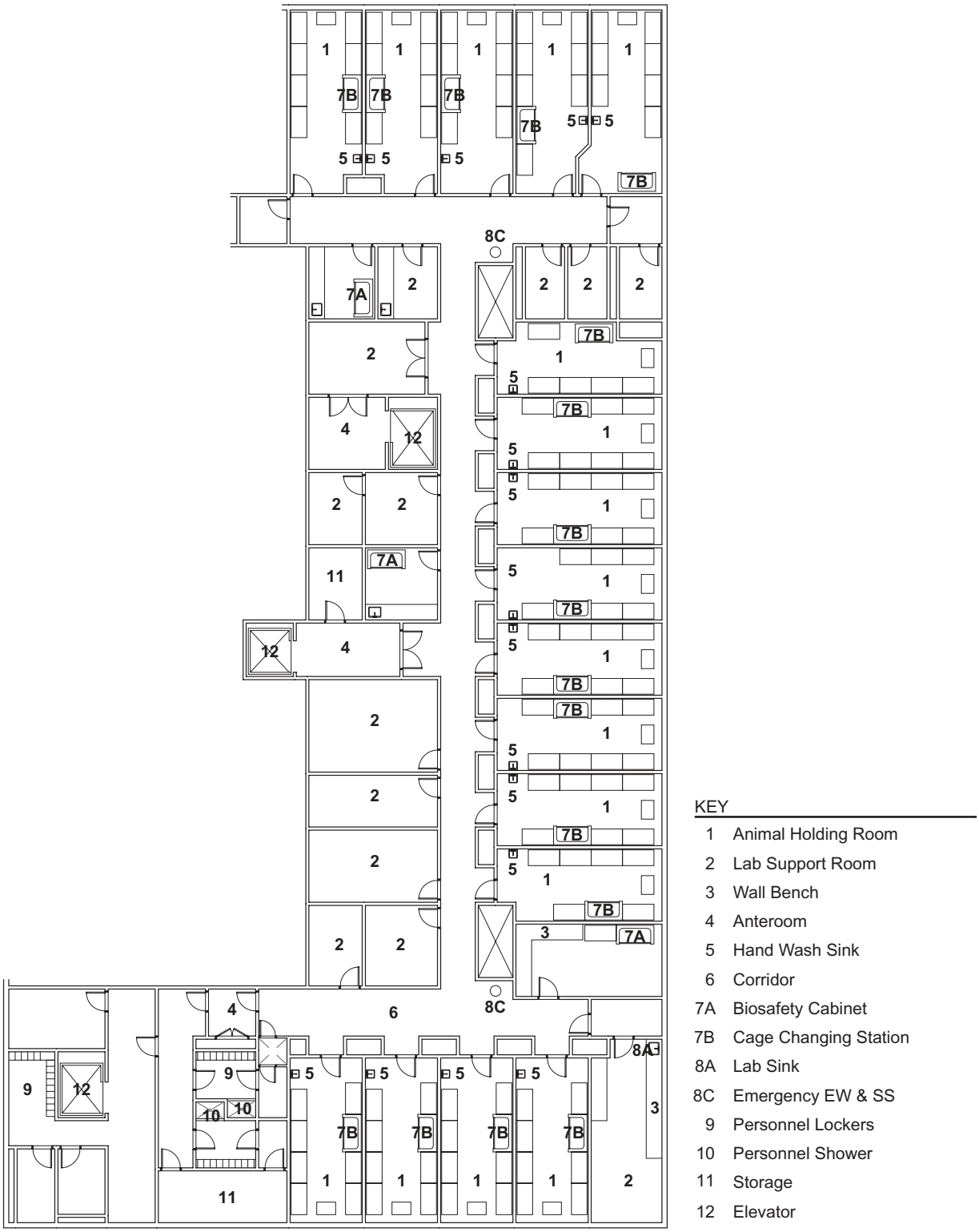


FIGURE 22-3. Example of a barrier animal laboratory facility layout.

22.2.6 Access Restrictions

Access should be limited to essential personnel to avoid unnecessary exposure of the animals to infections and contamination. Illegal activities of certain animal welfare groups make it prudent to maintain the animal laboratory behind locked doors.

Care must be taken to prevent entry of wild rodents and insects that will be attracted by the availability of food because they bring diseases usually absent from carefully managed animal laboratory colonies. This is done by keeping laboratory access doors closed when not being used for passage of personnel, supplies, or equipment and making certain that the crack under the door will not permit passage of even small mice. Door accessories that address this problem are automatic closers, weather stripping, and door bottom gaskets.

Other vermin, such as cockroaches, are also attracted to food and animal wastes in animal laboratories. Vermin can enter through unsealed or inadequate seals of penetrations in walls, floors, and ceilings. All penetrations for utilities, ducts, and structural members into animal laboratory enclosures should be completely sealed, tested, and inspected during commissioning to ensure that vermin cannot enter once facilities are operating. Chapter 37, Commissioning and Final Acceptance Criteria, discusses performance and final acceptance that apply to all laboratories especially for animal laboratories. In addition, "commissioning process should include a pest control inspection of the facilities and remedial or additional preventative action should take place" (Institutional Pest Management Program Description, MIT, 2009). These facilities should be certified as "pest free" before the owner offers final acceptance to the contractor (MIT, 2009). Chapter 1, Section 1.5 discusses design for pest control.

22.2.7 Individual Room Layouts

The essential layout requirements for quarantine rooms, cage washing and sterilization facilities, procedure rooms, sterile surgery, necropsy laboratories, and animal receiving and shipping facilities are described in the following sections. Personnel facilities such as locker rooms, animal husbandry, and veterinarian offices and lounges are required, but not discussed. Anterooms are described in Chapter 2, Section 2.2.2.3.3.

22.2.7.1 Quarantine Room. Quarantine rooms are used to monitor new animals for disease when the animal laboratory receives them, and prior to introducing new animals into the existing colony. Quarantine rooms are equipped with one or two racks of cages. There may be one or more quarantine rooms in animal laboratories; the number depends on the volume of animals the laboratory typically receives, quarantine protocols and waiting periods, and the number of species. Separate quarantine rooms are required for each species because diseases that have subclinical effects in one rodent species can kill another species (HHS, 2009). If there are two or more rooms, they will be arrayed in a suite arrangement with a common corridor and one door to the access corridor and entered from outside the animal laboratory. There should be a hand-wash sink within the facility. Soiled cages from quarantine rooms are removed from quarantine and usually brought to soiled cage-staging areas for cleaning. Because of this flow of supplies and cages, proximity to the animal laboratory is recommended.

Research rodents stay in quarantine rooms typically for 6 weeks, so any incipient communicable disease has time to incubate and present symptoms. If veterinarians find quarantined animals are disease-free, animal caretakers then are permitted to bring them into the animal laboratories.

22.2.7.2 Procedure Room. Research animals require routine veterinary care and are also subjected to a wide variety of experimental medical procedures as part of the research protocol. These procedures are best done in a room separate from animal housing, due to disturbances of noise, vibration, and smells, which normally occur when animals are removed from cages. These activities stress other animals when performed in holding rooms.

There should be sufficient area in procedure rooms for two persons to work, a work surface, an animal rack, and any other equipment required for experiments and veterinary treatment. Procedure rooms require a stable surface upon which to place animals for procedures. This surface should be constructed of seamless stainless steel, or other material that will maintain an impervious, smooth finish when cleaned with harsh sterilization agents, such as bleach solutions. Work surfaces may be tabletops, bench countertops, or wall-mounted and fold-down countertops, if space is tight. Ceiling- or wall-mounted procedure light fixtures on articulated, adjustable arms, should be installed above work surfaces. In addition, a general use sink or a hand-wash sink in each procedure room is required. One sink should be equipped with an emergency eyewash fountain. Other provisions may include BSCs or other local exhaust ventilation hoods, and special equipment for experiments and for veterinary care, such as small scales for weighing animals.

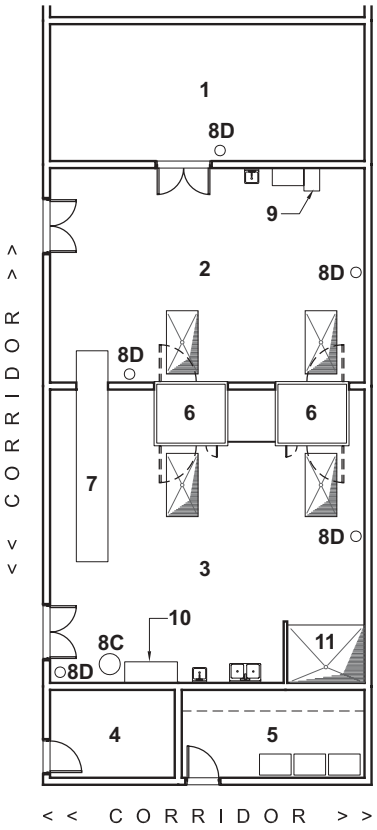
22.2.7.3 Cage Washing and Sterilization. Cage washers are generally organized to load soiled cages on

one side and remove clean cages on the opposite side. The input side of cage washers should always be located in the dirty side of the animal facility. The output side of cage washers should open into the clean side. Figure 22-4 is a sample layout of a cage washing and sterilization suite for a moderate-sized small animal facility. There is no person-door connecting the dirty and clean sides to reduce risk of contamination. On the dirty side, there may be an access door beside the washers for equipment service personnel to inspect and work on utility connections, motors, and control systems. Large size washers can accommodate and clean one or more racks and cages. Two-door, pass-through autoclaves for sterilizing cages and equipment are frequently installed on the clean side in cage washing facilities. Cage washers, rack washers, and autoclaves require canopy exhaust hoods above equipment doors on the clean sides of units to remove excessive steam and hot air when doors are opened to remove clean materials after cycles are completed. Autoclaves also need canopies on the soiled side because materials are removed from that side occasionally. Generally, canopies are not needed on the soiled side of tunnel cage washers and rack washers because materials are typically removed only from the clean side. Chapter 22, Section 22.3.2.3 and Chapter 32, 32.10 provide more information on local exhaust hoods, devices, and systems in cage-washing facilities.

Cage-cleaning personnel do not normally move from dirty to clean sides without a change in clothing. At minimum, one person operates on the dirty side, while another person(s) operates on the clean side. Adequate area should be provided on both the soiled side and the clean side of cage-washing facilities for staging racks of cages prior to and after cleaning, and prior to sterilization.

In minimum small animal laboratories, where volumes of cages that need cleaning daily are low or where there is not sufficient space for a tunnel washer, cage wash rooms should be located on the soiled-side of the animal laboratory. There, cage washing may be done manually in large sinks or in small single-door washers.

When sterilized cages and animal feed are required, such as for a barrier facility, a two-door, pass-through sterilizer should be used, where clean cages and unsterilized feed bags are loaded on the dirty side and sterilized cages and feed bags are removed in the clean side within barrier animal laboratories.



KEY

1	Cage Wash Storage
2	Clean Cage Processing
3	Soiled Cage Processing
4	Bedding Storage
5	Animal Feed Storage
6	Cage/Rack Washer
7	Tunnel Washer
8C	Emergency EW & SS
8D	Fire Extinguisher
9	Feeder Bottle Filler
10	Bedding Change/Dump Station
11	Hose-Down Booth

FIGURE 22-4. Cage wash facility layout for moderate-size animal laboratory.

22.2.7.4 Sterile Surgery Suite. Under current NIH and AAALAC guidelines, provision of sterile surgeries for small facilities holding only research rodents is not required for AAALAC accreditation. However, research protocols and experiments may be best performed under sterile conditions provided in sterile surgeries. Sterile surgery facilities are arranged in suites with an animal preparation room, surgeons' scrub room, sterile surgery theatre, and postoperative recovery area. Animal preparation rooms and postoperative recovery facilities and can be combined in the same space, if operating schedules and protocols are established to maintain adequate and humane care of animals pre- and

postop. Sterilization and surgical equipment can also be located within animal preparation/ postop recovery rooms. This multifunctional approach leaves a minimum of three separate spaces: animal preparation/ postop recovery laboratory, surgical scrub room, and operating room(s).

1. Animal preparation/postop recovery laboratories require sufficient area for two persons to work with animals, and load and operate sterilization equipment. Open floor area is needed for a laboratory cart(s) used to transport animals, to turn around and park it. These laboratories need stainless steel tables or countertops upon which animals are shaved and prepared for surgery. Supply storage and laboratory sinks are required. Animal preparation laboratories, used for postoperation recovery, need additional area to keep recovery environmental chambers or cages where animals can be observed and held until they are able to return to normal housing. Sterilization equipment may be a bench-top unit for sterilizing surgical instruments, or a floor-mounted autoclave if surgical packages are sterilized as well as instruments.
2. Scrub rooms are small anterooms with surgical scrub sinks, at which surgeons wash their hands and gown before entering sterile surgeries. Scrub sinks have hands-off operation of water valves, either with infrared sensors or knee-operated levers. Foot-operated faucets are not recommended because of strict cleaning considerations. There may be a shelving rack to store sterile surgical gowns if no other facility is available.
3. Surgeries for small rodents require area for one or more small operating tables in the room or a stainless steel countertop upon which sterile operations are performed, and area for a minimum of two persons to work. Ceiling-mounted operating room multihead lights on adjustable arms are installed above operating tables. If animals are anesthetized with inhaled agents, area for anesthesia machines and scavenging systems are required. In addition, area may be needed for mobile racks of monitoring and control instruments around the operating tables. If surgeries are used for teaching or training purposes, large windows are installed to allow students to observe work without compromising sterility in surgeries.

22.2.7.5 Necropsy Laboratory. Animals are brought to the necropsy laboratory for evaluation on the cause of illness or death, and if required, euthanized then examined. Necropsy is important for maintaining the health of research animals because necropsy can confirm an outbreak of disease. Necropsy laboratories require adequate space for two persons to work. Major equipment needed includes a necropsy table with water source and drain, BSC for examination and dissection of deceased animals, a refrigerator for temporary tissue specimen storage, and microscopes on vibration-isolation tables or countertops. A freezer should be convenient to necropsy laboratories, dedicated to temporary storage of carcasses.

Laboratory furniture includes general-use benches for preparation work, a low counter or desk for data entry, and storage for supplies. Piped services may include vacuum or gas. A laboratory sink(s) and a separate hand-washing sink for personal hygiene are required. Necropsy laboratories should be equipped with an emergency eye wash fountain and deluge shower because caustic and irritating chemicals such as phenol and formaldehyde may be used. Ceiling-mounted procedure or operating room light fixtures need to be mounted directly above necropsy tables.

Necropsy tables may be a down-draft type to capture odors. Slot exhaust devices may be designed and installed at standard necropsy tables. In Chapter 32, Section 32.10 the design of slot exhaust hoods is described. Chemical fume hoods may be required if perfusions are commonly performed to preserve tissues with formalin or other preservative chemicals. According to the volume of necropsies performed per day, additional veterinary technicians and more than one necropsy table or BSC may be required to safely handle the workload; these factors require that the laboratory area increases commensurately. Except for very small animal facilities, tissue preparation and histology activities would normally take place in laboratories separate from and outside of animal laboratory facilities.

22.2.7.6 Animal Receiving and Shipping Facility. Jurisdictions having authority normally require separation of animal receiving and general loading facilities by a physical barrier, such as a wall, if they are adjacent. In animal laboratories' receiving and loading area, if multiple spaces are available, one space for parking a dumpster dedicated to collection of animal facility waste material should be considered. Automated soiled bedding systems are available that transport soiled materials from the soiled side of the cage-washing area through a sealed conduit directly into a sealed tank at the loading dock. These systems reduce the spread of soiled particulate and evaporation of urine within animal laboratories, which in turn reduces exposure to rodent allergens for animal laboratory personnel.

A second truck space can be used for delivery of animals and animal supplies and vans for transport of soiled and clean cages, if cage-washing facilities are not in the same building as the animal laboratory. It is desirable to provide a receiving room immediately connected to the receiving dock, to inspect arriving animals and their shipping records, to remove packaging, and to place animals in clean cages prior to transporting them to quarantine facilities. There are clean bedding delivery systems that can be installed near the clean receiving zone. Bedding is automatically transported mechanically or pneumatically into cage preparation facilities.

22.2.8 Floors, Walls, and Ceilings

Install impervious, monolithic floors, walls, and ceilings constructed of materials and finishes resistant to cracking and damage from washing detergents and disinfectants, including chlorine-containing compounds. Walls and floor structure as well as finishes must withstand very rough treatment because of the large racks and carts that will be rolled through corridors and holding rooms, banging and gouging surfaces.

Many animal facilities do not have windows to the exterior to enhance security. Personnel facilities and break rooms on exterior walls may have windows. Corridors within animal laboratories may have windows if views in are not possible from adjacent buildings or exterior circulation pathways. This is possible if animal laboratories are on top-floor locations. If there are windows, they should have metal frames, resistant to damage from moisture and mildew that are permanently closed to lock out pests. Animal-holding rooms should not have windows because they are equipped with automatically controlled lighting cycles.

Exterior and interior doors into animal laboratories must be animal-proof when closed to prevent the entry of wild species (attracted by the easy availability of food) and loss of loose laboratory animals.

All penetrations must be completely sealed for utilities (electricity, water, drains, fire sprinklers, heating and ventilating ducts, etc.) to eliminate harboring places for vermin. It should be kept in mind that application of insecticides in active animal colonies is often prohibited because of the unknown influence these poisons may have on the outcome of experiments then underway. Therefore, it should be accepted from the start that the only useful vermin control program is strict prevention of infestation. This is one of the reasons why an isolated quarantine room(s) is essential to prevent the introduction into the main animal colony of infected and infested animals. Some experts in pest control recommend applications of boric acid in wall voids during construction or renovation to reduce cockroach problems.

Animal laboratories require impervious surfaces and structural joints that are sealed to become vermin-proof, easily cleaned, and decontaminated. Walls should be monolithic and made of washable and chemical-resistant plastic or composite material panels, or coatings of baked enamel, epoxy, and polyester on standard wall construction. Floors also must be highly durable and washable with harsh cleaning and disinfectant agents. Monolithic floor coverings should be carried up minimum of 8 in. (0.2 m) of the wall with coved, gently rounded joints to prevent accumulations of dirt and wastes in the corners. Cove bases, integral with the flooring material, allow more thorough cleaning and use of washing equipment by protecting wall finishes. Corridors subject to heavy traffic from the transportation of cage racks and hand trucks moving feed and wastes must be constructed of materials resistant to wear, cracking, and frequent washing with detergents and disinfectants. Smooth, hard-surfaced concrete and neoprene terrazzo are often recommended for floors, but no ideal floor construction method or material can be identified as totally trouble-free; frequent maintenance and repairs are required. Quality installation of the slab beneath strongly affects the durability and performance of all flooring materials. Floor slab strength, installation method, curing, and thorough drying affect slab performance.

Bumper guards (or rails) on walls in corridors and animal holding rooms will go a long way toward maintaining a sanitary and vermin-free animal laboratory. Bumper guards prevent cage racks and handcarts from colliding with the walls, gouging surfaces, and scratching or rupturing monolithic wall coatings.

Floor drains are not essential in animal rooms housing rodents. Some veterinarians experienced in rodent care believe that moisture associated with the use of floor drains for cleaning purposes and drain traps, which grow bacteria, are detrimental to small animal health. In animal facilities that include holding for animal species larger than mice and rats, drains may be required to manage animal waste and room cleaning. Drains of sufficient diameter and flow capacity are required in cage washing and sterilization zones.

Standard suspended acoustic ceiling tiles in metal grids hide from view the many services to the laboratory and produce a pleasing, finished appearance, but they represent a serious impediment to pest control. Solid gypsum wallboard ceilings with washable coatings or composite panel ceilings are preferred. Solid ceilings require access doors for inspection, adjustment, and repair of heating and ventilating controls, valves, and

ducts, and water and electrical services, should it be necessary to run these services above animal holding rooms at all. Access doors should have gaskets of neoprene or other material on all edges to close gaps to deter vermin from entering holding rooms. Successful designs arrange utilities and ducts above corridor ceilings where metal access doors allow servicing. Animal-holding room ceilings are then free of these encumbrances.

22.3 HEATING, VENTILATING, AND AIR-CONDITIONING

22.3.1 Introduction

Animal laboratories require rigid and reliable control of temperature, humidity, and air movement in animal rooms at all times to provide optimal conditions for the health and growth of the species housed therein. To understand the complexities of HVAC design of animal laboratories, we recommend that design engineers use computational fluid dynamics (CFD) methods to ensure reliable and efficient HVAC systems design. The NIH outlines the use of CFD in the design of HVAC for animal laboratories using micro-isolator caging systems (NIH, 1998).

In addition to a need for better than usual HVAC control systems, alarm systems are essential to alert responsible personnel to a system failure long before conditions deteriorate to a level that would affect the animals adversely. The importance of alarm systems to signal HVAC malfunction will be in direct proportion to the duration of the animal experiments that will be conducted. Standby power to operate HVAC and its control systems is required by National Research Council guidelines (NRC, 2010). When animal stress from unfavorable environmental conditions must be avoided at all costs, standby HVAC equipment as well as emergency power will be needed. Otherwise, portable cooling or heating equipment can be brought in temporarily (NRC, 2010).

Negative-pressure differentials between animal rooms and the remainder of the building housing the laboratory must be maintained to avoid spread of unpleasant animal odors and allergy-producing dander to areas outside the animal laboratory. Within animal laboratories, pressure differentials should be maintained so that air flows directly from clean areas into dirty areas, never the reverse.

As a rule, air should not be recirculated from animal rooms; it should be discharged to the outdoors, usually after filtration that typically occurs in holding rooms to facilitate regular cleaning or replacement of filters. The need for filtration of exhaust air should be evaluated for each case and will depend on the activities within the facility, and local rules and policies.

TABLE 22-4. Range of Dry Bulb Temperature by Animal

Animal	Dry Bulb Temperature			
	Degrees C		Degrees F	
	low	high	low	high
Mouse, rat, hamster, gerbil, guinea pig	18	26	64	79

TABLE 22-5. Heat Gain Values for Common Rodents

Rodent	Weight Grams	Heat Gain Kcal/h	Heat Gain Btu/h
Mouse	21	0.403	1.599
Hamster	118	1.470	5.833
Rat	250	2.581	10.242
Guinea Pig	350	3.322	13.182

Source: ILAR News, Vol. XIX, No. 4, 1976, National Academy of Sciences, "Long-Term Holding of Laboratory Rodents", Institute of Laboratory Resources.

22.3.2 Criteria

The HVAC requirements for animal rooms are contained in publications by the NRC (2010) and the National Institutes of Health (NIH, 2009) (similar agencies in other countries). For laboratory rodents, dry bulb temperature should be between 65° and 79°F (18° and 26°C) and relative humidity between 35% ± 5% RH (NRC, 2010; NIH, 1998, revised May, 2010). Table 22-4 shows recommended dry bulb temperatures. The number of air changes per hour (ACH) for animal rooms is determined in part by the total animal sensible heat contribution to the environment. Heat gain values for commonly used rodents are shown in Table 22-5 Generally, 10–15 ACH will be needed for animal care rooms containing large numbers of rodents housed in conventional cages. If holding rooms are densely populated and animals are housed in micro-isolator cages, ventilation rates as high as 20–25 ACH may be required. Micro-isolator cage tops have filters that drastically reduce airflow into cages (NIH, 2012). If ventilated caging systems are used, lower ventilation rates may be adequate. Very high ventilation rates are undesirable because of the difficulty of providing a draft-free air supply. New types of large-area perforated ceiling diffusers are designed to solve this problem. Displacement air systems that flood the floor area with supply air and remove it through ceiling vents reinforce natural con-

TABLE 22-6. Room Ventilation Recommendations for Common Rodents

Rodent	Weight Grams	Ventilation	
		m^3/h/animal	ft^3/min/animal
Mouse	21	0.25	0.147
Hamster	118	0.69	0.406
Rat	250	1.38	0.815
Guinea Pig	350	1.97	1.150

Source: ILAR News, Vol. XIX, No. 4, 1976, National Academy of Sciences, "Long-Term Holding of Laboratory Rodents", Institute of Laboratory Resources.

nective flow induced by the animal heat and provide good air distribution around and through racks with conventional open-top cages. Room ventilation requirements for commonly used rodents are shown in Table 22-6. If CFD analysis performed for animal holding rooms proves that lower air exchange rates are suitable for the species, cage, and rack types proposed for these rooms, then HVAC systems may operate at lower air exchange rates (NIH, 2012). Caution should be taken before considering lowering system design capacities because use of holding rooms change, as do caging and rack systems. Changes may require higher, standard air exchange rates.

Air-conditioning of animal quarters is a complex consideration involving temperature, relative humidity, and air exchange rates, each of which is known to influence the physiological well-being of the animals, irrespective of whether these effects are exerted independently or in combination. Control of environmental conditions in animal facilities may affect not only the usefulness of the animals as research subjects, but also the quality of the data obtained from the research efforts (NRC, 2010). Micro-isolator cages and individually ventilated caging systems, described in Section 22.3.3, usually provide adequate filtered ventilation for most research purposes.

Each animal species has an ideal air temperature, air humidity, and air movement rate that promote health and longevity. Drastic average deviations and substantial random variations from these ideal conditions will adversely affect longevity of the animals. The seriousness of uncontrollable environmental conditions within animal laboratories will vary with the normal animal holding period. For acute toxicity experiments, as for determining LD_{50} data, longevity greater than a week is seldom important. However, for low-level chronic toxicity exposure experiments, extreme longevity of the experimental animals is critical to success, and every possible effort must be expended to promote the health and safety of animal colonies for the duration of long experimental periods.

Breeding animals are also extremely sensitive to environmental changes. They may lose or destroy their young when under stress. Health, safety, and reduction of stress have been promoted by individually ventilated cages mounted on self-contained multiple cage rack systems that continuously bring filtered particle-free air to each cage, described in Section 22.3.2.1. These arrangements were originally developed to maintain sterile conditions for holding transgenic mice, but their use for less-valuable animals can be advantageous as explained in Section 22.2.2.

For optimal HVAC conditions, it is necessary to maintain the interior laboratory climate with as little variation as possible; therefore, windowless holding rooms are highly recommended and may be necessary to maintain correct light cycles for certain animal species. However, animal handlers may become dissatisfied with working conditions when they cannot see the outdoors, even if it is only through sealed window glass. Animal laboratory designs that include windows that bring natural light into personnel break rooms, offices, support laboratories, and training rooms are highly desirable.

Animal holding rooms should be capable of an adjustable temperature range between 65°F and 84°F (19–29°C) and a relative humidity range between 35% and 70%. Current design conditions require maximum 70% RH for guinea pigs and other large animals (NRC, 2010; NIH, 2012). In animal holding rooms containing many closely spaced cage racks, with open-top or micro-isolator cages, uniform ventilation rates and temperatures from top to bottom and side to center are difficult to maintain. Special HVAC arrangements and diffusers may be needed to ensure that every animal in conventional open-top and micro-isolator filter-top cages will be maintained continuously under the preselected environmental conditions. The overall temperature and relative humidity maintained in animal holding rooms may not be indicative of conditions inside the cages. Therefore, the arrangement of cage racks and cages must be considered carefully to ensure a high degree of air circulation around individual cages at all times. Racks with individually ventilated cages are not subject to stringent arrangements, as described in Section 22.2.2. However, consideration should be given to the additional heat load generated by motors and fans that operate individually ventilated cage racks.

Because of animal odors and risk of contamination, it is not advisable to recirculate air from animal rooms unless special air-cleaning facilities are provided, as discussed in Chapter 31, Section 31.2.3. Therefore, all of the ventilation air should normally be discharged to the

atmosphere after a single pass through the animal quarters. It may be necessary to filter the air before discharge to remove animal fur and dander, bedding fragments, and feces. These filters are explained in Section 22.3.3.1. When no toxic substances are involved, medium-efficiency filters are usually adequate and filters may be installed directly in animal holding rooms. Certain procedures with animals should be conducted in BSCs or in conjunction with biosafety laboratories, as described in Chapter 32, Section 32.9 and Chapter 14, Section 14.3, respectively.

22.3.2.1 Quarantine Room. These rooms are technically outside the perimeter of animal laboratories. However, the care and maintenance of steady environmental conditions for the animals housed in quarantine have the same requirements as within animal laboratories.

22.3.2.2 Procedure Rooms. Animals are not usually held overnight in procedure rooms, but they may occupy them for several hours, so environmental conditions (temperature, humidity, and ventilation) must be maintained at the same standard as in holding rooms. Procedure rooms may have BSCs, partially or fully exhausted to the building exterior according to the chemicals used. If inhalation anesthesia is used for procedures, an anesthesia scavenging exhaust is required. If other hazardous agents or organic solvents are used, slot hoods, enclosures, or canopy hoods may be used to capture fumes. Guidelines for these devices appear in Chapter 32, Section 32.10.

22.3.2.3 Cage Washing and Sterilization. This equipment should be ventilated through welded stainless steel or aluminum ducts to avoid corrosive attack by the cleaning chemicals. Capture hoods should be provided for washers and sterilizers to extract steam and vapors. ACGIH provides guidelines for hood design (ACGIH, 2010a) and these hoods are described in in Chapter 32, Section 32.10.

22.3.2.4 Sterile Surgery Suite. Ventilation of these facilities should be designed comparable to human operating rooms. Ventilation rates of 10–15 ACH are required, and HEPA-filtered supply air may be required. Addition of HEPA filters increases static pressure and will possibly increase energy use. An anesthesia gas scavenging exhaust system is required where inhalation anesthesia agents are used. Surgical suites should be positively pressurized with airflows moving out of suites, toward the animal laboratory corridor to avoid contamination from the animal holding and servicing areas. Within sterile surgery suites, airflows go from surgeries into connecting surgical scrub rooms and then to animal preparation/ postop recovery laboratories before leaving the suite.

22.3.2.5 Necropsy Laboratory. Because animals do not leave this laboratory alive, sterile conditions are not required. Necropsy laboratories may be equipped with down-draft exhaust necropsy tables to contain odors and BSCs or other ventilated tissue trimming stations for dissections. Exhaust from down-draft tables may be combined with the general animal laboratory exhaust system. BSCs may be partially or fully exhausted to the building exterior, dependent upon the chemicals used. Chemical fume hoods may be installed in necropsy laboratories to perform perfusions with formaldehyde-containing tissue preservatives, as shown in Figure 22-5.

22.3.2.6 Animal Receiving and Shipping Facilities. Animal receiving rooms need to maintain constant temperature and humidity conditions within the limits required in animal holding rooms for rodent species. Live animals are held there temporarily, ideally only for short periods of time and not overnight. Animals are normally transferred into quarantine rooms or they may go directly to holding rooms. If no animals are present, night set-back on ventilation rates may be possible.

Receiving and shipping dock facilities may be outside building enclosures where temperature control may not be possible. Seasonal heating devices, such as unit heaters, may be installed to reduce build-up of ice on the working platforms of docks. Animals in boxes should be moved through dock facilities quickly, so temperature shock will not occur.

FIGURE 22-5. View of slot exhaust dissection stations in necropsy laboratory.

22.3.3 Performance and Testing of Ventilated Caging Systems

The use of rodent caging systems, which provide individually ventilated isolator cages, is described in Section 22.2.2. These systems have been shown to considerably improve the micro-environmental conditions in which rodents live. Ventilated caging systems have also been shown to enhance containment capability at the cage level, reducing the opportunity for cross-contamination.

Individually ventilated caging systems are available from a number of manufacturers and in a variety of configurations with regard to the location and mounting method of integral and attached fan and motor equipment. In general, these systems provide filtered air directly into each cage, thereby pressurizing it. Caging systems may be purchased with an exhaust system that scavenges air as it exits from the juncture of the cage top and bottom and the cage top filters. Exhaust air is subsequently filtered and released back into the room, or may be released directly into the animal laboratory exhaust system. Other caging systems provide an exhaust port at each cage to control the amount of air exhausted and exits directly into the animal laboratory exhaust system. Exhaust options are commonly purchased due to concerns about the increase of allergens released from ventilated cages into the room environment, which increases the risk of allergies in personnel. Exhaust scavenging may also increase the potential of cross-contamination.

Optimal ventilation rates for individually ventilated cages have not been determined. Rates differ between systems; over time, manufacturers have modified rates in newer models. Whereas increased ventilation rates may have the advantage of decreasing levels of ammonia within cages, carbon dioxide, and humidity levels, they also increase the velocity of air to which animals are exposed. Chilling, especially of hairless mouse strains and neonates, and suspension of particles in the airstream may lead to detrimental effects on the health and normal behavior patterns of the animals. The shape of the wire grid lid, the presence of feed, and the water bottle may dramatically impact ventilation patterns within cages. These factors may contribute to differences reported between systems with respect to accumulation of micro-environmental contaminants.

It is still unclear whether ventilated caging systems equipped with exhaust scavenging are suitable for use with hazardous agents. When air is exhausted directly into animal laboratories' exhaust system, they may be suitable for use with some volatile chemicals or when rodents are exposed to moderately pathogenic agents.

There is no standard method of testing these systems. However, NIH has conducted computational fluid dynamic and physical studies of ventilated caging systems (NIH, 2012). Several other attempts have been made to critically evaluate these units (Bilecki, 2006; Hogland, 2001; Tu, 1997). A careful evaluation of the design and the air exchange rates in each cage should be made and acceptance criteria established. This should include volume flow rates for each cage, air velocity in the cage, directional airflow, and containment capability.

22.3.4 Filtration

Exhaust air from animal housing and treatment rooms should be filtered before discharge to remove fur, bedding, and feces. An 85% efficiency filter will be adequate for this service unless the animals are harboring human pathogens. In that event, secondary filtration through HEPA filters will be required in addition to normal filters. If the animals are to be maintained in a germ-free environment, HEPA filtration of all supply air will be required and use of micro-isolator cages is advised. When using trace quantities of especially toxic volatile chemicals in conjunction with biological experiments, it may be prudent to add an efficient adsorber (generally activated carbon) as an additional effluent air cleaning stage, as described in Chapter 31, Air Cleaning.

22.3.4.1 Exhaust Grille Filters. In animal rooms, disposable 85% efficient filters at all exhaust air grilles provide an excellent way to prevent animal dirt, food particles, fur, etc., from entering exhaust ducts. When exhaust grille filters are not provided, exhaust ducts tend to become plugged with debris. This reduces exhaust efficiency and alters the prearranged pressure relationships between areas. With inadequate air exchange, the entire animal laboratory zone tends to become malodorous. Should exhaust ducts become plugged, cleaning operations are expensive, difficult, and time consuming. Generally, animals will have to be moved to some other location while the ducts are being cleaned. Therefore, it is cost-effective to install exhaust grille filters at the outset and to institute a rigorous program of filter maintenance and replacement. In addition, without adequate exhaust filters and maintenance program, the decommissioning of animal laboratories becomes more difficult and expensive.

22.3.5 Controls

Pressure control can be maintained within animal laboratories by providing a constant ratio of supply to return

plus exhaust air with the aid of differential pressure controllers, modulating dampers, fan inlet vanes, or a combination of all of these. Airflow variations should be minimized to support good control of room pressure. Continuous operation of hoods, cabinets, and local exhaust systems is an important aid in maintaining reliable pressure control at all times. For odor control, positive-pressure two-door anterooms to adjacent areas are recommended (Chapter 2, Section 2.2.2.3.3). Specifications for anterooms should comply with those required by the General Services Administration (GSA, 1988).

Temperature and humidity controls, on the other hand, may require a constant volume reheat system. All aspects of controls must be considered before deciding on a final control strategy. Built-in safety aspects should be considered during the design stage. For example, use of N.O. (normally open) control valves on reheat coils should be avoided; otherwise, loss of control signals may overheat animal spaces.

22.3.6 HVAC Systems

In general, a constant-volume terminal reheat (TRM) system is preferred. Zone controls for individual areas are provided by a dedicated reheat unit serving the zone. Humidification controls can also be zoned, but care must be exercised to equip humidifiers with sufficient duct length to provide adequate mixing with air. When adequate duct lengths are not available, central humidification systems should be considered. Packaged room humidifiers and VAV systems should not be considered for application in animal laboratories.

22.3.7 Alarms

Alarms should be provided for automatic watering systems and HVAC systems as outlined in Chapter 1, Sections 1.4.5.2 and 1.4.5.3. An additional alarm should be provided to notify personnel when filters become dust loaded to a critical point. The information on air-cleaning system monitoring instruments and alarms contained in Chapter 23, Section 23.3.2.4 for microelectronics and clean room laboratories also applies to alarm systems for animal laboratories.

22.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

The recommendations for loss prevention, industrial hygiene, and personal safety contained in Chapters 1 and 2, Section 4 apply generally to animal laboratories.

22.4.1 Personal Protective Equipment

Work around animals sometimes results in sensitization to animal dander and other animal products. Should this occur, disposable dust respirators approved by NIOSH will generally relieve the symptoms. They can prevent initiation of allergy if worn as a prophylactic measure. Air-supplied respirators may need to be used in more severe cases of animal allergies. Use of Class II BSCs or HEPA-filtered cage changing stations (see Figure 22-1) during cage changing protects the animal handlers as well as the animals from contamination. Personal cleanliness is essential to avoid infection, and it is recommended that animal laboratory personnel (especially those who care for the animals) wear laboratory coats or coveralls and use gloves. When personnel handle research animals and perform injections, they need special gloves to protect their hands against animal bites, scratches, and needle sticks. These garments should not be taken out of the animal laboratory. Therefore, provision for storage of clean garments and a protocol for safe disposal or laundering of those that become soiled must be delineated at the laboratory design stage. Laboratory coat laundry facilities are best located next to locker rooms and should not be located within a cage-washing room. Area for racks should be provided within personnel locker rooms or within entry airlocks to store daily supplies of clean PPE. Storage rooms within animal laboratories also need area to store bulk quantities of disposable PPE supplies.

Convenient face- and hand-washing facilities are needed inside animal laboratories for maintaining personal hygiene. Showers and clean clothes locker rooms for animal care personnel are highly recommended. Personnel need to rinse off animal dander and airborne odors that cling to clothing and skin. Emergency eye wash fountains are required in some rooms of animal laboratories including cage wash and sterilization facilities, procedure rooms, and necropsy laboratories. Necropsy laboratories also require emergency deluge showers because phenol and formaldehyde-containing chemicals are used there.

Wall cabinets containing first-aid materials to treat animal bites and scratches, cuts and punctures from sharps, and other injuries should be provided in several convenient and highly visible locations: procedure rooms, animal preparation/postop recovery laboratories, cage-washing room, personnel break rooms, locker rooms, and in major corridors outside animal holding rooms. These are locations where caretakers

and researchers handle animals and where there may be broken glass. Safety officers should be consulted.

22.4.2 Fire Suppression

Sprinkler systems intended for animal holding rooms must be designed for rooms that are likely to contain very tall cage racks, or racks with top-mounted ventilation equipment. Crowded arrays of tall cage racks tend to shield sprinkler heads from prompt exposure to heat and will interfere with the normal spread of the water spray patterns, resulting in an uncontrolled fire hazard. Additional sprinkler heads placed in animal holding rooms where there is likely to be permanent clear floor space, may be required. Smoke detectors are recommended in animal quarters to provide early detection and protect the animals from smoke or other toxic products of combustion.

Chemical extinguishers, fixed or portable, are likely to be an additional hazard to animals. Veterinarians and animal health specialists should participate in the selection of the type of extinguishers to use. If only water extinguishers are used, only Class A hazards should exist in the room (wood, paper, cloth, other normal combustibles). For this reason, Class B hazards, flammable and combustible liquids, should be strictly controlled. Chemicals should be stored in metal containers within officially approved fire-resistive cabinets. Class C hazards are electrical and should pose only a normal threat of fire in animal laboratories.

22.4.3 Decontamination

It is sometimes necessary to decontaminate entire animal laboratories when stubborn animal diseases take over. Depending on the organism of concern, gaseous formaldehyde or vaporized hydrogen peroxide (VHP) decontamination may be required. It is normally conducted by heating paraformaldehyde to release formaldehyde vapors into a space that has been thoroughly isolated to prevent escape of formaldehyde vapors to adjacent occupied areas. Compact, mobile VHP generators are manufactured and can be conveniently operated from outside the animal laboratory. NSF International Standard Number 49 contains a recommended microbiological decontamination procedure (NSF, 2010). For less-critical types of decontamination, use of lower-toxicity chemicals, such as Alcide ABQ, may be satisfactory.

22.4.4 Waste Material Handling

Animal laboratories produce several types of regulated and unregulated waste: soiled bedding from healthy animals, food waste, and trash. The largest volume of waste generated in animal laboratories is soiled bedding materials. If soiled bedding is from cages with healthy animals, it may be composted or go into landfills. If soiled bedding is from cages with sick animals, it can be disposed of by incineration. Regulated medical waste generated in animal laboratories may include soiled bedding from sick animals, animal carcasses, blood, and tissues, and sharps. Other regulated waste is chemical waste that may be generated in cage washing and procedure rooms. Radioisotopes may be injected in animals as part of research procedures. Animal tissues and carcasses may still be contaminated with radioactive materials and must be disposed of properly.

Provisions for short-term storage of wastes discussed above should be considered early in the design process. Long-term and agency-related storage should be designed following the recommendations of Chapter 27.

22.5 SPECIAL REQUIREMENTS

22.5.1 Illumination

Certain animal species, including mice and rats, follow a diurnal pattern of nighttime activity and daytime rest. For these animals, provisions must be made for reversing the usual illumination sequence by installation of automatic time-clock controllers for each holding room.

Light levels of about 325 lux (30 ft^3) about 3.3 ft (1.0 m) above the floor appear to be sufficient for animal care. These levels do not cause clinical signs of phototoxic retinopathy in albino rats (Bellhorn, 1980); higher illumination levels may cause damage to their pigmentless eyes.

Fluorescent or LED lighting is recommended because it is efficient and has less effect on HVAC requirements than incandescent lamps. However, discussion with veterinarians on the color range of fluorescent lamps is recommended. Standard lamps may not be beneficial or may be harmful to certain animals. High-intensity lamps and special ceiling- or wall-mounted fixtures are required in procedure and sterile operating rooms.

22.5.2 Noise and Vibration Control

Most animals are susceptible to audible and electronic noise; breeding colonies are particularly disturbed by vibration. Appropriate shielding is necessary to eliminate these noises when they are present. Vibration also affects small animals adversely and should be minimized by providing vibration isolation on moving

machinery such as elevators, fans, and compressors within the building or near animal laboratories.

22.5.3 Emergency Electrical Power

Emergency power should be installed, and the supply and exhaust fan system should be connected to it, as well as automatic watering system components and monitors. All alarm and temperature-control systems should also be connected to the emergency power source.

22.5.4 Security

Designers and managers of animal research laboratories need to consider methods of isolating the animal quarters and laboratories from the general public. Door key, card lock, and biometric security systems are frequently used for this purpose. The security considerations discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1 should be reviewed for specific applicability.

23

MICROELECTRONICS AND CLEANROOM LABORATORIES

23.1 DESCRIPTION

23.1.1 Introduction

A cleanroom laboratory is a specially constructed and tightly enclosed work space with modulating HVAC control systems to maintain design standards for (1) a very low concentration of airborne particulate matter; (2) constant temperature, humidity, and air pressure; and (3) well-defined airflow patterns. Cleanrooms are classified by particle count per cubic foot of air. Six levels of cleanliness (referred to as *classes*) are recognized in cleanroom practice. It is important that the level of cleanliness to be maintained is determined from the beginning of the design process because selection of structural materials, HVAC services, air filters, and cleanroom layout and furnishings will be dictated by the cleanliness class selected. The cleanliness designations derived originally from Federal Standard 209D (GSA, 1988) have been revised and now are superseded by ISO 14644-1 Part 1: Classification of Air Cleanliness (ISO, 2001); and ISO 14644-2 Part 2: Specifications for Testing and Monitoring to Prove Continued Compliance with ISO 14644-1 (ISO, 2000). These versions are considered the current ANSI standards in the United States and are shown in Figure 23-1 and Table 23-1. It can be seen that there are now nine classes of cleanliness that are designated based on the number of particles per cubic meter of six different size particles. Table 23-1 shows that there are different counts allowed for 0.1, 0.2, 0.3, 0.5, 1.0, and 5.0 μm particles for each class. Although untreated atmospheric dust usually has a log-normal size distribution, it is not likely that it will remain so after several stages of filtration. Therefore, although Figure 23-1 shows log-normal size distributions for each class, the data points mean that the designated sizes should not be exceeded regardless of the shape of the observed particle-size curve. The cleanliness class may be verified by measuring one or more of the sizes designated by a data point in Figure 23-1 or in Table 23-1. Federal Standard 209D contains statistical criteria for dust counting. Other sources are Federal Standard 209E, "Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones" (FS, 1992) and British Standard 5285, "Environmental Cleanliness in Enclosed Spaces" (BS, 1989). The National Environmental Balancing Bureau published *Procedural Standards for Certified Testing of Cleanrooms* in 2009 (NEBB, 2009). Cleanrooms designed for particle counts of no more than 10 per cubic foot are becoming common in the microchip industry, and cleanrooms designed for no more than 1 particle per cubic foot of air are considered to be the leading edge of cleanroom construction. This chapter will deal only with Class 100 cleanroom laboratories that permit no more than 100 0.5-μm particles per cubic foot of laboratory air (3500 0.5-μm particles/m^3). The Class 100 term is still commonly used even though the ISO designations are now in effect. However, most of the safety features discussed here can be applied to other classes.

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

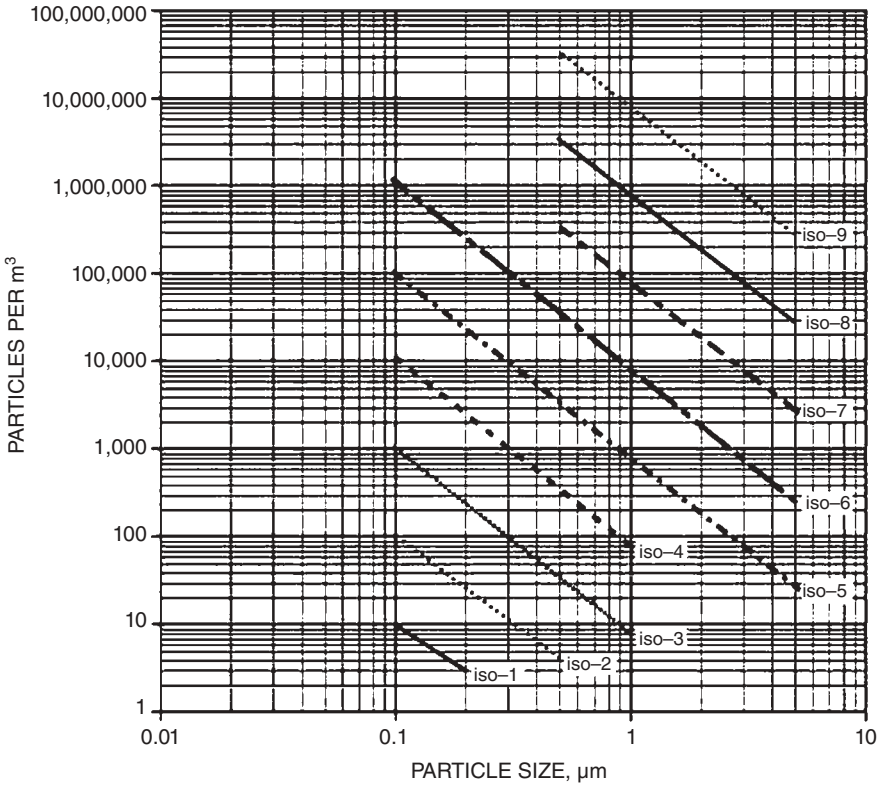


FIGURE 23-1. Cleanliness classification.

TABLE 23-1. Class Limits in Particles per Cubic Foot of Size Equal to or Greater than Particle Sizes Shown

Class	Measured Particle Size (Micrometers)[a]				
	0.1	0.2	0.3	0.5	5.0
1	35	7.5	3	1	NA
10	350	75	30	10	NA
100	NA	750	300	100	NA
1,000	NA	NA	NA	1,000	7
10,000	NA	NA	NA	10,000	70
100,000	NA	NA	NA	100,000	700

[a]The class limit particle concentrations shown in the table and in Figure 23-1 are defined for class purposes only and do not necessarily represent the size distribution to be found in any particular situation.
NA = not applicable.

A microelectronics or semiconductor laboratory is a specially constructed and tightly enclosed work space with modulating environmental control systems to maintain the most strict design standards for a low concentration of airborne particulate matter and maintenance of a preselected constant temperature and humidity. The release of numerous toxic substances associated with the preparation of materials used in semiconductor research and development must also be controlled. Control of airborne particles, temperature, and humidity is accomplished in the manner described in Section 23.3. The controlled space is maintained at positive pressure relative to its surroundings (an exclusion laboratory) to prevent intrusion of unconditioned air. Release of toxic airborne substances must be controlled by local and general exhaust ventilation without upsetting airflow distribution and pressure balance.

The design of buildings in which hazardous materials are used in semiconductor research and development is regulated by some state building codes; design, construction, and operational requirements generally follow those discussed in Article 80 of the California Uniform Fire Code (State of California, 1997). The International Building Code (IBC, 2012) classifies semiconductor fabrication facilities that use hazardous production materials (HPM) as High Hazard Group H-5 structures. These facilities must comply with the H-5 limits of chemicals listed in Tables 307.1(1) and 307.1(2) and provisions of construction of Section 415.8 (IBC, 2012).

23.1.2 Work Activities

The activities performed in a cleanroom laboratory are characterized by a need for extreme cleanliness rather than by the nature of the activities.

Experimentation with, and development of, electronic microchips, miniature gyroscopes and switches for guidance systems, pharmaceuticals, and photographic films and film-processing techniques are examples of the kinds of work that require ultraclean laboratories for successful operations. Chemical treatment, precision machining, solvent cleaning of parts and mechanisms, and use of a wide spectrum of precision measuring devices are activities characteristic of cleanroom laboratories as a class. The cleanroom laboratory may also be used for storage of materials that require a high degree of cleanliness as well as temperature and humidity control in accordance with a variety of experimental operating procedures. The laboratory has access restrictions, with donning of special lint-free clothing and other coverings for hair, beards, and shoes required as an aid to maintaining the required low dust level.

In contrast, the activities performed in a microelectronics laboratory are characterized by a need for (1) extreme cleanliness as defined in Chapter 23, Section 23.1.1, and (2) the exercise of extreme caution while using highly toxic materials in the production and testing of "wafers" and "chips." Activities performed here will include deposition of silicon (SiO_2) on base silicon wafers, etching, cleaning, and measuring the properties of the wafers. Gallium arsenide technology presents more of a health concern than silicon-based technology. This laboratory also has access restrictions with the donning of special lint-free clothing, and hair, beard, and shoe covers before entrance into the work area required as an aid to maintaining the required low particulate levels.

Pharmaceutical laboratories may operate under cleanroom conditions, but use potent compounds. In this case, the issues addressed in Chapter 6, High-Toxicity Laboratory should be reviewed for applicability. Laboratories performing trace chemical analysis may also need to operate in a "clean" environment. In this case, the issues addressed in Chapters 5 and 6 should be reviewed for applicability.

23.1.3 Special Requirements

Cleanroom laboratories may contain multiple rooms, each with different requirements for contamination control. Each room within the cleanroom laboratory should be maintained at a static pressure higher than atmospheric and higher than that in adjacent indoor spaces to prevent air infiltration from less well-controlled areas. Differential pressures should be maintained between adjacent rooms of the multicompartmented cleanroom laboratory to ensure airflow outward from the cleanest spaces to those maintained at a lesser standard of air dustiness (see Section 23.3 below). Rooms of simple rectangular shape without projections enhance desired airflow patterns and are easier to keep clean.

The special requirements for a microelectronics laboratory are similar to those for the generic cleanroom laboratory. The specific class of cleanroom needed will depend on the specific activities that will be conducted in it. The major difference is the need for more critical control of airflow patterns between the work area, anterooms, and adjoining areas related to the use of highly toxic materials. Differential pressure zones should be maintained to allow air to flow from the work areas to the anteroom and from the space outside the anteroom into the anteroom. In some cases, two anterooms, one clean and one dirty, may need to be provided. See Chapter 2, Section 2.2.3 for design of anterooms. The remainder of the work area must be sealed to prevent airflow out of the work space into adjoining areas. The reason for this pressure relationship is to prevent flow of unconditioned air (i.e., dirty air) into the cleanroom work area, while at the same time preventing air that might become contaminated with toxic materials from escaping into surrounding occupied areas. In some cases, a pressurized cleanroom using hazardous materials is surrounded by a negative-pressure "corridor" or "area" that is not accessible to the general public. This is sometimes called a *hazardous materials corridor*.

The construction quality control for anterooms is critical. Most contractors will not normally seal the penetrations of piping, conduit, and other building systems, but this must be done in these special spaces. Work surfaces and wall seams are not typically sealed, but they will have to be. Without special attention to these details, neither the desired cleanliness nor the desired pressure relationships will be obtained.

23.1.3.1 Finish Materials. Cleanroom laboratories should be constructed of smooth, monolithic, easily cleanable materials that are resistant to chipping and flaking. The interior surfaces should have a minimum of seams and be devoid of crevices and moldings. Walls should be faced with stainless steel or plastic sheeting, or they should be covered with baked enamel, epoxy, or polyester coatings with a minimum of projections. Ceilings should be covered with metal pans, plastic-faced panels, or plastic-finished acoustical ceiling tiles. Floors should be covered with seamless sheet vinyl or with a poured epoxy application that will form a monolithic surface with a gently rounded cove base. All of these

structural materials should be fire-resistant or treated to acquire this characteristic. Walls and doors should be at least 1-h fire-rated assemblies.

23.1.3.2 Structural Materials. For a microelectronics laboratory as well as other types of cleanrooms, there may be some equipment that requires a vibration-free environment, e.g., individual isolation platforms with structural system stiffness, mass, and local isolation. Common vibrations originate from machines and motors, air jets and convection currents, excessive fluid velocity in pipes, exterior motor-vehicle traffic, and footfalls of people walking normally in corridors and laboratory aisles. Walking is the least predictable source of vibration and is often the most disruptive to vibration-sensitive equipment and procedures. In sensitive areas, corridor floors should be supported independently from the microelectronics laboratory floors from the foundation structure on up. This is an expensive option and should only be used when local isolation of the equipment will not be sufficient. Because of the quantities and nature of toxic materials used for fabricating microelectronics, buildings containing these laboratories should be structured for seismic loads in all locations that could possibly experience earthquakes. Some state and local codes require seismic design.

When renovating a building to install a microelectronics laboratory, a structural assessment should be done early. If the building does not already meet structural requirements for a microelectronics laboratory, it will likely be cost-prohibitive to retrofit adequately.

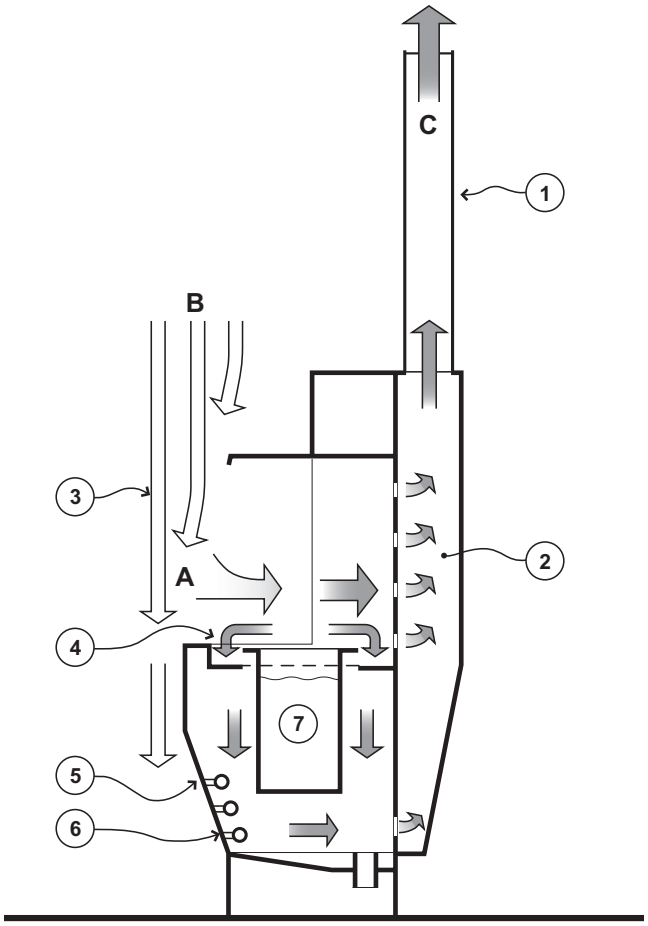
FIGURE 23-2A. View of microelectronics vented wet workstation. (*Source*: Courtesy of Labconco Inc., Kansas City, MO.)

23.1.3.3 Personal Cleanliness. Personnel practices are very important in cleanroom laboratory operations. To ensure cleanliness, personnel should be provided with lint-free smocks, gloves, shoe covers, and head and beard covers; provision must also be made for the garments' storage and disposal. Workers should have available wash areas with soap or lotion containing lanolin to tighten the skin and thereby reduce sloughing of skin fragments. All equipment and materials should be thoroughly cleaned before being brought into a cleanroom laboratory.

23.1.3.4 Laminar Flow Workstations. It often happens that one or only a few operations require more rigorous dust control than can be provided by the selected cleanliness class of the cleanroom. Rather than upgrading the entire cleanroom to accommodate a small but critical operation, it is possible to use individual workstations located inside the cleanroom that will provide the required class of local dust control.

Laminar flow workstations (Figure 23-2A) are self-contained units consisting of a canopied workbench equipped with a fan and HEPA or ULPA (ultra-low-penetration aerosol) filters. Filters are placed above the work surface (vertical flow) or in the rear wall of the work space (horizontal flow) and serve to envelop the entire work area in a flow of particle-free air. The interior of the cabinet will be at positive pressure relative to the rest of the cleanroom, and all of the air introduced into the cabinet will exit through the work opening into the worker's breathing zone. This means that toxic materials must not be used or generated in the horizontal- or vertical-flow workstation. If toxic products will be present, workstations that provide worker as well as work protection (e.g., Class II BSCs) must be substituted for laminar flow clean workstations. In addition, specially designed workstations that provide both product and personnel protection can be designed, as shown in Figure 23-2B. When cleanroom needs are greater than can be accommodated by a laminar flow cabinet, but not large enough to call for a normal room-sized facility, it is sometimes satisfactory to construct a self-contained "small room" cleanroom inside a standard laboratory.

Another method used to upgrade workstations above the cleanroom rating is to install packaged fan and filter units at strategic locations inside the cleanroom. Usually,



KEY

1	Exhaust Duct
2	Exhaust Slots to Negative Pressure Exhaust Plenum.
3	Air Curtain
4	Lip Vent (Around Bath Tank)
5	Water Manifolds
6	Plenum Rinse
7	Heated Bath
□	Clean Air
■	Contaminated Air

AIR FORMULAS

A + B = C

FIGURE 23-2B. Section through a vertical laminar flow cabinet.

these units are mounted in the ceiling directly over a workbench that requires special protection from contamination. A typical fan and filter ceiling unit is shown in Figure 23-2C. Often, clear plastic curtains extending from the filter to the bench top will be used on the sides and back to provide additional confinement of the particle-free zone.

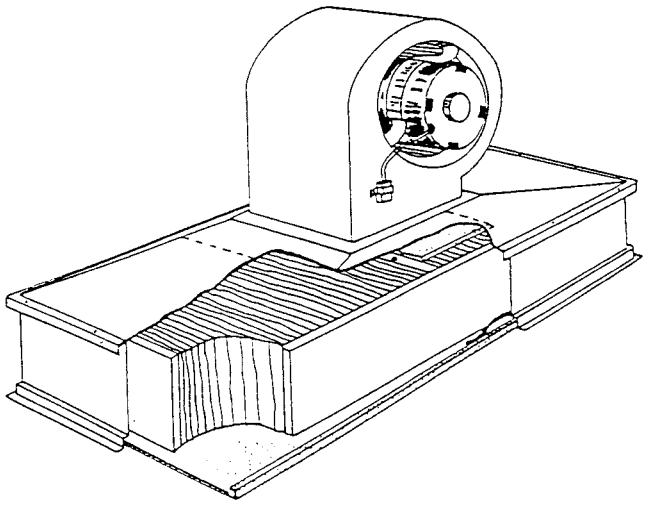


FIGURE 23-2C. Diagram of fan-filter unit. (*Source:* Weber Technical Products, Hampstead, New Hampshire)

23.1.3.5 Auxiliary Ventilation Facilities. The high ventilation rates required to maintain air cleanliness may dictate a need for auxiliary fan rooms. Special attention must be given to their design, cleanliness, and maintenance requirements. See Chapter 18 in ASHRAE HVAC Applications (ASHRAE, 2011) for additional information.

23.2 LABORATORY LAYOUT

23.2.1 Introduction

The layout of a cleanroom laboratory may be a single room with a dust-free air-pressurized vestibule, or it may be a laboratory suite of several separate rooms interconnected by an interior, pressurized corridor as shown in Figure 23-3. For emergency evacuation, the interior corridor should connect to a building egress corridor through pressurized or nonpressurized vestibules. A clean-air-pressurized robing room is an essential adjunct of a cleanroom laboratory. A pressurized vestibule may be used for this purpose if there is adequate space for storage of clothing and installation of a hand-washing sink, a shoe cleaner, and a sticky shoe mat. Otherwise, a separate robing room must be provided in the plan. When a robing room separate from a pressurized vestibule is used, it should be at a higher air pressure than the access corridor, but a lower air pressure than the vestibule and clean laboratory rooms. Access to the clean laboratory room will usually be through an air-blast chamber placed between the robing

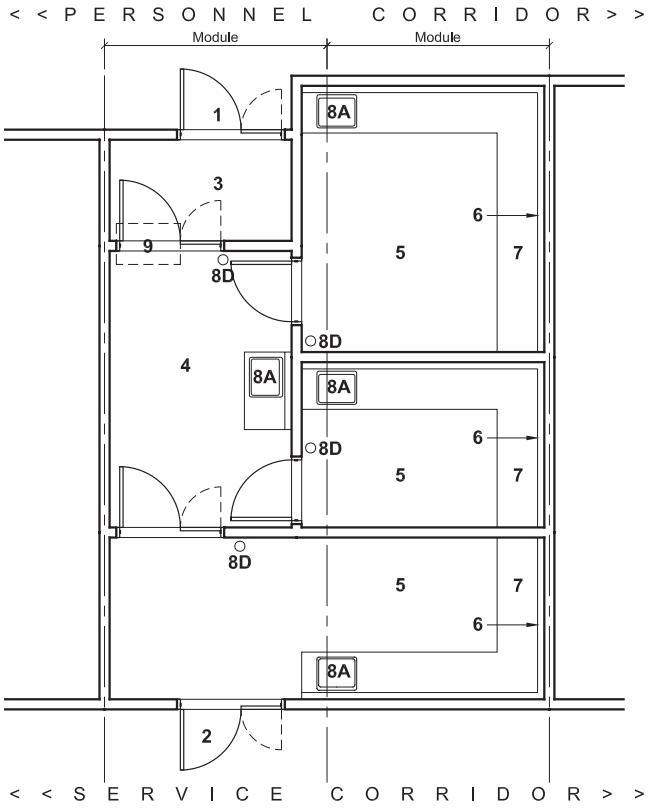


FIGURE 23-3. Layout of a small cleanroom suite.

room and the laboratory rooms. The purpose of this chamber is to blow lint, skin fragments, hair, and so forth, from personnel before their entry into the cleanest areas of the suite. The minimum dimension of a clean laboratory room work space module should be 7.5 ft (2.4 m). A typical small cleanroom is shown in Figure 23-3. Vertical-section views through a class 100 cleanroom laboratory are shown in Figure 23-4. It shows a multifilter ceiling; floor-level return air openings, and the HVAC components needed to service the cleanroom laboratory facility. Very frequently, a cleanroom laboratory suite will be constructed completely inside another structure, such as a manufacturing building or a chemistry laboratory building, and will draw its makeup air supply from the space surrounding it. Makeup air may also be drawn in from the outside through a prefiltering and tempering unit. The recommendations provided in Chapter 1 and 2, Section 2 apply to cleanroom laboratories except as modified in the following sections.

23.2.2 Special HVAC Requirements

The layout of a microelectronics laboratory will meet the same general plan required for a cleanroom. In addition, the access restrictions discussed in Chapter 6, Section 6.2.6 should be considered, particularly the viewing window into the work area. A sample layout is shown in Figure 23-5. The microelectronics laboratory layout is essentially a series of "modules" within a cleanroom. The backside of production equipment and auxiliary equipment, for example, vacuum pumps, gas cylinders, and HVAC equipment, are located in the service areas adjoining the work area.

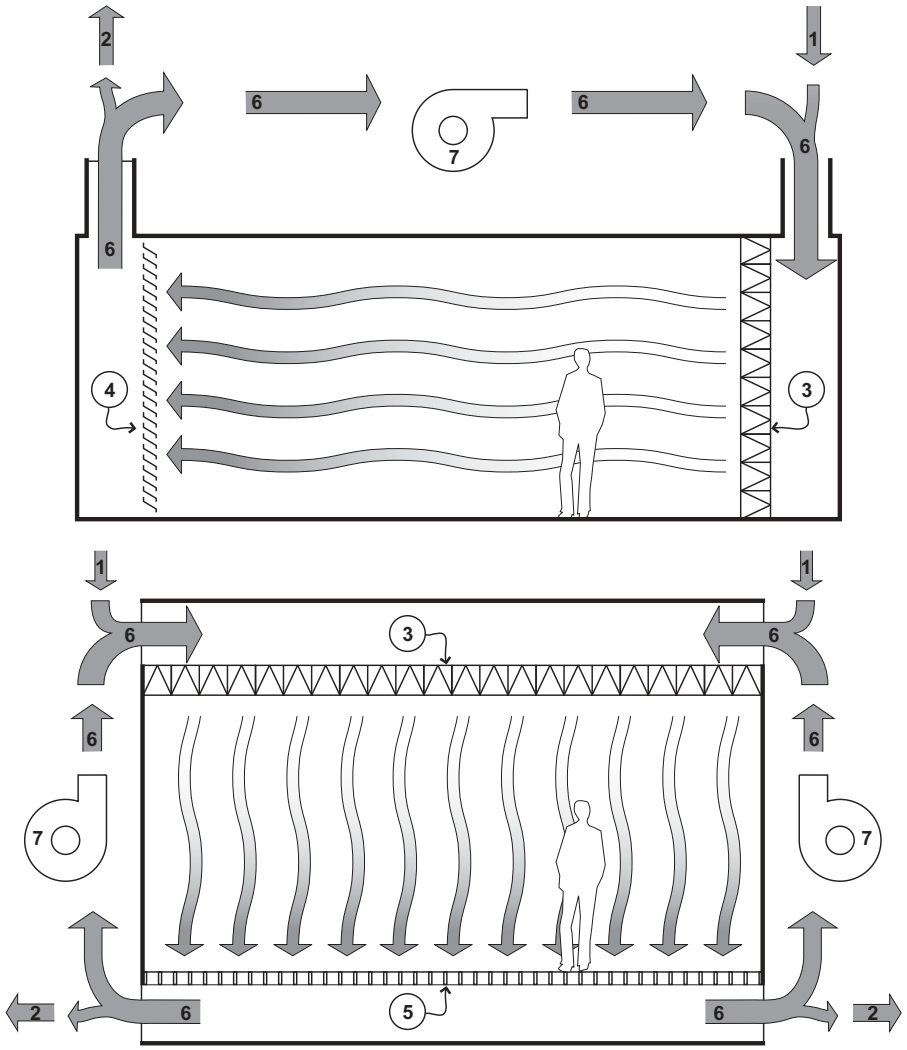
The clean and dirty corridor concept discussed in Chapter 22, Section 22.2.2 may also be applied here. Generally, there is a service corridor that allows access to all utility connections and motors connected to production equipment, plus auxiliary equipment for maintenance and repair, making it unnecessary for service people to enter the clean area.

To meet the general requirement that the laboratory area must be positive to surrounding areas, and that airflow must be from low-hazard to high-hazard areas, the use of a double-shell structure is recommended. This arrangement allows air to flow from the laboratory to the lower-pressure inner space between the double shell and permits air in the adjoining corridors and other spaces to flow into the same inner space that is maintained negative to both. In effect, this becomes a combined exclusion and confinement facility. The inner space should be designed for seismic loading.

An alternative arrangement is to construct some of the mechanical space directly below the cleanroom and to have ventilation ducts and plumbing pipes penetrate up through the floor of the cleanroom, or preferably, through the service chase. This has been done successfully at the Massachusetts Institute of Technology (Demeo, 2000).

23.2.3 Circulation

23.2.3.1 Egress Routes. A minimum of two separate emergency egress routes from each cleanroom laboratory unit is recommended. One of these may be the

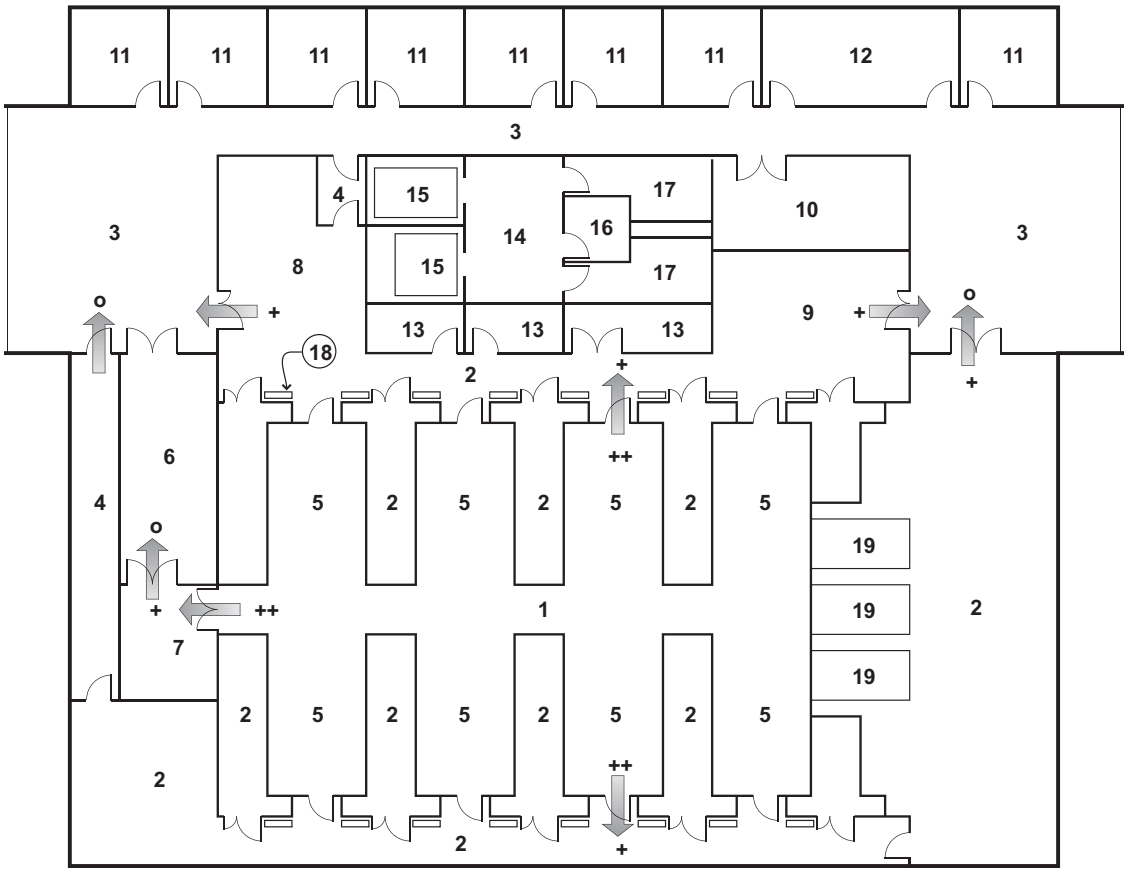


KEY

1	Air Supply
2	Air Exhaust/Return
3	HEPA Filter
4	Exhaust Grille
5	Grated Floor
6	Recirculated Air Loop
7	Fan
□	Clean Air
■	Contaminated Air

FIGURE 23-4. Sections through two cleanrooms, showing laminar air flow: Vertical and horizontal.

normal entrance through the anteroom. The exits should be as far apart as possible and should lead to different fire zones as a safety measure. In addition, there should be no dead-end corridor longer than 20 ft when measured from the centerline of the door of the farthest room to the door that opens onto a building egress corridor. Check applicable codes thoroughly before deviating from this recommendation. Emergency exits may be so labeled and audibly alarmed to deter use except under emergency conditions. An approved crash bar or



KEY

1	Clean Corridor	-	Negative Air Pressure	(-0.05)
2	Semi-Clean Service Corridor	o	Neutral Air Pressure	(0.00)
3	Dirty Corridor	+	Positive Air Pressure	(+0.05)
4	Air Lock	++	Greatest Air Pressure	(+0.10)
5	Microelectronic Laboratories			
6	Gowning Room			
7	Glove Room/Air Lock			
8	Staging Laboratory			
9	Toxic Gas Alarm Room			
10	Supply Room			
11	Office			
12	Secretary/Reception Area			
13	Mechanical Space			
14	Elevator Lobby			
15	Elevator			
16	Janitor's Closet			
17	Toilet			
18	Gas Cabinets			
19	Furnaces			

FIGURE 23-5. Layout of a microelectronics laboratory with multiple work bays.

"California paddle firelock" hardware will allow emergency egress, but limit unauthorized entry. In large cleanroom complexes, emergency egresses may have to be supplemented with crash panels in walls that abut safe passages to the outside. In multibay facilities, it is advisable to have an emergency exit at the end of each bay.

23.2.3.2 Traffic Flow. When particulate contamination from outside the cleanroom laboratory unit is controlled by pressurized anterooms, a one-way flow of traffic from a separate entrance to a separate exit is not essential. However, in situations in which contamination is generated or toxic substances are contained within the cleanroom and must be prevented from leaving the area, a restricted one-way flow of traffic may be needed. This calls for a place in which personnel may don protective garments before they enter a pressurized vestibule giving access to the clean laboratories. A similar space at the exit end of the cleanroom facility that includes wash basins or showers and an autoclave for sterilizing outgoing materials and protective garments may be needed as well. When showers are required, the one-way interior corridor should loop back to the changing room to permit personnel to gain access to their street clothes. The project engineer should discuss with industrial hygiene and safety consultants the degree of cross-contamination that will be allowed between the building air supply and the cleanroom air supply. There are many possible arrangements whereby a series of controlled spaces can be made to meet various air cleanliness and interlocking air pressure gradient specifications. Biosafety laboratories, which have many similar requirements, are discussed in Chapter 14.

23.2.3.3 Interlocking Doors in Ingress and Egress Pathways. It is frequently proposed that access corridors, pressurized vestibules, and anterooms associated with cleanrooms and cleanroom laboratories be provided with interlocking doors so that personnel will be prevented from opening both doors simultaneously and thus inadvertently introduce contamination into clean areas. This is a very dangerous arrangement because under the stress of a fire, explosion, or other emergency in a cleanroom laboratory, it is unlikely that an orderly opening and closing of doors will take place. People can become trapped between locked doors in a vestibule or anteroom under panic-producing situations. It is acceptable to place visual and audible alarms on double-access doors to alert supervisory personnel to failures in dust-control discipline so they may take prompt corrective measures, but no barriers to emergency egress should be permitted.

23.3 HEATING, VENTILATING, AND AIR CONDITIONING

23.3.1 Introduction

The HVAC equipment that will be needed for a cleanroom laboratory depends on the cleanroom class, the temperature and humidity requirements, the need for fume hoods, glove boxes, laminar flow hoods, and spot exhaust hoods or snorkels, and the presence of major heat-generating equipment and activities. The items contained in Chapters 1 and 2, Section 3 apply to cleanroom laboratories and should be implemented. In addition, the following provisions should be considered for inclusion in building and laboratory plans.

23.3.2 Environmental Control

23.3.2.1 Ventilation. Good ventilation is critical in a cleanroom. Large volumes of dust-free air and excellent air velocity and directional control are needed to provide the required cleanliness level. The ventilation system for the cleanroom should be independent of the general building supply system. This is shown in Figure 23-4. When toxic chemicals or infectious microorganisms are to be used, local exhaust, chemical fume hoods, or BSCs will be needed to meet the provisions of Section 2.3. Information on ventilation of toxic gas cylinder storage cabinets is contained in Section 23.5.1 below and in numerous publications (Burgess, 1985; Burton, 1995).

23.3.2.2 Filtration. Filtration is required for all outside supply air (called *primary air)* and for the combined prefiltered outside air plus recirculated air (called *secondary air)* delivered to a cleanroom laboratory. Primary air should be filtered, first, by a roughing filter capable of removing coarse particles and fibers; second, by a prefilter of 85–95% atmospheric dust efficiency; and third, by a HEPA filter having efficiency rated at 99.97% or higher for a monodisperse aerosol of 0.3-μm particles. Secondary air is usually filtered only through HEPA filters. In a cleanroom laboratory, the supply air may be delivered to a ceiling plenum containing a continuous bank of HEPA filters that provide filtered air circulation downward to the floor, where return air grilles will be located. A fraction of the air will be exhausted to the outside or to the building housing the cleanroom laboratory, and the remainder will be recirculated through the HEPA filters. When horizontal airflow is desired, a similar arrangement is possible by building a wall of HEPA filters at one end of the room and locating return grilles in the opposite wall. These ventilation plans are illustrated in Figure 23-4.

23.3.2.3 Room Pressure Balance. Pressure control within the cleanroom should be maintained by static pressure controllers that operate dampers, fan inlet vanes, or a combination of both to maintain the correct ratio of supply to return and exhaust air. To provide close control of room pressure, disturbances to airflow should be minimized by operating fume hoods and local exhaust points continuously and providing air locks between adjoining areas. Thus, cleanrooms are not easily compatible with variable air volume systems. However, with the advent of more advanced ventilation control systems it is possible to do and can be effective in reducing energy use. The specifications for maintaining room pressure balance are set forth by ISO Standard 14644-2, Specifications for Testing and Monitoring to Prove Continued Compliance with ISO 14644-1 for Cleanrooms. Generally, the pressure differential between contiguous pressure control zones will be 0.05 in. w.g. (13 Pa). Higher differentials between zones tend to make large doors difficult to open and close, whereas lower differentials lack effectiveness in separating the zones. In certain applications, simplified systems without the use of separate primary/secondary fan systems may be sufficient. [See Chapter 18, HVAC Applications (ASHRAE, 2011), for an additional reference; see also Figure 23-1].

23.3.2.4 Malfunction Alarms. Audible and visual alarms should be provided to indicate a malfunction of the directional airflow arrangement. Additional alarms should be provided for the filter banks to notify service personnel that the filters are becoming loaded with dust to a point where airflow delivery is being affected adversely. It should be kept in mind that it is necessary to measure total airflow rate as well as filter bank pressure drop to evaluate the condition of the filters correctly.

Alarms typically go to a centralized building management system monitored by facilities or security management. Some alarms may trigger an autopaging system to immediately notify key personnel.

23.3.2.5 Humidity Control. It is important that humidity and temperature conditions be controlled. Humidity control is required for corrosion and condensation control, static electricity elimination, and personal comfort. Temperature control provides stable conditions of operation for instruments and personnel. In addition, personnel may be wearing personal protective clothing such as full body suits and respirators that will affect their comfort.

ASHRAE HVAC Applications, Chapter 18, discusses this issue in more detail (ASHRAE, 2011). In general, conditions to be met are as follows:

Temperature: 68°F–73°F ± 1°F (20°C–23°C ± 0.5°C)
Relative humidity: 30–50% ± 5%

In critical applications, tolerances of ±0.1–0.5°F (0.06–0.3°C) and ±0.5–5% RH may be required. When a relative humidity of less than 35% is to be maintained, special precautions for static electricity control must be taken.

Specific conditions will depend on laboratory requirements.

23.3.3 Contaminant Control Ventilation

Several types of contaminant control exhaust ventilation systems have been designed for use in microelectronics laboratories and manufacturing facilities. Their selection and installation should conform to the International Fire Code (IFC, 2012). The principles of ventilation design provided in Chapter 3 of the ACGIH *Industrial Ventilation Manual* (ACGIH, 2010a) should be followed when no specific guidance is provided here. The *Semiconductor Exhaust Ventilation Guidebook*, by Jeff Burton (1995), provides an excellent description of typical exhaust hoods used in the semiconductor industry and design guidelines.

23.3.3.1 Gas Cylinder Storage Cabinets. Gas cylinder storage cabinets provide a physical separation between gas cylinders and the operator's environment and provide a fixed path for exhaust airflow at the desired capture velocity for the gas. The design of these cabinets has been studied (Burgess, 1985; Burton, 1995), and recommended ventilation rates are provided in the IFC (2012) (see Figure 23-6).

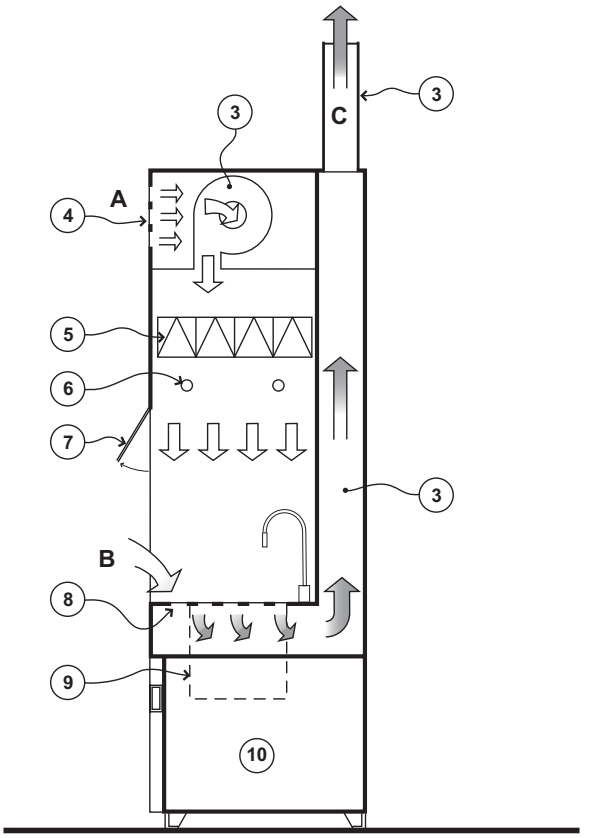
Vented gas cylinder storage cabinets are usually designed to provide an exhaust quantity of 200 fpm

FIGURE 23-6. View of Ventilated Toxic Gas Cabinets.

(1.0 m/s) face velocity through the window openings (State of California, 1988) or 80 CFM per square foot (.4 cubic meters per second-square meter) of cabinet floor area. This exhaust air quantity is designed to handle small leaks in the systems, not high-volume accidental releases. The best solution for cylinder handling and leakage control is to keep cylinders in a gas cylinder farm, either external to the building or in a controlled area on an outside wall, and pipe gas to the point of use in the laboratory. Silane gas cylinders are sometimes used from an outside concrete pad and would not require a gas cabinet. Gas cabinets and other gas sources must always be kept out of any recirculated airstream. Restrictive flow orifices and excess flow check valves should be used (see Section 23.4.2 below).

23.3.3.2 Exhaust Ventilated Workstations. Exhaust ventilated workstations are used in microelectronic laboratories to provide product and personnel protection simultaneously. In this regard, they resemble Class II BSCs; in some cases, these are used as workstations. However, unlike Class II BSCs, no specific performance standards have been developed to regulate or assess the ability of these workstations to provide the required product and personnel protection. They are constructed in a variety of configurations, depending on their intended use (solvent cleaning, acid cleaning, or other chemical manipulations). Typical workstations are shown in Figures 23-7 and 23-8. The general control principle for many of these facilities is the use of lip exhaust slots around the entire perimeter of a recessed "well" in the work surface that is used for acid or solvent baths. An exhaust slot is usually present along the back of a workstation. Some workstations have no recessed wells, and their operational mode more closely resembles that of Class II BSCs. Cabinet manufacturers must be consulted to obtain the design airflow exhaust rates for their equipment. This is usually expressed in CFM per foot of bench length. It is desirable to conduct performance tests on these hoods to confirm the manufacturer's recommendations. The performance test commonly used is ASHRAE 110-1995, modified to meet specific design needs (ASHRAE, 2010; NIH, 2012). When design air exhaust flow rates are not available, consult Chapters 3 and 5 of the *Industrial Ventilation: A Manual of Recommended Practice for Design, 27th Edition* (American Conference of Governmental Industrial Hygienists [ACGIH], 2010a), Burton's *Semiconductor Exhaust Ventilation Workbook* (Burton, 1995), or SEMI guidelines (SEMI, 2012). Because these hoods typically use slot exhausts, one can calculate the required slot velocity and CFM needed for control.

When clean air is supplied directly inside the hood, the air supply and exhaust volumes for these hoods



KEY

1 Exhaust Stack to the Roof
2 Negative Pressure Exhaust Plenum
3 Fan
4 Pre-Filter Air Intake
5 HEPA Filter
6 Lights
7 Acrylic Face Shield
8 Semi-perforated Work Surface
9 Sink (Beyond)
10 Storage
□ Clean Air
■ Contaminated Air

AIR FORMULAS

A + B = C

FIGURE 23-7. Section through a microelectronics vented wet workstation.

FIGURE 23-8. View of a microelectronics vented wet workstation.

should be balanced to prevent escape of contaminants. The exhaust flow quantity must be large enough to exhaust the air supplied directly into the hood and maintain an adequate flow of air from the room into the face of the hood.

23.3.3.3 Ventilated Equipment. Much of the equipment used in microelectronics research is designed to be operated under vacuum or is provided with a local exhaust outlet to carry away toxic gases and vapors. Therefore, exhaust system capability must be provided. Examples of such equipment include chemical vapor deposition systems, diffusion furnaces, etchers, ion implanters, vacuum ovens, and spinners. Manufacturers will provide information on the required exhaust volume flow rates for their equipment. A central exhaust system can be used when effluents from each unit are compatible after mixing. No recirculation of this potentially contaminated air should be allowed. A certified industrial hygienist or certified safety professional can provide assistance in evaluating the compatibility of chemicals in exhaust air manifold systems.

23.3.4 Treatment of Exhaust Air

Chemical vapor deposition reactors may need to be equipped with effluent gas stream scrubbing systems designed to remove specific toxic particles and gases. For arsenic and phosphorus trioxide, it is recommended that the air-cleaning train be composed of at least one dry trap for condensing solid material, one bubbler with caustic scrubbing liquid for reduction of post reactions initiated by the presence of oxygen, a nitrogen purge, and a charcoal trap to remove unreacted toxic gases (ACGIH, 2009). Activated charcoal adsorption alone has been used in other applications. Some manufacturers provide air cleaning equipment for the exhaust stream as part of their equipment, and this should be verified before purchase. All of this equipment must be vented to the outside atmosphere.

23.3.5 HVAC System Considerations

In general, constant-volume reheat-type systems are most desirable and provide reliable temperature control. Variable-volume exhaust systems should be used with caution because of the difficulty in maintaining desired pressure relationships, and hence room cleanliness. However, their use can realize energy savings by minimizing airflows during periods when equipment is not operating.

Replacement or conditioned air distribution is important to prevent cross-drafts and excessive turbulence in these rooms. The recommendations in Chapter 2, Section 2.3 should be carefully reviewed.

23.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONNEL SAFETY

The information contained in Chapters 1 and 2, Sections 4 applies to cleanrooms, and where applicable, microelectronics laboratories and should be implemented with the following additions.

23.4.1 Toxic Gas Monitoring

A continuous gas-detection system specific to the gas or gases used should be provided to detect the presence of gas in the room or area in which the gas is stored and used. Generally, this is required for gases with toxicity levels that are below odor thresholds. For more information, see NFPA 55 (NFPA, 2010). The most common gases monitored are the hydrides. Monitors should be capable of responding to one-half the OSHA permissible exposure limit or the ACGIH TLV, whichever is lower. The detection system should shut down gas flow, initiate an audible and visual local alarm, and transmit a signal to a continuously staffed remote location that can provide immediate response to the alarm. The alarm should provide warning both inside and immediately outside the alarmed area or building. Under alarm conditions, the laboratory pressure should become negative with respect to surrounding areas. This is usually accomplished by eliminating or reducing the supply air to the space.

For infrequent uses of small quantities of toxic gases contained in lecture bottles, a portable gas-detection monitor may be used and operated during the use of the gas.

When the gas or gases are used continuously in more than one location, a multipoint detection system can be used. Multiple sampling-point monitoring systems with 8–72 sampling points are commercially available (see http://www.industrialcontrolsonline.com/honeywell-mda-scientific-chemcassette). Detection points should be established at every location that has a potential gas release. The key areas for detection points include gas storage cabinets, reactor exhaust enclosures, an operator's breathing zone while at specific operational equipment, such as organometallic chemical vapor depositions (OMCVDs), the general room or area, and possibly the exit to the exhaust stack or after the air cleaner.

For a more detailed discussion of locations for sampling points and types of monitoring systems, see *Hazardous Gas Monitoring: A Guide for Semiconductor and Other Hazardous Occupancies* (White, 1997).

23.4.2 Toxic Gas Piping Systems

Piping should be designed and fabricated from stainless steel or other materials compatible with the material to be contained and transported (State of California, 1988). In addition, piping should be of strength and durability sufficient to withstand the pressure, structural and seismic stress, and chemical exposure to which it may be subjected. Piping should be welded. Fittings, if any, should be in an exhaust-ventilated enclosure.

Double-walled piping should be used throughout for highly toxic gases, such as arsine, stibene, and diborane, and for highly flammable gases, such as hydrogen, as a safety measure. The outer space between the inner piping and outer wall should be under slight negative pressure with respect to the room atmosphere. This is usually one of the toxic gas monitoring system points and a leak detected here may result in an automatic page to key personnel (see Chapter 23, Section 23.3.2.4).

23.4.2.1 Excess Flow Control. An automatic shutoff valve of a "fail-safe to close" design should be provided for each toxic gas cylinder on main and branch pipes. The shutoff valve should be activated by any of the following: gas detection, excessive gas flow, remote location alarm, failure of emergency power, exhaust air failure, seismic activity, failure of primary containment, or fire activation of a manual alarm. Portable tanks and cylinders should be provided with excess flow controls and restricted flow orifices. Valves should be permanently marked to indicate the maximum design flow rate.

23.4.3 Air-Supplied Respirator System

Depending on the toxicity of the gases used and the nature of the work activities performed in these facilities, it may be advantageous to install a breathing air respirator system. During some activities, such as changing gas cylinders and cleaning equipment, it is advisable to wear respiratory protection. Self-contained breathing units could be used, but they are cumbersome. Supplied air respirators, connected to piped in breathing air, are usually better. Extreme caution should be used to prevent any potential for accidentally connecting the air supply system to the toxic gas system. For these systems, the requirements of OSHA 1910.134 must be followed (OSHA, 2012).

23.4.4 Use of Plastic Ductwork

When metal cannot be used, several types of plastic hoods and ducts are available. The more common types are polypropylene and polyvinyl chloride (PVC). PVC-coated metal is also available. Recent experiences with fires involving polypropylene and polyethylene have proven disastrous. Use of fire-retardant versions of these plastics is required by some state plumbing codes, including that of Massachusetts. Therefore, a careful evaluation of the choice of materials should be made based on hood location, length of duct run, materials to be used inside the hood, and extent of the fire protection system as well as local fire codes. Generally, we recommend the use of fiberglass-reinforced polyester or PVC, but if other plastics must be used, they should be treated for fire resistance and fire-spread retardation in conformance with local building codes. Wherever stainless steel can be used, it is preferred (see Chapter 33).

PVC hoods and ducts should be evaluated for the need to provide a sprinkler system in the hood and in the duct run areas. Carbon dioxide (CO_2) as an extinguishing agent can be used in a hood or a nonflammable tool (a tool that may be stainless steel) that contains flammable solvents. However, the release of CO_2 should be coupled with the shut off of the exhaust air ventilation, otherwise the CO_2 will be diluted and may not be effective.

23.4.5 Warning Signs

Consideration should be given to the installation of lighted signs that can be turned on to warn persons approaching the laboratory of the presence of operational hazards.

23.4.6 Standards

The National Fire Protection Association has two standards that affect the design of microelectronic laboratories: NFPA 318 Standard for the Protection of Semiconductor Fabrication (NFPA, 2012) and NFPA 55

Compressed Gases and Cryogenic Fluids Code (NFPA, 2010). Both should be reviewed for their applicability.

23.4.7 Portable Fire Extinguishers

In addition to the fire extinguisher recommendations contained in Section 1.4.4.2.2, space should be provided during the planning stage for hand-portable fire extinguishers to be used in the event of a filter fire. The size and type of extinguishers should be determined with the aid of a safety professional. Carbon-dioxide-filled or Dupont FE-36 (hexafluoropropane) extinguishers are favored by cleanroom operators because they leave no particulate residues. In the presence of the high airflow rates that are characteristic of cleanrooms, however, an inert blanket of carbon dioxide has only limited persistence and will prove inadequate under these special circumstances. It should be remembered that when there is a fire in a cleanroom, the facility is already severely contaminated and the extinguishing agent should be selected solely on the basis of effectiveness.

23.4.8 Hazardous Waste

To minimize handling inside the clean facility, the hazardous waste from laboratory operations can be plumbed directly out of the facility to the maintenance area. This is more readily done by gravity when the support areas are directly below the cleanroom.

23.5 SPECIAL REQUIREMENTS

23.5.1 Safety Storage Cabinets for Cylinders Containing Compressed Arsine, Phosphine, and Diborane

Some of the chemicals used for processing microelectronic chips are acutely toxic at low concentration, highly flammable and pyrophoric. Some will spontaneously ignite in air at 100°F (36°C) or above. Among them are arsine, diborane, and phosphine, which are gases at ambient temperature and pressure and are supplied in pressurized cylinders. SDS cylinders (material adsorbed on zeolite) are commonly used to generate toxic gases to avoid using compressed gas cylinders. See the following two sites for more details: http://www.prnewswire.com/news-releases/atmi-and-matheson-tri-gas-deliver-sdsr3-for-enhanced-safety-and-productivity-54353082.html or http://www.prnewswire.com/news-releases/atmis-sds-inventors-awarded-semiconductor-honor-drs-glenn-tom-and-w-karl-olander-receive-semi-award-76073352.html

Design requirements will be different depending on the option chosen to deliver the hazardous gases, so a careful review with the users about current and future plans needs to be conducted.

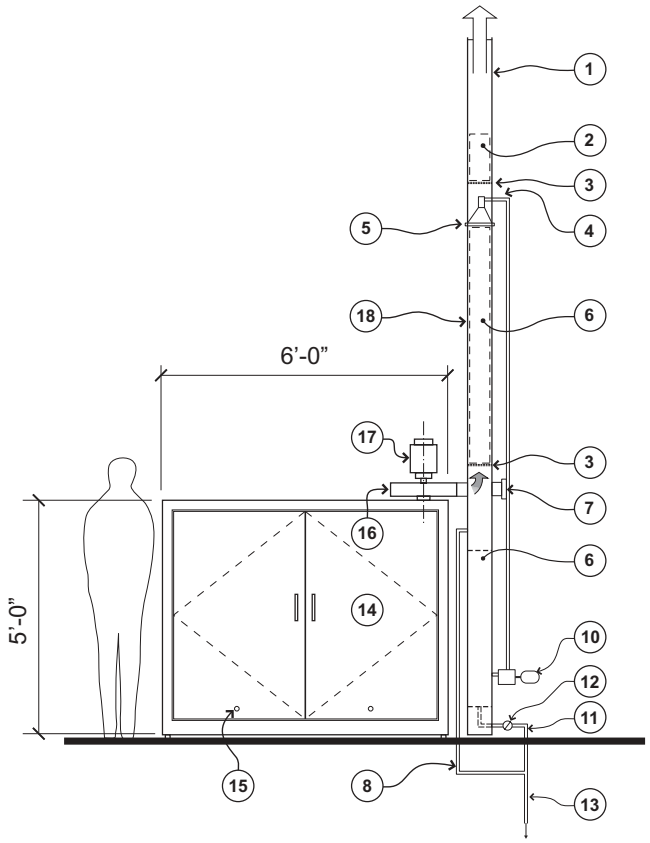
Fully charged large storage cylinders contain the following gas volumes when released at normal temperature and pressure:

Arsine (2P cylinder of 100% gas)	75 ft^3 (2 m^3)
Phosphine (2P cylinder of 100% gas)	75 ft^3 (2 m^3)
Diborane (1L cylinder of 1% diborane in argon)	275 ft^3 (8 m^3)

For safety, these compressed gases should be stored in ventilated storage cabinets, and the air from the cabinets should be discharged to the outside atmosphere from a point well above the roof and surrounding tall buildings. A very small volume cylinder leak from a faulty connection or valve (fraction of a milliliter per minute) can be handled satisfactorily by this method, inasmuch as (1) the negative-pressure cabinet protects the worker in the area, and (2) the dilution produced by the cabinet purge air volume, along with the elevated discharge point, prevents significant environmental health exposures. Figure 23-9 shows several ventilated cylinder storage cabinets connected at the top to a common discharge manifold. Each cabinet is ventilated at the rate of 25 CFM (0.13 m^3/s) of room air that enters small openings in the bottom of the cabinets. See 23.3.3.1 for more details.

A very dangerous situation arises in the event of a major uncontrolled gas emission resulting from a dropped cylinder or broken valve. The gas release rate may reach several liters per minute, and the purge rate would be inadequate to dilute the escaping gases to safe levels. Under these conditions, it may be unsafe to dis-

FIGURE 23-9. View of ventilated toxic gas cabinets.



KEY

1	Exhaust Stack to the Roof
2	Droplet Eliminator Packing (1Foot)
3	Perforated Support Plate
4	Spray Nozzle
5	Flange and Gasket
6	Absorber Packing (5 Feet)
7	Liquid Fill Hatch
8	Safety Overflow Drain Line
9	Liquid Reservoir (6 Gallons $KMNO_4$ 10% Solution)
10	Liquid Pump
11	Bottom Drain
12	Valve
13	Drain to Sewer
14	Cylinder Storage Cabinet
15	1 1/2 Inch Diameter Vent Holes (4)
16	Blower
17	Motor with Thrust Bearings
18	Absorption Tower
□	Clean Air
■	Contaminated Air

FIGURE 23-10. Emergency purge air-cleaning system.

charge untreated cabinet purged air to the atmosphere. There are usually safeguards built into the system such as automatic shut off valves as described in Section 23-4.2.1. Therefore, one option is the discharged air from the cylinder storage cabinets should be connected to a standby purification system that can be activated instantly in the event of a serious gas leak. A wall-mounted switchboard next to the cylinder storage cabinets and outside the room can be used to activate the emergency air-purifying system and redirect the air from the cabinets through it before reaching the stack.

A typical emergency purge air-cleaning system is shown diagrammatically in Figure 23-10. It consists of a 6-in. (0.15-m) inside diameter (I.D.) polyester absorption tower filled with 1/2-in. (0.013 m) polyester saddles to a depth of 5 ft (2 m) and topped with 1 ft (0.3 m) of dry saddles for droplet elimination. Caustic potassium permanganate solution is stored in a reservoir below the absorption tower and spread on top of the wetted saddles with a spray nozzle operated by a chemical pump located below the reservoir liquid level to be self-priming. A spray rate of 2 gpm (7 L/min) at 10 psi (69 kPa) is satisfactory to achieve at least 95% reduction in gas emissions.

Figure 23-11 is a photograph of the emergency air-cleaning system that can be associated with the ventilated gas-cylinder cabinets shown in Figure 23-9. This particular system is used for a similar application to treat the exhaust air from a research tool (OMVPE or organometallic vapor phase epitaxy system).

In some cases, larger scrubbers can be installed on the roof and serve the entire microelectronics facility. One scrubber can be used for exhaust air that may contain solvents while another can be used to treat exhaust air that contains acids. The appropriate scrubber must be selected based on the material to be removed from the exhaust stream.

23.5.2 Lighting

Cleanroom laboratory lighting should be flush-mounted and sealed from the room. Illumination levels of 100 ft^3 at 30 in. (1 m) above the floor will be adequate to provide a reasonable illumination level for fine, precision work that will avoid eye fatigue. Because of the smooth, hard nature of the room's surfaces, special care must be exercised to provide soft, even lighting and an absence of direct or reflected glare.

FIGURE 23-11. View of emergency purge air-cleaning system for a single toxic gas cylinder.

23.5.3 Security

Microelectronics and other cleanroom laboratory operations may involve proprietary or hazardous materials that require security control. See security considerations discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1.

23.6 RENOVATIONS

Renovations to cleanroom and microelectronics laboratories must be performed with great care because of the need to operate under the appropriate cleanliness condition. All the issues in Chapters 3 and 4 should be carefully reviewed for applicability. Particular attention should be paid to decontamination of surfaces, equipment, and ventilation systems for toxic materials such as arsenic compounds. Because cleanliness and directional airflow are critical needs, new penetrations through walls, floors, or ceilings should be avoided. When it is necessary to make penetrations, they should be completely resealed.

24

PRINTMAKING STUDIO

24.1 DESCRIPTION

24.1.1 Introduction

A studio workroom is the artist's and craftsman's equivalent of the scientist's laboratory. In many types of work, artists and artisans deal with toxic and highly flammable substances, often in quantities that have a potential to cause injury, illness, a fire, or an explosion. Professional artists and crafts workers tend to work alone or with small groups in private studios that are often combined with their living quarters. Larger numbers customarily work together in art school settings.

Many serious artists serve an apprenticeship at one or more art schools. Therefore, when professional artists work in "kitchen studios" and have dangerous work habits (as has been widely noted), one must look to the art schools to see what sort of safety training student artists receive while in their formative period. The information contained in this chapter is intended for studios devoted to large group teaching.

Although all artists and artisans work with or generate some amount of toxic materials, printmakers seem to work with the greatest variety and largest amounts of toxic chemicals. Printmaking uses a few basic techniques with many variations to prepare a master plate, as in woodblock cutting (perhaps the oldest printmaking technique), engraving and etching of metal, lithography, and screen printing. A brief description and a list of materials used in each of four generic processes follow so that the nature of the hazards involved and the protective measures required will be clear. The basic printmaking processes, as they have been described, are rather simple and straightforward. However, modern materials and artistic ingenuity have developed an almost infinite number of variations and combinations that make it impossible to attempt to cover them adequately in a brief review. Detailed treatment must be sought in specialized texts prepared for art students and professional practitioners (see Curtiss & Snyder, 1996; McCann, 1993; Rossol, 1990; Seeger, 1981; Spandorfer, Grabowski, & Fick, 2009).

24.1.2 Work Activities

24.1.2.1 Intaglio Process. An image is scratched (dry point), engraved, or etched into a flat metal plate (usually copper, steel, or zinc). In the dry point and engraving processes, the surface of the plate is cut directly with a cutting tool, whereas the etching process requires that the polished plate be precoated with a specially prepared material called a *ground* and that the image be cut into the ground with an etching needle. The prepared plate is then immersed in a bath that chemically cuts the metal surfaces that have been exposed. Nitric acid-water solution (1:20) is used in the bath for steel, and ferric chloride bath is used for copper. Finally, the ground is washed off in a suitable solvent and the plate is ready for printing.

The printing process starts by forcing ink into the grooves in the plate and then wiping clean the uncut

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

TABLE 24-1. Common Materials Used in Printmaking

		Intaglio and Relief Materials		Lithography Materials	Screen Printing Materials
Hazards			Hazards		Hazards
FL		Oil-base inks (etching inks)	FL	Oil-base inks (lithography inks)	Water-base inks
		Oil-base ink modifiers		Oil-base ink modifiers	Transparent base
		Water-base inks	FL	Lithotine	Windex
		Water-washable inks		Gum arabic	409 spray cleaner
		Soy-based inks		Hot water	Photo-emulsion remover
		Transparent base		409 spray cleaner	Bleach
FL	TOX	Mineral spirits		Copy machine toner	White vinegar
		Anti-skin spray		*Asphaltum	Emulsions: Diazo
AC		Nitric acid		Tuche: liquid, stick, or paste	dual cure
		Burnt plate oil		Mineral spirits	presensitized photopolymer
		Easy-wipe compound	FL	Acetone	
		Hard universal etching ground	AC	Nitric and/or citric acid	
		Soft universal etching ground		Phosphoric and/or tannic acid	
		Hard graphic ball ground		Denatured alcohol	
AC		Hydrochloric acid		*Rosin	
EX		Asphaltum (powdered)		Talc	
		Putz Pomade		Glycerin	

FL = flammable liquid; AC = acid/corrosive; EX = explosive; TOX = toxic.

surface of the plate. A print is made by laying a slightly damp paper on top of the inked surface and passing them together at great pressure through a press that forces the paper into the inked grooves and transfers the inked image to the paper. The plate must be reinked and the surface recleaned for each print. At the conclusion of printmaking, the plate, press, and inking implements must be cleaned by wiping and washing with ink solvents. A list of frequently used materials is shown in Table 24-1; those associated solely with etching are marked with an asterisk.

24.1.2.2 Relief Process. Wood and linoleum are the most frequently used media for preparing relief-cut transfer masters. In this process, the material between the lines is cut away with knives and gouges, leaving the drawing in high relief. The relief surfaces can be inked with a roller. Prints can be prepared by rubbing the back of a piece of paper laid face down on the inked surface; however, prints are usually made in a printing press. Inks and cleaning solvents characterize most of the materials used in this process; frequently used materials are listed in Table 24-1.

24.1.2.3 Lithography. Flat, fine-grained stones are prepared for this use by grinding and etching a horizontal surface until it holds a thin film of water when wetted. Another lithographic material commonly used is positive-working aluminum plates. They are prepared with hot water. When sections of the surface are greasy, water will not wet them; this is the basis of the lithographic process. A master plate is prepared by drawing or painting the image directly on the stone surface, or aluminum or polyester plate with a greasy ink, a grease pencil, or a crayon. Now, when the stone or plate is wetted and an inked roller is passed over the wet surface, ink will adhere only to the greasy places. The inked image is transferred to paper in a specially designed traveling bed lithography press that squeezes the paper onto the surface of the stone or plate below. The surface is inked again for each print. When the print run is completed, the aluminum plate is washed and dried; the stone is prepared for reuse by grinding or etching a new surface. A drawing made on paper with a lithographic crayon can be transferred to a stone surface by placing the image face down on the stone and running them together through the lithography press.

Photolithography is done with positive-working aluminum plates that are light-sensitive using digital photographic images. The only chemicals required are universal developer and a gum arabic/ phosphoric acid compound.

Materials frequently used in stone and aluminum plate lithography process are shown in Table 24-1; they include (1) strong mineral acids for stone etching, (2) inks, and (3) organic solvents for ink cleaning and stone degreasing. Aluminum plate lithography does not require use of hazardous chemicals.

24.1.2.4 Screen Printing. Master plates are prepared by placing stencils on the surface of a tightly stretched fine-mesh screen (frequently a synthetic woven fabric, traditionally silk) to block out all areas that are not intended to transfer ink. A paper is placed in contact with the undersurface of the screen, and ink is placed on top of the screen at one margin. Ink is then squeegeed across the surface to the opposite end, squeezing it through the open screen areas between the stencils and onto the paper directly underneath. Simply adding additional ink to the screen can make multiple prints. Water-based inks are generally used; so clean up is with soap and water. In addition, a variety of gums and adhesives are used to stick stencils to the screen. Table 24-1 lists materials commonly used for screen printing.

24.1.3 Equipment and Materials Used

24.1.3.1 Inks and Colors. All of the printmaking processes can use the same variety of monotone inks, usually black, but woodblock and screen printing are especially adaptable to multicolor printing. This is done by preparing a master plate for each color and imprinting a paper with each master plate in turn.

24.1.3.2 Photographic Transfer Methods. An innovation of wide application to all printmaking processes, with the possible exception of engraving, is digital photography. Many methods have been invented for transferring a photographic image to a blank master plate as a first step in preparing etched plates, lithography stones, wood blocks, and screen stencils for printing. This means that a print department at an art school needs to have standard- and large-format digital printers.

24.1.4 Exclusions

The information contained in this chapter does not apply to commercial printmaking enterprises. Information is intended to apply specifically to institutions handling large student groups in teaching situations. Small private studios may adapt the same principles, safe practices, and protective methods.

24.2 PRINT STUDIO LAYOUT

24.2.1 Introduction

Printmaking studios have a number of common layout features; there are special requirements for some. Many studios are furnished with mobile tables and benches to allow rearrangement according to the projects undertaken. Artists stand for many printing processes, so standing-height tables and adjustable height tables are recommended as ergonomic improvements.

24.2.2 Common Needs

Each studio requires (1) numerous large benches for layout and printing work, (2) storage shelves and cabinets for printing papers, (3) sink facilities for personal washing and for cleaning printmaking materials, (4) approved chemical and solvent storage facilities of limited capacity, (5) safety equipment that includes fire extinguishers and stores of personal protective equipment (goggles, gloves, aprons), (6) a chemical fume hood for handling dangerous chemicals, and (7) facilities for receiving, recycling, and safely storing large quantities of ink-stained and solvent-saturated waste papers and rags.

Studios may need access to photography services; a single facility may be held in common. In all printmaking studios, electrostatic charge effects can make it difficult to handle large sheets of paper. Therefore, in persistently dry environments, it is necessary to maintain the relative humidity in the supply air near 50% for ease in working.

24.2.2.1 Construction Methods and Materials. The fire-resistive construction requirements of the IBC (2012) or the current building code for Class A fire-resistive buildings should be followed. Studios are subject to hard usage due to the nature of the activities conducted there, and materials and construction methods should be selected that are resistant to a variety of caustic chemicals and easy to clean when soiled by inks, dyes, and pigments.

24.2.2.2 Floors. Selection of floor materials should also take into consideration a need for (1) resistance to acid and organic solvent spills, and (2) ease of removal of inks and paints. Splashes and spills may make flooring slippery. Nonslip finishes should be used. Stress-relieving mats help artists to maintain good posture and reduce fatigue while working long hours.

24.2.2.3 Walls. Studio walls should be totally or partially constructed of materials that allow mounting of unframed artwork produced by students for temporary exhibition. These materials should also have fire-resistive qualities and should not fuel a fire.

24.2.2.4 Print-Drying Racks. All printmaking studios need facilities for drying freshly made prints. Generally, totally enclosed print-drying racks are placed around studios in convenient locations. Enclosed and ventilated drying racks reduce the volume of fumes released into

studios. The need for these racks can become very substantial when successive classes use the same studio.

24.2.3 Individual Room Layouts

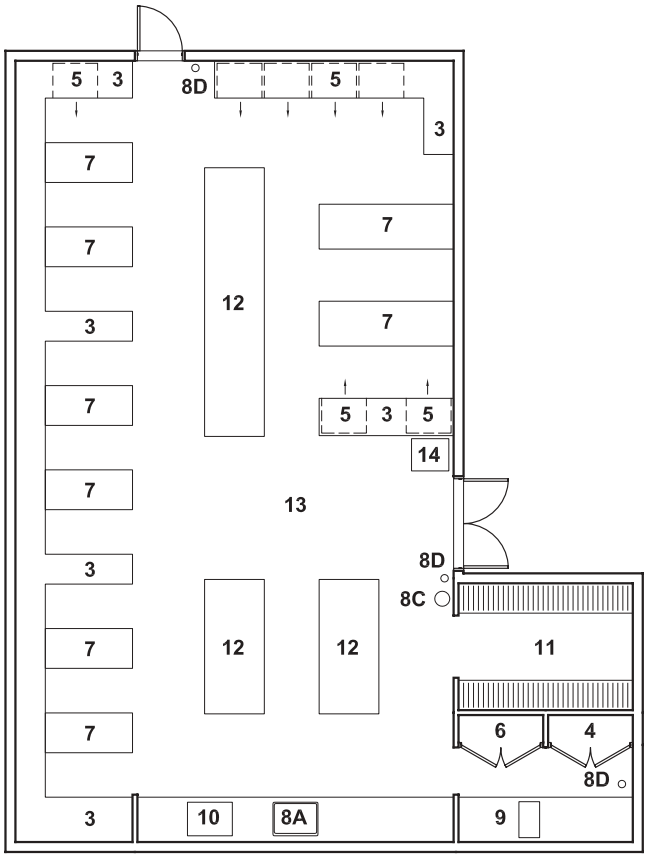
In addition to the enumerated common needs, studios have requirements that are unique to the specific nature of each printmaking process.

24.2.3.1 Lithography Studio. Concentrated floor loads for presses are a matter of special concern for lithography, if stones are normally used, and often the lithography studio will be located at a basement level to take advantage of the strength of a concrete floor laid over compacted fill. Forklifts and carts are used for moving lithography stones around the studio. Their needs must also be considered when evaluating clearances in floor designs. Metal plate lithographic processes do not have these considerations.

Additional special facilities for lithography using stones include (1) spacious and very strong shelving to store large, heavy blocks of stone; and (2) very large and strong exhaust-ventilated sinks and drain boards for solvent washing and acid etching of stones. Figure 24-1 is a typical layout for a lithography studio.

24.2.3.2 Etching Studio. The etching studio presents special problems with regard to flammable solvent use because grounds such as asphaltum and rosin powder are often applied to metal blanks and heated on an electric hot plate to a temperature that causes melting and fusing. In addition to isolating hot plates from areas where solvents are used, it is essential to make certain that the electrical equipment on the hot plate (on/off, thermostatic temperature controller) is spark-proof. Figure 24-2 is a typical layout for an etching studio.

24.2.3.3 Screen-Printing Studio. Use of volatile organic solvents in many screen-printing studios has diminished and may have been eliminated. Water-based inks are used that do not require special ventilation. Figure 24-3 shows a typical layout for a screen-printing studio.



KEY

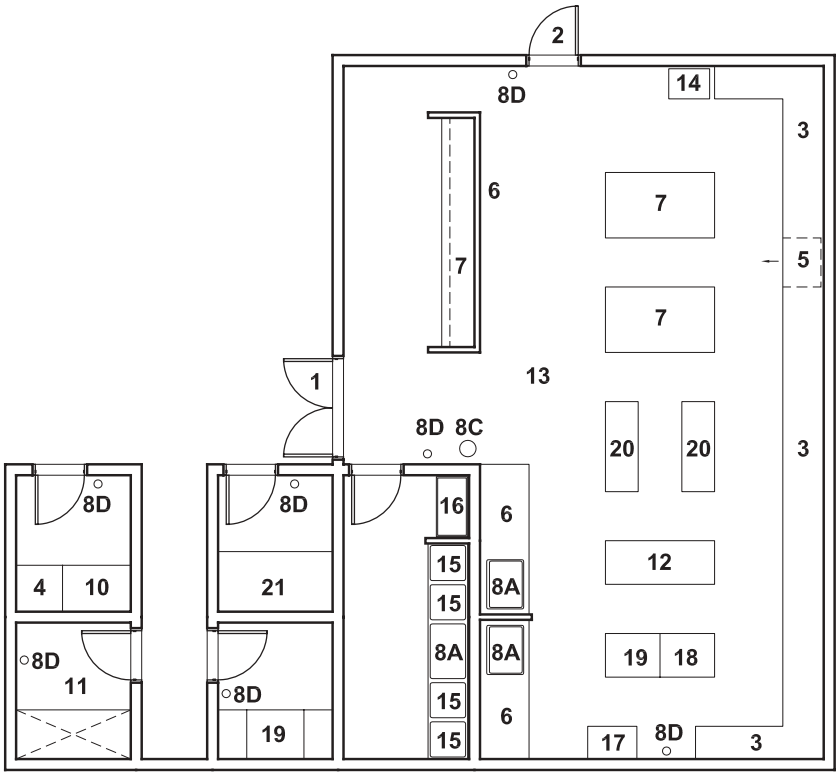
1	Primary Entry/Exit
2	Emergency Exit
3	Counter
4	Chemical Storage (Ventilated)
5	Flat Files (Under Counters)
6	Ink Storage
7	Press
8A	Sink
8C	Emergency EW & SS
8D	Fire Extinguisher
9	Plate Processing Ramp (Ventilated)
10	Stone Processing Sink (Ventilated)
11	Stone Storage
12	Table
13	Teaching Studio
14	Hazardous Waste Disposal

FIGURE 24-1. Lithography teaching studio layout.

24.3 HEATING, VENTILATING, AND AIR-CONDITIONING

24.3.1 General Requirements

24.3.1.1 Ventilation Rates. All studios need a level of general room ventilation with outside air that is adequate to dilute to safe levels all the solvents evaporating directly into the room from inks, paints, and cleaning



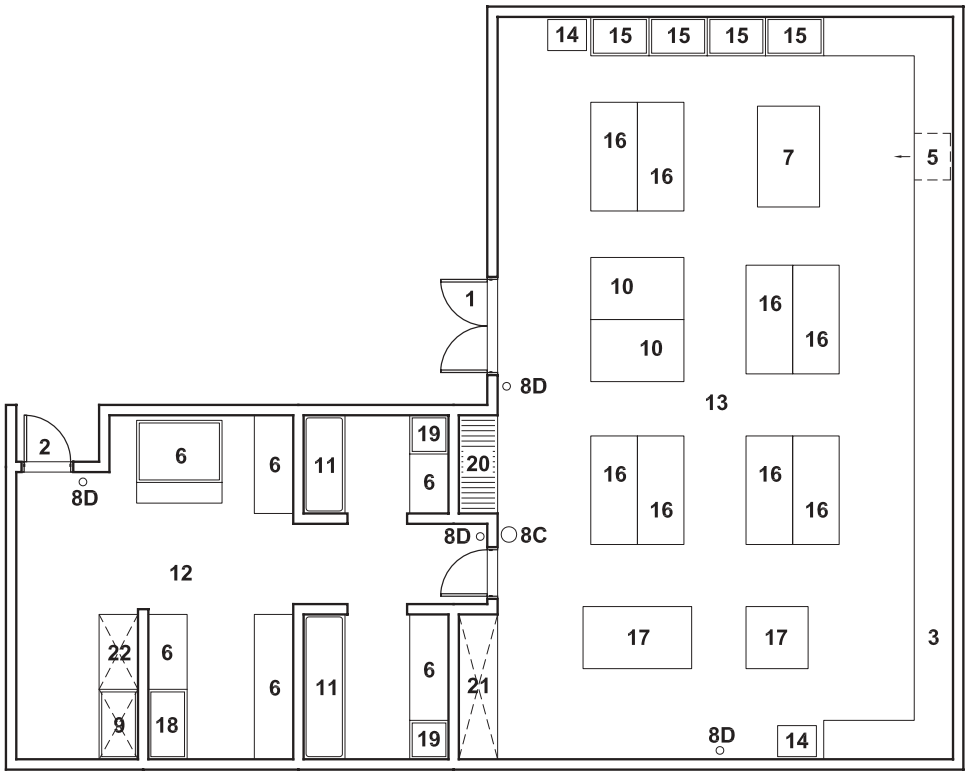
KEY

1 Primary Entry/Exit
2 Emergency Exit
3 Counter
4 Cabinet
5 Flat Files (Under Counters)
6 Display Wall
7 Press
8A Sink
8C Emergency EW & SS
8D Fire Extinguisher
9 Plate Processing Ramp (Ventilated)
10 Rosin Box (In Grounded Room with Spark Proof Electric Fixtures)
11 Spray Booth
12 Table
13 Teaching Studio
14 Hazardous Waste Disposal
15 Acid Bin
16 Acid Storage
17 Asphaltum Table (Ventilated)
18 Cooling Table
19 Hot Table
20 Inking Table
21 Plate Cutter

FIGURE 24-2. Etching teaching studio layout.

operations, which cannot be performed in a chemical fume hood or other form of local exhaust ventilation. Generally air is not recirculated, but in cases where it is, follow ANSI Z9.7 (ANSI Z9.7/AIHA, 2007). Fifteen air changes per hour are recommended as a minimum for screen-printing studios, and 10 air changes per hour are recommended as a minimum for lithography and etching studios when the studios are in use. Three air changes per hour are considered adequate for dissipating vapors from drying prints and solvent-soaked trash in disposal containers when the studios are unoccupied. The air-change rates cited are based on average student space allotment and chemical usage in a class studio setting. Lower values may be estimated by calculations illustrated in Section 24.3.1.3 below for dilution ventilation. Good understanding of the materials and processes commonly used and allowed in print studios is important in HVAC system selections.

24.3.1.2 Coordination of Supply and Exhaust Air Volumes. The local exhaust ventilation systems that are needed in each studio to control point source emissions (e.g., the acid-etching baths and grounds heating facilities in an etching studio and the printing benches in a screen-printing studio) are likely to provide adequate volumes of unrecirculated exhaust air to satisfy the air-change requirements for occupied studios. Therefore, a low level of general room dilution ventilation need only be provided for unoccupied periods. This means that the volume of air supplied to each studio must be



KEY

1	Primary Entry/Exit	8D	Fire Extinguisher	16	Screeding Table
2	Emergency Exit	9	Photo-Etch Sink (Ventilated)	17	Vacuum Table
3	Counter	10	Drying Rack	18	Screen Drying Cabinet (Ventilated)
4	Shelves	11	Enclosed Sink (Ventilated)	19	Screen Drying Rack
5	Flat Files (Under Counters)	12	Photography Suite	20	Screen Storage
6	Plate Maker	13	Teaching Studio	21	Cleaning Station (Ventilated)
7	Copy Camera	14	Hazardous Waste Disposal	22	Photo-Etch Counter
8C	Emergency EW & SS	15	Light Table		

FIGURE 24-3. Screen printing teaching studio layout.

coordinated with studio use and unoccupied periods. In practice, all the studio local exhaust systems and a high studio supply air volume must go on and off together to provide the design air exchange rates and maintain the air balance arrangements that keep the studios at a somewhat lower pressure than surrounding corridors, offices, classrooms, and lunch rooms to prevent contaminated studio air from flowing into these clean areas. When studio heating, cooling, and humidity are also provided by the ventilation air, the studio control systems tend to become complex. Nevertheless, because these are one-pass systems, energy costs for heating and cooling will be unusually high, and carefully designed control systems that minimize energy utilization are needed. Consideration should be given to selection of comfort control systems and separate contamination control and ventilation systems.

24.3.1.3 Print Drying. The very essence of printmaking is the production of multiple copies in a short time. Despite this, the use of instant-drying inks is inimical to orderly printmaking; as a consequence, large numbers of prints must be hung on conveniently located racks while they dry, often for several hours and overnight. In busy printmaking studios that have facilities for hanging hundreds of freshly made prints, the amount of solvents evaporated into the studio air from this source can become a matter of health and fire concern unless provision is made for adequate studio ventilation or effective containment of drying prints in ventilated

enclosures. Not only must the air exchange rate be great enough to dilute the vapors to a low concentration, but the location of the drying racks in relation to the exhaust air vents must draw the vapors away from the breathing zone of the printmakers. Often, prints will be allowed to dry in the racks overnight, making it essential to keep some minimum amount of studio ventilation operational at all times when the studios are in daily use.

The minimum air-exchange rate required for handling solvent vapors can be calculated based on annual solvent and oil-based ink consumption. Average daily consumption can be calculated by dividing annual consumption by the number of days the studio is used each year. Experience indicates that maximum solvent evaporation will be approximately four times the daily average when the studio is used intensively, and the studio air-exchange rate must be based on this number. The minimum air-exchange rate for unoccupied studios must be based on the maximum number of drying prints that can be accommodated on the drying racks.

Most of the solvent will be consumed in cleaning operations that take place during, as well as at the conclusion of, printmaking with oil-based inks. Therefore, solvent consumption figures must be calculated studio by studio, and the ventilation system requirements for each studio will be based on the results (see Chapter 4, General Industrial Ventilation; ACGIH, 2010).

24.3.2 Exhaust Air Systems

24.3.2.1 Fans and Motors. All exhaust air systems from studios using flammable volatile solvents should be equipped with spark-resistant fans and appropriately rated fan motors. Type B construction, as defined in the Air Movement and Control Association's Standard 99-0401-86 (AMCA, latest edition) should be adequate for this service. It calls for the fan to have an entirely nonferrous wheel and a nonferrous ring about the opening through which the shaft passes. Spark-resistant construction should not be confused with explosion-proof construction, an electrical term that calls for the device to be able to successfully withstand the effects of an internal explosion and not propagate such energy outside its containment. This is a considerably more costly item to purchase.

24.3.2.2 Local Exhaust Ventilation.

24.3.2.2.1 Screen Printing. In addition to good general studio ventilation, exhaust-ventilated screen-printing benches are needed. Figure 24-4 shows a typical slot-type exhaust hood serving two screen-printing benches (see Chapter 2, Table 2-7 for slot exhaust design).

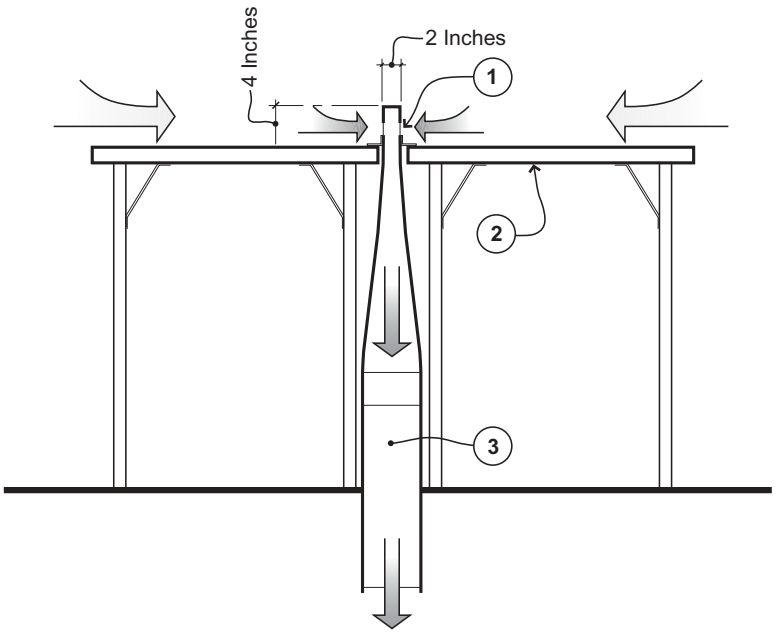
24.3.2.2.2 Lithography. An exhaust-ventilated spray booth is needed for spray-coating stones with photographic emulsions and for other surface treatments. Use of metal positive-working photographic plates reduces use of spray booths (see Chapter 2, Table 2-7 for spray booth design sheets).

24.3.2.2.3 Etching. The special need to heat etching plate grounds on an electric hot plate has already been noted. This operation should be conducted in a laboratory-type fume hood dedicated to this activity. Another facility unique to the etching studio is the acid-etching baths. These may be 4×5 ft (1.2×1.5 m) in cross-section and filled with dilute hydrochloric acid. The acid attack on copper and zinc produces bubbles of hydrogen, which break the surface carrying fine droplets of acid into the air above the surface. Even when idle, the tanks continuously give off acidic hydrogen chloride gas. Therefore, the acid-etching tanks must be provided with covers and with exhaust ventilation facilities. Because the need for exhaust ventilation will be greatest during the brief periods that the tank cover is open, a considerable saving in energy requirements can be realized by modulating the exhaust volume rate with the cover movements—that is, maintaining a low air bleed to extract equilibrium acid vapors when the cover is closed and a high-volume exhaust flow for effective vapor and droplet control when the cover is open. A simple mechanical arrangement to accomplish this task is shown in Figure 24-5. Figure 24-5 shows a typical ventilated photo-etching bench (see Chapter 2, Table 2-7 for a design plate).

24.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

24.4.1 Introduction

Although it is not practical or wise to attempt to restrict the materials that may be used by professional artists and crafts workers, the situation may be otherwise for students, especially for beginners. Many art materials are available for printmaking that are nonhazardous and could easily be incorporated into educational programs. Water-based paints and inks come readily to mind; not only are volatile organic solvent vehicles absent from these materials, but none are needed for cleaning purposes. Less drastic possibilities for reducing solvent exposures reside in the use of more single-service, disposable items (such as uncoated metal plates, precoated photographic plates, screens, scrapers, and brushes) that do not require cleaning. Such material restrictions may be considered inappropriate for more



KEY

1 4 Inch x 60 Inch Exhaust Slots (1 Per Side) Covered with 1/4 Inch Wire Mesh Paper Stop.

2 Silkscreen Screeding Bench

3 6.5 Inch Duct through Floor

□ Clean Air

■ Contaminated Air

FIGURE 24-4. Section through screen print bench with slot exhaust.

advanced students; in any event, advanced students must be taught while at school as learners to handle their materials in safe ways if they are to carry the lessons over to their professional activities. This makes it unlikely that the health and safety safeguards that have been recommended for printmaking studios will become unnecessary in the foreseeable future because of developments in new art materials.

24.4.2 Flammable Solvent Use

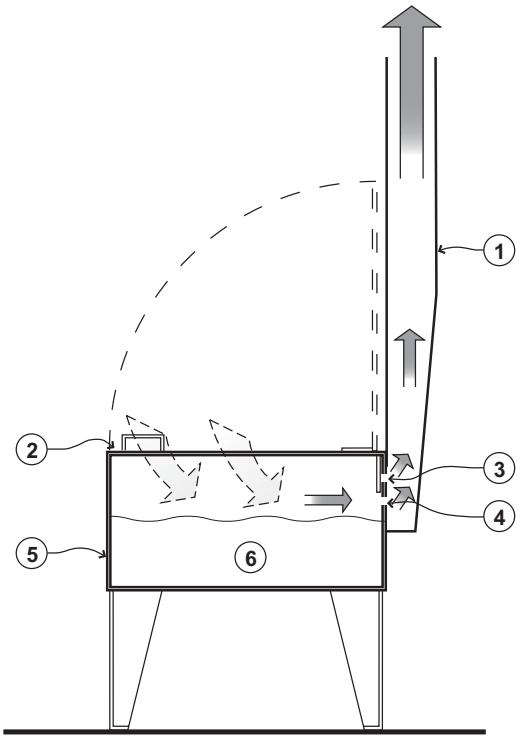
24.4.2.1 Permissible Quantities. Printmaking studios used for student instruction come under special rules governing the maximum amounts of flammable and combustible liquids (See Chapter 28, Section 28.1.3.2) that can be stored in classrooms and the nature of the containers in which they can be stored. Safety containers for daily-use must be of small size and correctly labeled. Although local building and fire prevention codes customarily establish minimum safety regulations for the storage and use of flammable and combustible liquids, the NFPA Standard No. 30, Flammable and Combustible Liquids Code (NFPA, 2012) offers guidelines. Consult current building code regulations, adopted by the jurisdiction having authority, on the allowable quantities of hazardous chemicals. In In NFPA 30, Table 1-3 lists the maximum recommended quantities of five classes of solvents and four classes of containers acceptable in teaching studios. Most solvents used by printmakers are flammable according to definitions shown in Chapter 28, Section 28.1.3.2. Excellent nonflammable solvents are commercially available and are greatly preferred from the standpoint of safety, but regrettably they tend to be highly toxic (often carcinogenic), detrimental to the ozone layer, and much more expensive. This means that printmakers must be constantly on guard to prevent fire and explosion.

24.4.2.2 Flammable Solvent Protective Measures. The presence in educational facilities of flammable solvents is certain to become a matter of keen concern for the fire marshal, and this individual should be consulted very early in the facility planning stages to learn what limitations will be imposed and what special require-

ments will be mandated. Likely requirements will include at least one fire-resistant UL-approved flammable liquid storage cabinet in each studio, using and storing flammable solvents and solvent-containing inks, paints, and colorants; fire-extinguishing equipment appropriate for flammable liquids and for solvent-saturated wastepaper and rags; fire alarms; two or more ways of emergency egress from each studio; and possibly installation of sprinkler systems throughout. Appeals of fire marshals' decisions are difficult and usually unrewarding; therefore, advance approvals are essential.

24.4.2.2.1 Flammable Liquid Storage Cabinets. The fire marshal may insist that all flammable liquid storage cabinets in studios be ventilated and maintained under negative pressure as an additional fire protection measure (see Chapter 2, Section 2.4.6.3). The cabinets can be connected most conveniently to the studio room exhaust air system inasmuch as no air is recirculated. All exhaust air systems from studios using flammable volatile solvents should be equipped with spark-resistant fans and totally enclosed fan motors.

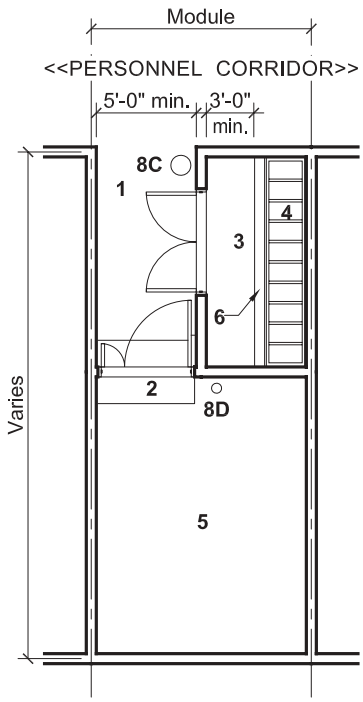
24.4.2.2.2 Bulk Storage of Flammable Solvents. Although very small amounts of flammable and combustible solvents (scarcely a day's supply for a large and busy studio) should be permitted in studios, larger quantities must be available for resupply. In addition, there is a significant cost advantage when heavily used solvents can be purchased in 55-gallon drum lots. This means that a bulk solvent storage facility must be constructed outside the areas used for educational purposes,



KEY

1 Exhaust Duct (8 Inch Diameter)
2 Lid
3 Large Volume Exhaust Slot along Back of Tank, Open When Lid is Up.
4 Small Volume Exhaust Slot along Back of Tank, Open When Lid is Up or Down.
5 Acid Tank
6 Acid
□ Clean Air
■ Contaminated Air

FIGURE 24-5. Section through ventilated photo etching bench.



KEY

1 Entry Alcove
2 Ramped Floor Dike
3 Acid Storage Room (Ventilated)
4 Acid Storage Crates
5 Ink/solvent Storage Room (Ventilated)
6 Curb
8C Emergency EW & SS
8D Fire Extinguisher

FIGURE 24-6. Hazardous chemical storage facility serving art studios.

but should be reasonably accessible for daily replenishment of small studio safety containers. Additional information on flammable liquid storage may be found in Chapter 2, Section 2.4.6.3 and in Chapter 28, Sections 28.1.3.2 and 28.2.2.2.

24.4.2.3 Chemical Storage Other than for Flammable Solvents. The etching studio and the lithography studio use strong mineral acids and acid salts in their operations. Therefore, it is necessary for each of these facilities to provide suitable chemical storage facilities for daily use of small quantities within the studio and for bulk storage at an easily accessible location, as shown in Figure 24-6. Consult Chapter 1, Section 1.4.7; Chapter 2, Section 2.4.6; and Chapter 28 for information on bulk storage of chemicals.

24.5 SPECIAL REQUIREMENTS

24.5.1 Solvent Degreasers

In view of the large amounts of volatile solvents used for cleaning printing materials (including master plates), and most especially for silkscreen work, the installation of a centrally located industrial-type solvent degreaser needs to be given serious consideration for busy printmaking studios, not only to reduce solvent consumption, but to reduce the exposure of those using the studios to a level as low as reasonably achievable (see Chapter 2, Table 2-7 for a design plate). It must be kept in mind that art school students will usually be in their late teens and that the threshold limit values and permissible exposure limits applied to the adult working population may not be entirely appropriate for a younger group. It should also be recognized that the habits of students often include intensive work periods of 12–18 h at a stretch, especially near the end of a term, and these periods must be factored into the interpretation of safe exposure limits for this special population.

24.5.2 Lighting

Satisfactory lighting limits and lighting levels for studios will be similar to those mentioned in Chapter 1, Tables 1-12 and 1-13 for drafting rooms (2 W/ft^2) and for cartography, detailed drafting, and designing (100 ft^3 on the work task).

PART III

LABORATORY SUPPORT SERVICES

Laboratories are seldom able to function at all, let alone efficiently, as stand-alone units; support services of many types are called for. For example, laboratory waste must be handled as hazardous waste and disposed of according to the rules of local, state, and federal agencies (e.g., the U.S. Environmental Protection Agency). This calls for the construction and utilization of appropriate facilities, preferably on a centralized basis for the entire organization.

One such support service frequently associated with laboratories is an imaging and photographic facility. It is an essential adjunct of many types of scientific investigations and may be operated by laboratory scientists on an ad hoc basis or may have fulltime workers when the photographic or imaging workload is heavy.

Laboratories also have continuing needs for the fabrication and repair of all kinds of items that are not easily or quickly available from commercial sources. Often, they are unique instruments or structures that exist solely in the mind of the research investigator. To translate ideas into hardware requires the services of skilled, research-oriented craftsmen who are experienced in dealing with scientists and engineers. Large laboratory organizations find that in-house shop facilities with skilled personnel are an essential adjunct for laboratory operations. The health and safety of the personnel must be considered carefully when the shops are designed, constructed, and equipped. The rules of the Occupational Safety and Health Administration will govern in this part of the laboratory facility.

Support facilities for storage of bulk laboratory chemicals, some types of scientific specimens, and laboratory shop materials have special health, and safety requirements that need to be addressed in design and construction of laboratory buildings. As discussed in Chapters 1, 2, and many earlier type chapters, only amounts of chemicals for daily or weekly use are recommended. Bulk chemicals should be stored in central facilities with adequate and appropriate fire protection systems and fire-resistive construction. Organizations find it beneficial to hire persons trained in safety procedures in handling bulk chemical storage and decanting processes to operate these facilities. Some biological specimens, as mentioned in Chapters 18 and 19, and chemically preserved specimens in museum collections also require careful consideration of hazards pertaining to their storage. Specimens used for research in archaeology, paleontology and geology are normally dry and not preserved in volatile or hazardous chemicals. The safety issues focus upon the weight of specimen collections and strength of floors and structural members required to support these storerooms. The last category of storeroom is for laboratory shop materials and supplies that can pose physical and chemical hazards in shop storerooms.

Hazardous chemical, radioactive, and biological waste handling and disposal is highly regulated in the United States. Special rooms meeting specific design criteria must be provided. Failure to consider or meet these requirements can be costly in terms of retroactive construction, inspection agency citations and accident consequences. Chapter 27 in this part of the book contains much information relating to these needs.

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25

IMAGING AND PHOTOGRAPHIC AND FACILITIES

25.1 INTRODUCTION

For many years, the photographic process was the only way to capture visual information needed for documentation and use. Darkrooms were common in laboratory buildings. Today with the advent of digital imaging many more venues for capturing visual information are available. In addition, there are many processes such as computed tomography (CT), ultrasound, positron emission tomography (PET), and magnetic resonance imaging (MRI) used for human, animal, and other object diagnostics that are used for research purposes. It is anticipated that new and novel methods will be available to the researchers in the future. The intent of this chapter is to provide information on the design of darkrooms as traditional photography is still used, as well as information on the design of digital imaging rooms as digital imaging has become more widely used. However, many enthusiasts of black and white images prefer photographs over a digital image. Many forensic laboratories still have darkrooms as many courts still do not allow digital images as evidence.

25.1.1 Digital Imaging Facilities

Digital imaging provides a more flexible format for how an image can be captured and stored. It eliminates all the need for chemical processing of film. Most of today's diagnostic imaging techniques are only available digitally. Several human and animal tests for clinical research purposes are only possible by digital imaging.

Some of the more common digital imaging processes used are described below.

25.1.1.1 Computed Tomography. CT is used by researchers to obtain detailed visual information on humans in clinical studies, on animals, and on objects such as in fracture analysis in rocks and internal and external examination of critical machine parts. This process uses x-rays; the application, however, is much more sophisticated than traditional body x-rays.

The CT scanner sends x-ray pulses through the subject or the test object. Each pulse lasts less than a second and takes a picture of a thin slice of the object, organ, or area being studied. Each successive pulse takes information on another slice so a computer can generate a composite image. The subject or object rests on a sliding carrier that moves it into the bore of the instrument, as shown in Figure 25-1.

25.1.1.2 Ultrasound. Ultrasound uses reflected sound waves to produce an image inside the test subjects or animal body objects or organs.

For ultrasound testing, a gel or oil is applied to the object's surface or subject's skin to help transmit the sound waves. A small handheld instrument (a transducer) is moved back and forth over the area being examined. The transducer emits high-pitched sound

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FIGURE 25-1. CT scanner.

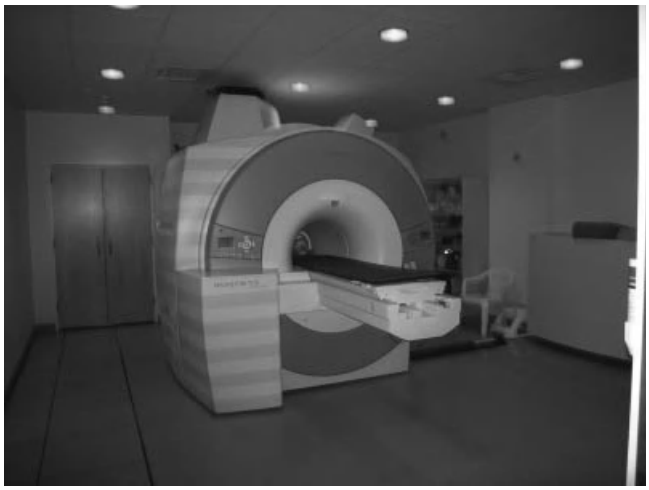


FIGURE 25-3A. Large animal-/human-sized magnetic resonance imaging (MRI) scanner.

FIGURE 25-2. Ultrasound.

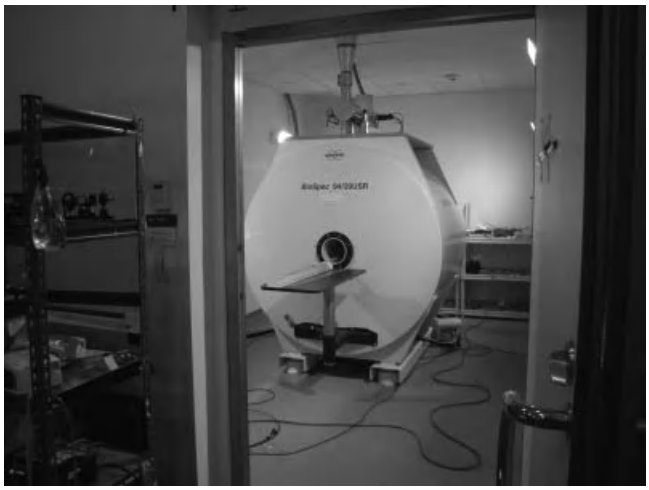


FIGURE 25-3B. Smaller animal MRI.

waves, which are above the range of human hearing. These sound waves reflect back to the transducer. A computer analysis of the reflected sound waves results in an image that is displayed on a screen. The image produced by this process is called a sonogram, echogram, or an ultrasound scan. A permanent record can be made in hard copy, or as a digital file or video. A typical system is shown in Figure 25-2.

25.1.1.3 Magnetic Resonance Imaging. MRI uses a combination of magnetic field and pulses of radio wave energy to make images of organs and soft tissues and structures in the body. MRI in general provides different imaging information from that of an x-ray, ultrasound, or computed tomography (CT) scan. MRI also may show anomalies that cannot be seen with other imaging methods. It has become a valuable research tool. Similar to CT scan, MRI instruments may have a sliding carrier to position the test subject correctly within the bore (see Figures 25-3A and 25-3B). Other MRI instruments have open bores that allow human subjects to sit—not lie down—and can accommodate larger vertical test subjects or objects.

25.1.1.4 Nuclear Medicine Imaging/ Positron Emission Tomography. Medical research imaging is often limited to viewing anatomical structures of the body.

Indeed, x-rays, CT, and MRI yield extremely detailed images. It is often useful, however, to acquire images of physiologic function rather than of anatomy. Such images can be acquired by imaging the decay of radio-isotopes bound to molecules with known biological properties. This class of imaging techniques is known as nuclear medicine imaging (see Ollinger, 1997).

The most common form of nuclear medicine scan uses a gamma-ray emitting radioisotope bound to a chemical with known physiological properties. After it is administered, single photons emitted by the decaying isotope are detected with a gamma camera. A two-dimensional histogram of the detected events forms a projection image of the distribution of the radioisotope and hence of the chemical compound. An example of such a procedure is a cardiac study using thallium-201. Image intensity is indicative of cardiac perfusion and can be used to diagnose defects in the blood supply; this test is widely used to screen for bypass surgery.

Gamma camera-based planar imaging has three major shortcomings.

1. Images are projection images, so the organ of interest can be obscured by activity in front of or behind the organ of interest.
2. The radiopharmaceuticals used must incorporate relatively heavy isotopes such as thallium-201 and technetium-99m.
3. The lead collimator absorbs many photons, thereby reducing the sensitivity of the camera.

PET has inherent advantages that avoid these shortcomings, but the process is costly. The short half-life of most positron-emitting isotopes requires an onsite cyclotron, which is a particle accelerator that requires a trained physicist to operate. The scanners themselves are significantly more sensitive and expensive than single-photon cameras. However, the results can be spectacular. PET not only provides detailed image of the organ being studied, but information on physiologic function status.

25.1.2 Photographic Facility

A photographic facility is designed to provide a variety of services to support research activities such as filming, developing, printing, enlarging, and cassette loading. Photographic darkrooms are used for processing black and white and color film and print paper of different types. They may be located in the laboratory building or in an ancillary building. Digital imaging has replaced most—but not all—wet-process photographic activities for laboratory-based science.

Darkrooms may be one of the following types:

- A small darkroom for research facilities
- Teaching darkrooms for photography and specialized art classes
- Automated photographic systems used for such purposes as medical x-ray processing and some kinds of research. (These are getting less used and have been mostly replaced with digital imaging systems.)

Darkrooms have unique design requirements as do some of the digital imaging processes such as MRI and PET.

25.1.3 Work Activities

25.1.3.1 Digital Imaging Rooms. Work activities include the preparation of animals, organs, patients (human subjects), plants, or other items to be investigated. For patients or human subject's waiting rooms, changing rooms, lockers, and toilet access is essential.

25.1.3.2 Photographic Darkrooms. Work activities include bulk film handling, mixing of chemicals, developing, washing, rinsing, drying, and printmaking. Photographic processes require carefully controlled environmental conditions, including control of light, temperature, and precise use of chemicals. Film coatings are primarily silver compounds.

25.1.4 Equipment and Materials Used

25.1.4.1 Digital Imaging Rooms.

25.1.4.1.1 MRI. MRI units have strong magnetic fields that are continuous. Good shielding to protect personnel and visitors is absolutely necessary. Other unique safety issues must be considered: The website www.MRIsafety.com provides some ongoing valuable information and is an excellent resource.

Most MRI magnets used in patient diagnostic and research are superconducting-type electromagnets. A superconducting MRI magnet has a superconducting wire coil, which has a resistance approximately equal to zero when it is cooled through immersion in cryogenic liquid helium. Once current is flowing in the coil, it will

continue to flow as long as the coil is kept immersed in liquid helium during the MRI scan.

The shielding on the magnet allows for a smaller fringe field. The fringe field drops significantly as one moves away from the magnet. This shielding is achieved by a second set of superconducting windings, outside of the main coil and with opposite current, which reduces the fringe field. This feature is very important for safety reasons and makes it easier to site the MRI magnet.

In the event of a "quench," the magnet shuts down; it is unplanned and can be catastrophic. The MRI equipment rapidly heats, raising the system temperature and resulting in the rapid boil-off of the liquid helium. Quench vents on the MRI equipment must be provided and carefully located to ensure proper discharge of gas in this event and prevent harm to humans. Catastrophic release of cryogenic gases can fill the laboratory, increasing the risk of suffocation or intoxication. In these cases, an emergency, high-rate room ventilation system to remove the asphyxiating or toxic gases flashing from the cryogenic liquid may be required.

25.1.4.1.2 Other Digital Imaging Rooms. Many digital imaging systems consist of a specially configured station where a patient, research subject, animal, or specimen is placed. Special support equipment is usually located in a separate room. This equipment in general produces a lot of heat; it is frequently better and more economical to provide local cooling than to oversize the central HVAC system. Depending upon the imaging system, some back-up power or uninterrupted power supply may be needed.

Where anesthetics are used on animals, well-designed exhausted locations are required. Many times slot hood stations are provided for this purpose. If animals need to be anesthetized on bench tops, good general exhaust is required.

25.1.4.1.3 Computer Data. A lot of computer information is generated. It is important that space be provided for necessary data storage and retrieval so valuable data cannot be lost or inappropriately used. Many facilities use an onsite server to store data and have a password-protected data-retrieval system. Cybersecurity may be an important issue.

25.1.4.2 Photographic Darkrooms. Equipment may include optic enlargers, open tanks, enclosed processing equipment (such as automatic processing units, sometimes referred to as X-O-Mats, shown in Figure 25-4), and dryers. Temperature control of water and chemical solutions is extremely important to the quality of the photographic image. Thermostatic controls are usually set to maintain the water and solutions at 75–68°F (24–20°C). Where manual operations are performed with chemicals in open containers, eyewash stations and emergency showers are needed.

FIGURE 25-4. X-O-Mat with silver recovery system.

TABLE 25-1. Typical Chemicals Used in Darkrooms

Silver compounds
Zinc
Cadmium
Hydroquinone
Acetates
Ammonium hydroxide
Thiosulfates
Trisodium phosphate
Hexacynoferrates
Benzyl alcohol

Many chemicals used in darkrooms and photographic processes are classified as hazardous. They may include solvents, metals, acids, alkalis, aldehydes, and amines (see Table 25-1 for a partial list). Care should be used to store these chemicals in cabinets designed for hazardous chemicals. Some have carcinogenic qualities and must be handled in an exhaust-ventilated area. (More-detailed descriptions of specific photograph processes and their associated health hazards can be found in Houk and Hart, 1987; McCann, 2005; Shaw, 1991.)

25.1.4.2.1 Packaged Processing Units. There are basically two types of packaged color-processing photographic systems:

- *Kodachrome:* Chemicals are an integral part of the film; the processors are very expensive and the quality is uneven.
- *Ektachrome:* Chemicals are applied to the film; these processors are more widely used.

Packaged processing units are designed for high-volume, assembly-line processing of 35-mm film. They do not require a darkroom facility. Packaged systems are popular because of their compact size and efficient chemical usage. Most machines can process black and white film, develop negatives and slides, and make prints. Packaged processing systems are either tabletop or floor mounted; tabletop models are smaller. They require a supply of tempered water, cold water, and drainage. Many of the package systems contain an electric heater for solution temperature control. The chemicals are stored in bottles and dispensed as needed. The spent solution is also stored in containers provided with the unit. Waste containers can either be drained for disposal or stored for silver recovery.

The amount of chemical waste produced in these systems is small. For example, a typical tabletop system that operates all day will generate approximately 2 L of chemical waste. Some of these chemicals are not considered hazardous waste and can therefore go down the drain. Other chemical wastes, including all silver-bearing wastes, are hazardous and must be disposed of accordingly. Many large and small darkrooms now consolidate waste fixer into 10- to 20-gallon drums for later silver recovery (shown in Figure 25-4) and hazardous waste disposal cost control. An area for collecting and holding waste chemical liquids, perhaps in their original containers or in drums, as with the fixer, should be considered in the design phase.

An exhaust outlet should be located near the unit for ventilation. Some machines have exhaust connections; otherwise, a canopy-type capture hood may be sufficient. See Chapter 32, Section 32-10.

25.2 PHOTOGRAPHIC AND IMAGING FACILITY LAYOUTS

25.2.1 Imaging Room Layouts

Special consideration must be provided for unique conditions, i.e., equipment weight, vibration, and shielding requirements; in the case of MRI, the magnetic field must be considered. Radiation shielding considerations are critical in a layout for a PET scanner. In general, a layout consisting of a support equipment room, control room, and a work room where the imaging device is located works well.

For imaging rooms, it will be necessary to have an anteroom used as a control room because of the radiation or magnetic exposure potential near some imaging machines.

The layout sometimes can be vendor specific. It is recommended that vendors be engaged early in the design process to confirm size of the room and establish other utility requirements.

The control room should have direct access to the scanner room and be close to other facilities to ensure a good traffic pattern.

25.2.1.1 PET Room Layout. All considerations provided in Chapter 13, Radiation Laboratory should be addressed. Anderson (2007) provides a good discussion of unique aspects of layout.

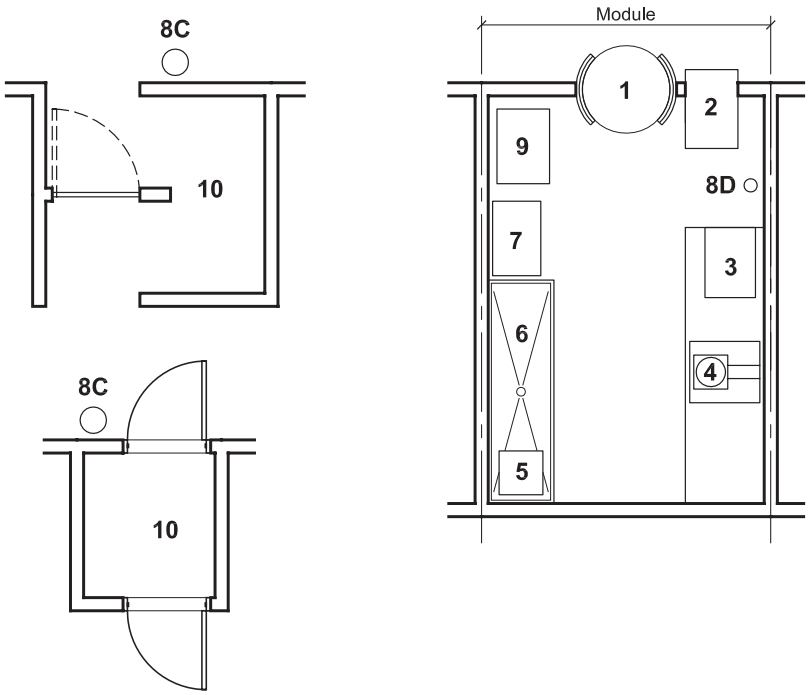
25.2.1.1.1 Injection Rooms. This is the space where the research subject or patient is injected with the dose. A toilet should be available close to the injection area so that the subject can empty his or her bladder prior to being escorted to the scanner. Privacy curtains, subdued lighting, and noise control should be also be considered.

25.2.1.1.2 Hot Lab. The hot lab has several special requirements. It is the space where doses are calibrated and possibly stored. Shielding requirements can be substantial. The laboratory benches need to be solidly built to withstand the weight of shielded containers of doses. These containers can be large and heavy. For example, one vendor's container is approximately 8 in. × 10 in. × 13 in. (20 cm × 25 cm × 32 cm) and weighs about 66 lbs (30 kg).

25.2.2 Photographic Darkroom Layout

All issues discussed in Section 2 of Chapters 1 and 2 should be reviewed, and if applicable, implemented. Criteria for a good photographic darkroom are the capacity for good ventilation, maintenance of lightproof conditions, and the ability to store chemicals in a safe manner. Figures 25-5 and 25-6 show typical darkroom layouts for small research and large teaching facilities, respectively.

25.2.2.1 Personnel Entry and Egress. In large teaching darkrooms, it may be advantageous to divide different types of work into separate rooms—for example, to put color processing, black and white processing, and



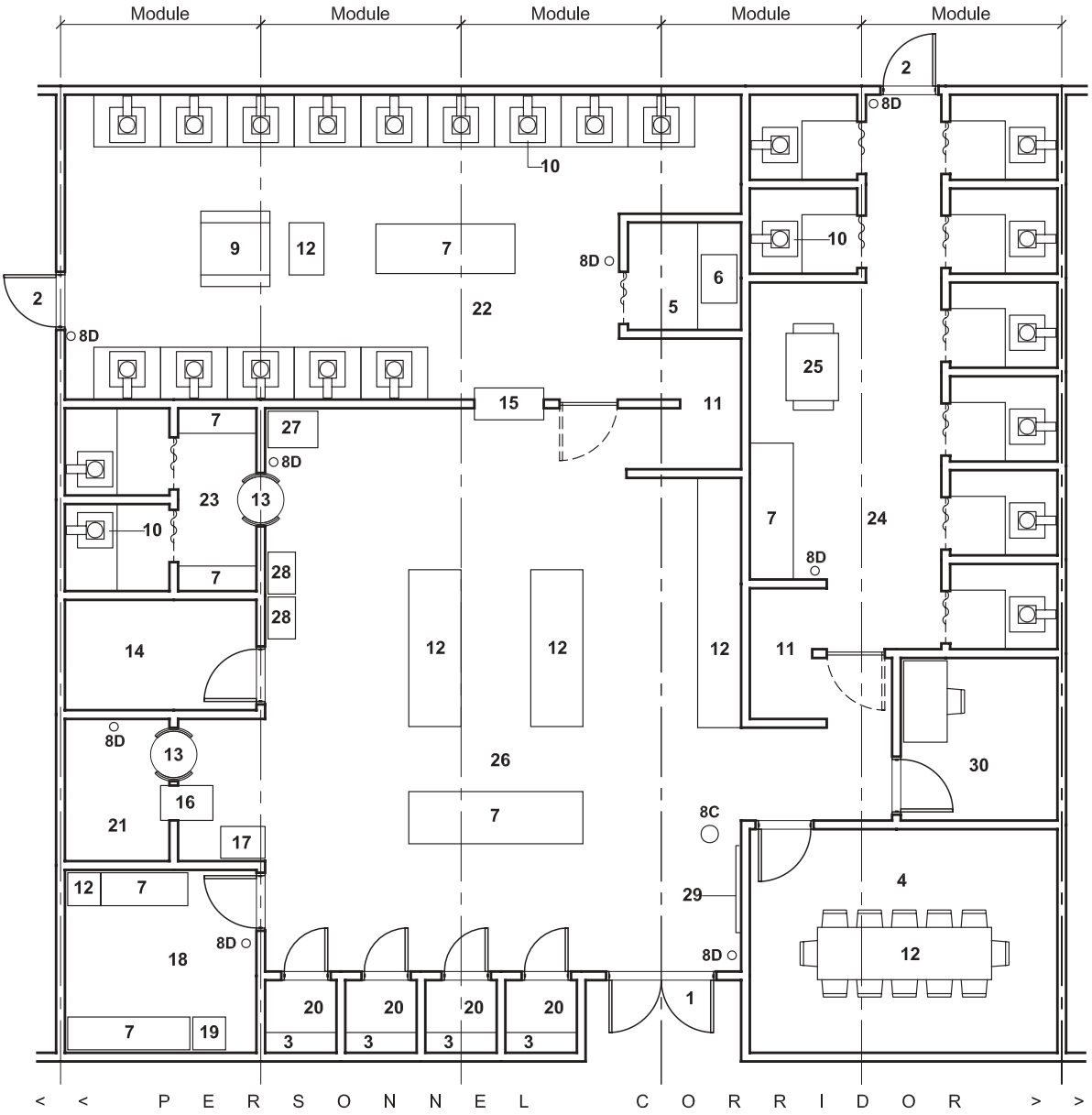
KEY

1	Revolving Darkroom Door with Emergency Breakaway Attachments.
2	X-Ray Film Developer
3	Light Table
4	Enlarger
5	Film Processing Tank
6	Sink
7	Print Washer
8C	Emergency EW & SS
8D	Fire Extinguisher
9	Print Dryer
10	Alternative Light Locks

FIGURE 25-5. Small teaching darkroom: Sample layout.

photofinishing in separate rooms. For rooms of less than 200 net ft^2 (19 m^2), one entry/egress is sufficient. Larger rooms require a second egress. Rooms should be wheelchair accessible.

Light control is absolutely necessary. As the name suggests, this room type should be capable of achieving total darkness. In small facilities, a special light-tight, multipaneled revolving door is used for entry and egress, but the revolving door must have panels that fold back under moderate pressure to provide unimpeded egress in case of an emergency or when a large piece of equipment must be introduced or removed. Revolving doors are available in l-h fire-rated assemblies for installation in fire-rated egress corridor walls. Consideration should be given to providing a swinging door of standard size in addition to a revolving door. It can be used for equipment moving and for personnel exit in an emergency. It can also provide access for disabled persons. Figure 25-7 shows an example of a revolving door. In large facilities, a zigzag-type light trap may be used to ensure darkness. This type of entry allows heavier traffic in and out of the darkroom without having to rely on sealed



KEY

1	Primary Access/Egress	11	Light Trap	22	B+W Printing Darkroom
2	Emergency Second Egress	12	Table	23	Advanced Student Darkroom
3	Counter	13	2 Way Rotary Light Lock	24	Color Enlarging Darkrooms
4	Classroom/Conference Room	14	Storage Room	25	Color Print Processor
5	Print Inspection Room	15	Pass-Thru	26	Finishing Area
6	Viewing Booth	16	B+W Film Processor	27	Wash
7	Sink with Eye Wash	17	Film Dryer	28	Dryers
8C	Emergency EW & SS	18	Film Processing	29	Bulletin Board
8D	Fire Extinguisher	19	Color Film Processing	30	Manager's Office
9	B+W Paper Processor	20	Film Loading Rooms		
10	Enlarger Station	21	Darkroom		

FIGURE 25-6. Large teaching darkroom: Sample layout.

FIGURE 25-7. Darkroom revolving door.

doorways. A sign or signal light outside the darkroom is used to indicate when developing is in process to ensure that lightproof conditions are maintained.

25.2.2.2 Darkroom Furniture Locations. Sturdy shelves for the storage of chemicals as well as other photographic equipment and supplies are needed. Some photographic supplies may need storage in a lightproof area or cabinet. It is important that sufficient countertop area be provided for equipment such as enlargers.

Silver recovery systems for the rinse water should be used where volumes are appropriate. Extra space for hazardous waste [5–25 gal (20–100 L) containers] may be needed, when bulking for waste solutions is required (See Chapter 27, Section 27.1.3.1 for a definition of bulking.)

25.2.2.3 Darkroom Surface Finish Considerations. Walls in darkrooms are sometimes painted dark colors to reduce chance reflections from an unexpected light source. When safe lights (i.e., special fixtures with a variety of light filters that provide minimum illumination so as not to damage or otherwise affect the photo plates) are switched on, normal working lights should be wired so they cannot accidentally be switched on. For floors subject to spills and splashes, surfaces should be slip resistant, and special mats should be provided with a raised texture or grids at sink work areas to reduce the risk of falls.

25.3 HEATING, VENTILATING, AND AIR-CONDITIONING

25.3.1. Digital Imaging Rooms

HVAC systems for digital imaging rooms pose their own challenges. Some of the requirements for MRI have been already discussed in Section 25.1.4.1. The support equipment room has most of the heat-producing devices. Local coolers provide an excellent approach to handle this heat load without impacting the overall building supply air system; no special temperature or humidity conditions are required.

Imaging rooms with strong magnetic fields require nonferrous duct and piping materials. Imaging rooms with quenching requirements that may release large quantities of helium must be ducted properly. As the discharges are occasional and may never happen, it is critical that the end of the discharge pipe be located to avoid obstruction and be examined periodically.

Most of the imaging equipment has local chillers for process cooling. The chillers are further cooled by the building's central systems as back-up. In more critical applications, a local back-up may need to be provided in addition to a central system back-up.

25.3.2 Darkrooms

Heating, ventilating, and air-conditioning systems for processing darkrooms can be very complex because of the high humidity caused by the use of chemical solutions in open tanks or trays and the wash and rinse processes that add additional humidity to the room. Humidity affects the drying time for negatives and film. When humidity is too low, however, it can cause static electricity that will streak processed film. Relative humidity between 40% and 50% is the recommended range. A temperature range of 68–78°F (20–26°C) is acceptable for most darkrooms. Conditions in excess of 80°F (27°C) and 50% RH should be avoided.

Because of the large amount of chemicals used and odors that might be objectionable to others, recirculation of air from the darkroom is not recommended. The pressure in darkrooms should be negative with respect to all other adjacent rooms. Local exhaust ven-

tilation should be used to control the nuisance level of odorous and irritating chemicals in mixing areas and at sinks.

Some photographic film processing requires darkrooms with a dust-free environment. For these, use of HEPA filters in a laminar flow cleanroom configuration or laminar flow workstations should be considered. Usually, 85% efficiency bag-type disposable filters will be adequate (ASHRAE, 2011).

25.3.2.1 Ventilation Rates. Darkrooms require a minimum of 0.5 CFM of outdoor air per square foot of floor area (0.0026 $m^3/min/m^2$) for ventilation. Alternatively, 8–10 ACH are sufficient under most conditions. The key is to have local exhaust hoods to capture contaminants at the source. Supply air outlets should be located so that they will not create drafts or cause short-circuiting of air into the exhaust air registers or systems. Long periods inside a closed, confined darkroom could be unpleasant without adequate ventilation. Therefore, a dynamic makeup air system should be included to heat and cool the darkroom and provide comfort conditions for those working there.

When calculating ventilation rates, it may be enough to match generation rate of contaminants with an adequate flow of dilution air (Crawley, 1985). A rule of thumb is to use 200 CFM (0.09 m^3/s) per processing machine.

25.3.2.2 Local Exhaust. A covered tank requires little exhaust; approximately 25–30 CFM per square foot of tank area (0.12–0.15 $m^3/min/m^2$) is adequate. However, an open tank requires an exhaust slot hood at the edge of the tank or in the middle, drawing 150–200 CFM per square foot of tank area (0.7–1.0 $m^3/min/m^2$).

For processes using open trays of chemical solutions, lateral slot exhaust openings or an enclosure hood should be used. The *Industrial Ventilation: A Manual of Recommended Practice for Design, 27th Edition* (American Conference of Governmental Industrial Hygienists [ACGIH], 2010) contains design guidance. Local exhaust systems are used because they provide better control of fumes before they reach the breathing zone of workers. Examples are shown in Figures 25-8 and 25-9.

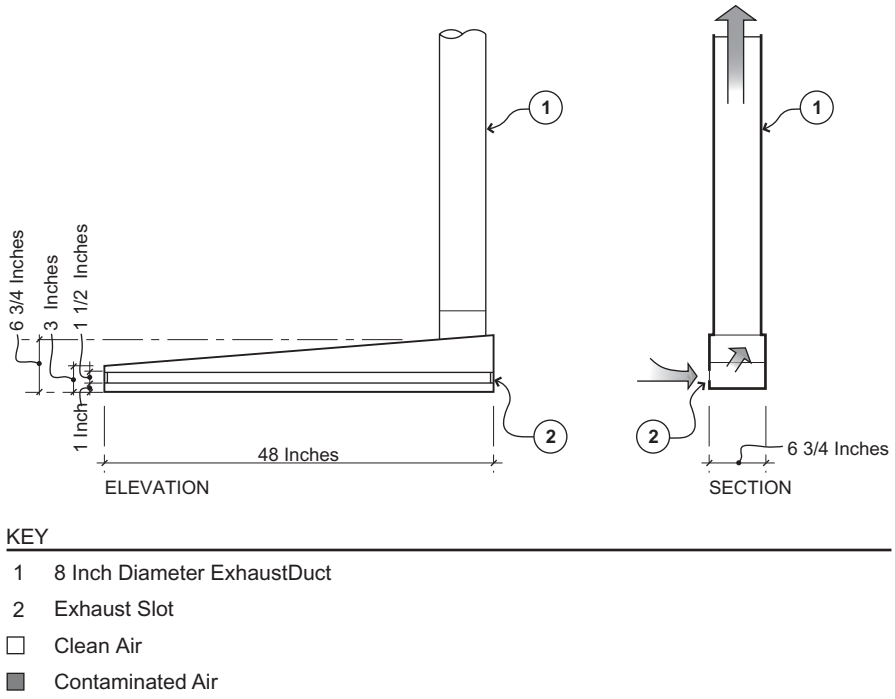


FIGURE 25-8. Small hood for darkroom: Elevation and section (Sizes may vary according to specific applications).

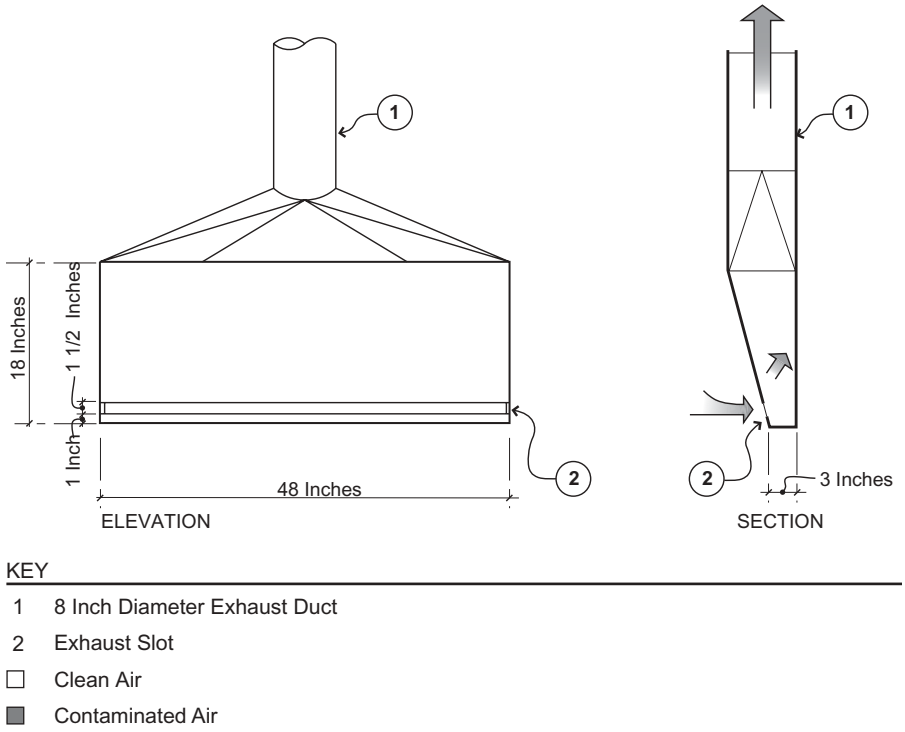


FIGURE 25-9. Large hood for darkroom: Elevation and section (sizes may vary according to specific applications).

25.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

All recommendations contained in Section 4 of Chapters 1 and 2 should be reviewed and implemented.

25.4.1 Digital Imaging Rooms

25.4.1.1 Imaging Rooms with Magnetic Field (MRI). Signage to prevent personnel from entering a room containing an MRI scanner with ferrous or metallic objects is vital. Training of personnel who use these systems is paramount. Protective equipment such as fire extinguishers must be of aluminum construction. Similarly, compressed gas cylinders must also be nonferrous and properly color coded for easy identification. Even then, it is necessary for the operator to have a magnetic wand to measure the magnetic field to confirm before any item is brought near the magnet. The 5-Gauss line around the magnet is usually considered to be a safety perimeter. Items inside are subjected to a potentially harmful magnetic field.

25.4.1.2 Oxygen Detection in MRI Rooms. Because of the large quantities of cryogens used such as helium, it is necessary to have a continuous oxygen monitor in the imaging room to detect any decrease in oxygen levels due to a leak in the cryogen system. The location of these detectors is critical because they need to be able to detect oxygen deficiency while at the same time not interfere with the operation of the imaging unit. They need to be in areas with adequate air movement and mixing. Some argue that imaging lab filling with cryogen. This can be any gas that is liquid at very cold temperatures and/or is under heavy pressure. In this case they are probably referring to cryogenic nitrogen. The detectors should be located at low level say 4 to 4.5 ft above the finished floor. The danger of these detectors getting damaged by room activity is greater if installed at lower levels.

25.4.1.3 Shielding in PET Rooms. Most commonly lead and/or concrete is used for area shielding in a PET facility. The attenuation factor necessary for shielding is likely to be no more than 10, but the high penetration of 511 keV photons can require a signi-

ficant thickness of either material. Use of concrete may be expensive. Lead is readily available in the form of leaded wallboard and as plate and sheet stock for special construction.

As the operator will spend most time in the PET scanner control room, shielding of control room should be reviewed. In addition, the injection rooms and hot lab also require radiation shielding.

25.4.2 Darkrooms

It is important that all electrical receptacles near sinks be provided with ground fault current interrupter (GFCI) devices to prevent electrical shock hazards. Flooring should be nonskid to reduce the chance of falls due to spills and splashing. A safety shower and emergency eyewash are needed. Emergency eyewash fountains plumbed with tempered potable water should be installed in a large student darkroom.

The water supply to the rinsing bath should have backflow preventers to protect the building water supply from accidental contamination.

25.4.2.1 Personal Protective Equipment in Darkrooms. Aprons face shields, safety glasses, goggles, and gloves should be used, and a convenient storage place should be provided for these items.

25.4.2.2 Chemical Exposure Hazards Darkrooms. The greatest health concern that results from continuous exposure to photographic chemicals is contact dermatitis or allergic contact dermatitis (ACD; Brancaccio, Cockerell, Belsito, & Ostreicher, 1993; McCann, 2005). Therefore, a high level of personal hygiene is called for, and washing facilities must be provided in the darkroom.

Most photographic darkrooms do not use chemicals in the quantities formerly used in medical x-ray film processing, so the dangers of developing these problems are less likely. With the advent of digital processes, most hospitals and clinics have switched their practices.

25.5 SPECIAL REQUIREMENTS

All items described in Section 5 of Chapters 1 and 2 should be reviewed, and those that are relevant should be implemented.

25.5.1 Storage

25.5.1.1 Darkroom Storage of Unprocessed Products. In the *ASHRAE Applications Handbook* (Chapter 22, ASHRAE, 2011), there is a recommendation that photographic products not be stored in damp basements or in high-temperature and high-humidity areas. The ideal storage temperature is 60°F (16°C) with a humidity range of 40–60%, with 40% RH being preferred. In tropical areas, refrigerated storage is recommended. Supplies should be kept in vapor-tight packages or placed in sealed containers. Black and white printing papers should be stored at 70°F (21°C) or below and color film or paper at 45–50°F (7°–10°C). Long-term storage of color film or papers at a temperature above 70°F (21°C) may affect color balance. When products are taken out of long-term storage, a warm-up time is necessary before use (ASHRAE, 2011).

25.5.1.2 Storage of Processed Film and Prints in Darkrooms. Usually, processed film and prints are not stored in the darkroom because storage requirements make it hard for processing and storage to be conducted in the same room. ISO 18911, "Imaging Materials – Processed Safety, Photographic Film Storage Practice" (2000) provides guidance on three levels of storage: medium term, long term, and archival. Specific details for storage environments are available in the ASHRAE Applications Handbook, Chapter 22 (ASHRAE, 2011).

25.5.2 Plumbing

25.5.2.1 Imaging Room Plumbing. In general, no plumbing is provided in imaging rooms. However, in rooms containing a CT scanner or where ultrasound is performed hand-wash sinks are needed. Radioisotopes may be used in CT scan rooms and the gels applied in ultrasound procedures need to be washed off before technicians leave the room.

Many imaging facilities require access to a toilet in or near changing rooms for human subjects or patients.

25.5.2.2 Darkroom Plumbing. Wash water discharged from photographic processes contains chemicals that may not be discharged directly into the sewer system, unless the volume is truly trivial. For example, in radiology processing, where large amounts of x-ray film are processed regularly, it will be cost effective to install a silver-recovery system. However, the chemicals used occasionally in a darkroom are unlikely to be large enough to warrant recovery. Plumbing fixtures should be selected to provide sufficient width, length, and depth

for the number of trays that will normally be used. Thermostatic mixing valves that maintain the correct temperature will be needed. In addition, the water supply may require filtration to remove particulate matter; a 50-μm filter is recommended.

25.5.3 Security

25.5.3.1 MRI Security. Three levels of security are required for MRI imaging rooms: (1) the room itself, (2) the control room, and (3) the surrounding laboratory or animal housing suite. All three must have controlled access.

26

SUPPORT SHOPS

26.1 DESCRIPTION

26.1.1 Introduction

Support shop areas for laboratory facilities contribute to research activities by providing assistance with instrument design, maintenance, and repair. Support services include machine, welding, electronics, glassblowing, carpentry, plastics, and scientific equipment. At small institutions, several functions may be combined into a single shop. Support shops may be located in a laboratory building or in an ancillary building that may also contain storage space and other types of shops for maintenance activities.

26.1.2 Work Activities

Support shop activities relate to the research or physical plant activities to which the shop is dedicated. Materials in these shops may be milled, cut, sawn, bent, blown, ground, sanded, polished, cleaned, dried, painted, soldered, welded, etched, doped, glued, heated, melted, molded, drilled, screwed, riveted, turned on a lathe, punched, or joined to construct or repair a variety of instruments, chambers, and all scientific apparatus or facilities used in research. This work may be performed at machines, on workbenches, or in the laboratories involved.

26.1.3 Equipment and Materials

Equipment used in machine support shops may include any combination of the following: milling machine (manual or digital controls); computer numerically controlled (CNC) milling and router machine for nonmetallic materials; metal, glass, or plastic cutter; laser cutter (tabletop to room size); saws (circular, table, band, jig); dust collection equipment; grinder; sander; polisher; acid dip tank; oven; paint sprayer; furnace; blowtorch; soldering iron; stereo lithography machine; welding machine; arc welder; drill press; three-dimensional rapid prototyping machine; industrial rotational molding chamber; riveter; punch; anvil; lathe; clamps; joiner; router; crane; hoist; a variety of hand tools; disc grinder; portable hand-grinding bench; welding bench; metal-cutting band saw; solvent degreasing tank; spray paint booth; buffing wheel; and abrasive blasting cabinet. Many items listed above now have digital controls and/or are computer driven with computer-aided design and manufacturing (CAD/CAM) programs.

Electronic support shops may contain electrical and electronic analytic instruments, transformers, and oscilloscopes. Computers are used extensively in electronic support shops.

Materials commonly used in support shops and stored in shop storerooms include any combination of the following: sheet metal and metal castings; wire, rods,

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

pipes, and extrusions; glass and plastic pellets, fine powders, and sheets; foam-core, wood planks, and plywood sheets; resins and resin powders; paint; glue; epoxy compounds; solvents; strong acids and other chemicals; volatile and flammable liquids; and compressed gas cylinders (see Chapter 28, Section 28.1.3.6).

26.1.4 Exclusions

Support shop areas are not production facilities; they are intended only to support laboratory activities. Access to professionally managed support shop areas may be limited to trained shop staff to maintain safety and security of machines, tools, and materials. Often separate shops and shop areas are specifically designated open for use by scientific staff members. Support shops open to all scientific staff, faculty, and students should be designed with careful consideration of the additional safety features needed for amateur craftspeople.

26.2 LAYOUT

Each item addressed in Chapter 1, Section 1.2 should be evaluated for its applicability to the specific needs of those who will use and occupy support shops, and items that are relevant should be implemented. Some layout considerations in Chapter 2, Section 2.2 apply to support shop areas and in Chapter 28, Section 28.2.3.6 to shop storerooms. The shop manager and users should be consulted throughout the design process and should be closely involved in exploring options in shop layout. They have important information for the materials, sizes of materials they intend to use, as well as the list of equipment, tools, and operations of the proposed machines to be installed. This interaction will improve safety and function of the space. Because most of the activities involving major shop equipment incur some risk to health and safety, good hazard zoning is important but may be difficult to achieve. In these and for other environmental considerations, control rooms separate from the machine and processing area are recommended to protect machine users of some hazardous processes using computer-driven and digital control systems.

26.2.1 Personnel Entry and Egress

A minimum of two exits should be provided from support shop areas that use chemicals or that have other potential high-hazard conditions such as high voltage, potential for fire or explosion, or high concentrations of airborne particulate matter. These exits must be placed apart. In code-compliant, fully automatic sprinklered buildings, this distance must be equal to or less than one-third of the length of the maximum diagonal dimension of the shop and measured in a straight line between exit doors (IBC 1015.2.1(2); IBC, 2012). Maximum travel distance to an exit is 50 lf from the furthest location in the shop. If any location is greater than 50 ft, most building code officials will require installation of another exit (see Chapter 2, Section 2.2.2.2).

Consideration should be given to access to support shops for bringing in equipment and materials. Either the support shop and storeroom areas should have their own loading dock or one should be conveniently nearby. Corridor and door widths between shops, shop storerooms, and loading dock should allow safe transport of large machines and bulky materials, and should comply with building codes of the jurisdiction having authority.

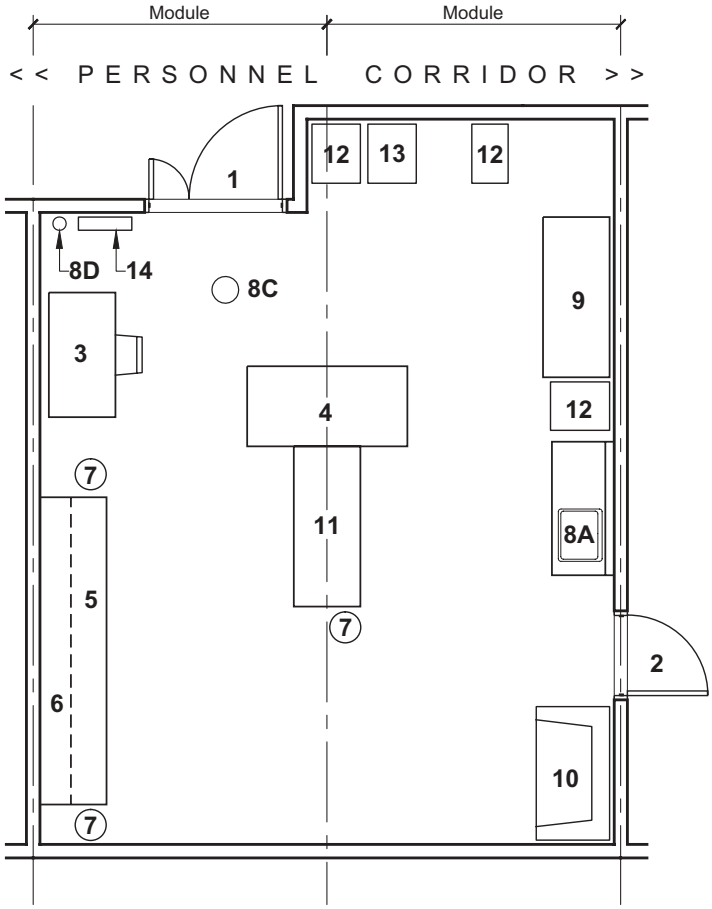
26.2.2 Aisles

Aisles between benches or machines should have a minimum clearance of 5 ft (1.5 m) to meet the requirements of the ADA (1990). Wider aisles allow workers to maneuver bulky materials safely, especially long bar or sheet stock. Adequate clearance also allows workers to safely back away from a machine or process if an unsafe condition develops.

Major aisles in machine and woodworking shops should be wider than 5 ft (1.5 m) to accommodate the large sizes of materials and apparatus commonly handled in these types of shops and materials' handling equipment. Aisles that are equipped with cranes should be wider for the same reason. The major aisle width should be determined by the largest machine used or largest piece of material to be processed to allow servicing, relocation, or replacement without moving other machines aside.

26.2.3 Location of Exhaust Hoods

Just as in research laboratories, hazardous chemical operations should be conducted in a chemical fume hood. Other forms of local exhaust ventilation that may be needed are a spray paint booth and slot exhaust systems for soldering benches, solvent cleaning tanks, welding and carpentry equipment, and grinding tables. Chemical fume hoods must be located away from the primary shop exit and circulation aisle for personnel safety and to reduce adverse effects on hood performance. Similar layout considerations apply to locations of most local exhaust devices at hazardous operations or equipment. Figure 26-1 illustrates a good location for a chemical fume hood within a glassblowing shop.



KEY

1	Primary Access/Egress
2	Emergency Second Egress
3	Desk
4	Work Bench
5	High Work Bench
6	Glass Storage Shelving
7	Gas Tanks
8A	Sink
8C	Emergency EW & SS
8D	Fire Extinguisher
9	Annealing Oven
10	Fume Hood
11	Lathe
12	Grinder
13	Cutter
14	Fire Blanket

FIGURE 26-1. Glassblowing shop layout.

The chemical hood in the corner is separated from normal traffic in the lab, but adjacent to an emergency egress.

26.2.4 Location of Equipment

Layout of support shop equipment, benches, and machines should be guided by several considerations:

1. Sequence of machine use in typical shop processes
2. Ability to service the machines
3. Accessories to machines, mounting position, clearances, and service access
4. Size of typical materials and safe approach to the machines by users handling those materials.
5. Potential breakaway or accident modes of the machine itself or of materials on the machine
6. In addition, equipment manufacturers should be consulted for advice on service access and any uses of the machine that may affect location.

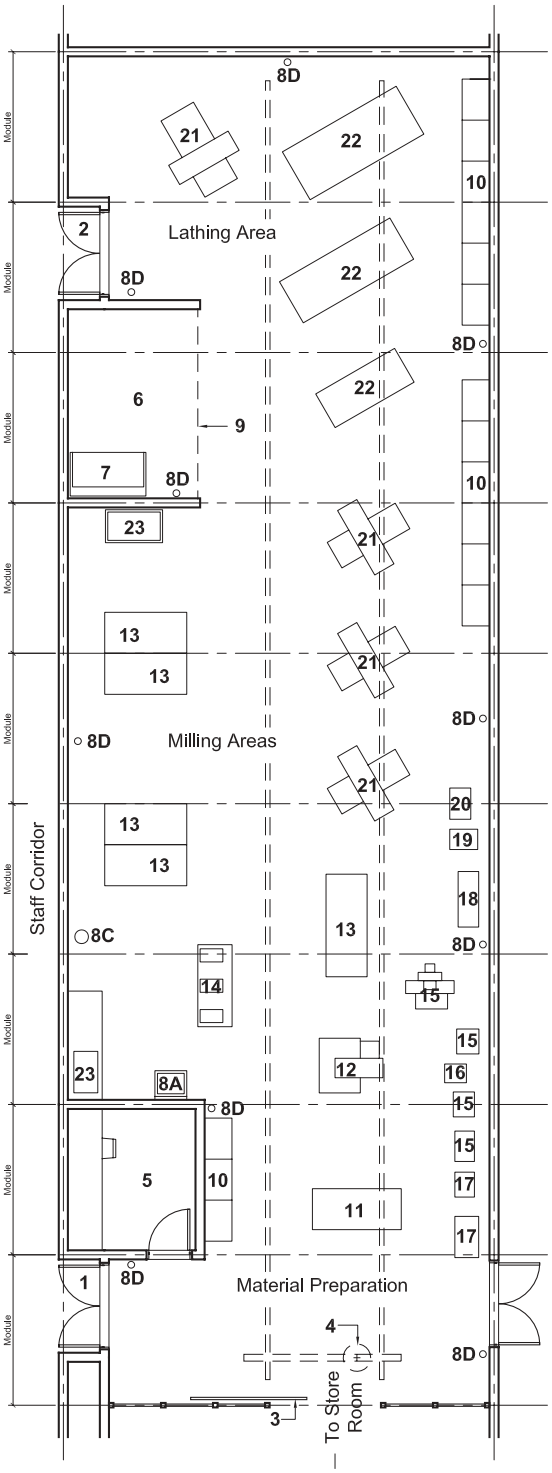
26.2.4.1 Sequence of Machine Locations. When machines or other pieces of equipment are arranged in the sequence in which they will typically be used, there may be a reduction of cross-traffic in the shop. An example of a central shop, for the use of shop professionals was designed with consideration of the sequence of shop equipment usage, as shown in Figure 26-2. As a result, persons transporting large pieces of material or working on initial cutting or bending processes are less likely to disturb those executing finer operations on small parts later in the sequence. The goal of this approach is to reduce traffic around machines. This allows shop workers to concentrate on their work and have better freedom of movement around the machine with which they are working. On the other hand, when particular machines are used frequently at many phases of the process, they should be located in a central position, accessible from all parts of the shop. Clearances on all sides of the machines should be ample to allow persons not using the machines to pass around them safely without interfering with their operation or the operator.

26.2.4.2 Service Clearances. All machines require servicing; the shop layout should allow clearances for safe and convenient conduct of these routine and major operations. It is prudent to refer to equipment installation manuals and to consult equipment manufacturers directly for this information to gain sufficient understanding of servicing issues. Many machines require local exhaust ventilation devices; clearances must be allowed for the required hoods and ducts, or dust collectors. Clearances should also allow easy floor cleaning behind and between machines.

26.2.4.3 Materials Handling Clearances. Maneuvering large sheets of metal, wood, plastic, and glass, long bar stock, and pipes can cause safety problems in shops. Often, the first task is to cut the material to a smaller size. The materials will be carried to a saw or cutting or bending machine (metal brake), placed, and correctly positioned on the work platform, and then processed. Lifting and securing large unwieldy materials onto the machine is difficult and unsafe when there is insufficient clearance around the machine, particularly when two or more workers must lift and position the material. Machines that are identified for use with large sizes of materials should be positioned so that there are no conflicting machines or activities on the sides of the machine where materials must be maneuvered. Consideration should be given to putting these machines in single-loaded aisle locations.

Furthermore, machine processes that produce fumes or by-products that may cause harm to people or other nearby machines should be located in a manner that reduces hazards of by-product dispersal (see Section 26.3.2.3 below). An example of this is grinders that routinely spin off scrap and particles. This type of equipment should be located in a safe place, protected by a movable screen or a heavy, stiff curtain so that the surroundings and people are protected.

26.2.4.4 Accommodation for Machine Accessories. Many new support shop machines are offered by manufacturers with a wide array of accessories, whether it is special computer programs for processes or for custom particulate collectors and exhaust devices. Understanding of all the impacts on the layout and use of machines is necessary for safe layouts of support shops. Computer numeric control (CNC) milling/router machines' particulate collection device is half the size of this large machine. Laser cutters and three-dimensional rapid prototype machines require control stations where the operator works. Control stations may need to be located behind a barrier or in a separate room from the machine, according to the hazards generated and size of the machine. Other accessories may increase the height of the machine when installed, which impacts ceiling heights and vertical clearances that may be required. These spatial impacts and utility requirements of accessories should be identified in the programming process and explored in detail in the planning process.



KEY

1	Primary Access/Egress
2	Emergency Second Egress
3	Gate
4	Overhead Bridge Crane
5	Office
6	Welding Zone
7	Welding Hood
8A	Sink
8C	Emergency EW & SS
8D	Fire Extinguisher
9	Fire Curtain
10	Storage
11	Metal Saw
12	Band Saw
13	Work Bench
14	Drill Press
15	Grinders
16	Tapping Machine
17	Sanding Belt
18	Hydraulic Press
19	Manual Punch
20	Punch
21	Milling Machine
22	Lathe
23	Dip Tank

FIGURE 26-2. Large machine shop layout.

26.2.5 Layout for Hazard Reduction

Support shop layout should be evaluated on potential breakaway or accident modes of each machine itself, as well as materials on that machine. Blades, drill bits, and armatures that are improperly installed, overstressed, weakened by overuse, or unsecured can be potentially dangerous missiles in a shop. Materials, too, can fly off milling machines and lathes at great speed. Saws, when improperly used, are hazardous for this reason. It is important to locate lathes and saws in positions where ejected materials are unlikely to hit a person. It is more difficult to position milling machines and drills to reduce danger from ejected materials because of their 360-degree horizontal trajectory.

In addition to physical hazards, some nonmetallic materials, such as resins used on machines can emit toxic and/or flammable vapors or fumes generated during the operation or in the curing or drying process. Some plastic materials are in the form of very fine respirable powders before they are cast or molded. Other materials may be dipped in vats or sprayed with cyano-acrylate or epoxy infusion materials. Some materials, such as foam-core sheets, cut by laser can emit toxic and flammable fumes. Laser cutters are manufactured with 30 W power for tabletop models and up to 300 W power for much larger size laser cutters that fill a room. Large laser cutters should be used with great care and have safety shut-off power interlocks when they are water-cooled.

Blowtorches for soldering and welding should only be used with appropriate personal protection gear. They should be used on a bench with a slot exhaust hood (see Chapter 32, Figure 32-8) or a portable exhaust capture hood. Screens and booths that block harmful light and heat can protect other workers in the shop. The goal of this approach in shop layout is to reduce the risk of an accident for those nearby. This allows shop workers to concentrate on the work.

Desk workstations should be protected from shop hazards and located near exits. Figure 26-2 shows a layout for a machine shop in an academic research building that was designed with hazard zoning in mind in the arrangement of equipment and processes.

26.2.6 Walls, Floors, and Ceilings

Walls of support shops are subject to impacts from machines and materials. Sturdy materials should be used to construct walls and floors. Walls of concrete masonry units reinforced with steel or walls constructed of steel studs with high-impact gypsum wallboard surfaces are serviceable and durable under support shop conditions. Bumper-rails protect walls when carts and hand-trucks crash into rails. Fire-rated assemblies can be made from these materials where required by building codes and jurisdictions having authority. Finished ceilings are optional in shops and may be installed for aesthetic and acoustical needs.

Flooring materials such as sealed concrete and sealed end-grain wood parquet can be maintained easily. Floors must hold up to grease and solvent spills as well as to destructive scrapes, cuts, and impact loads from falling materials and sharp tools. Metal particles and shavings can become a hazard when embedded in flooring materials. Currently, the EPA requires copper and lead metal shavings to be collected off floors and work surfaces and handled as hazardous waste (Resource Conservation and Recovery Act of 1976, 40CFR 261.5; EPA, 2012).

26.3 HEATING, VENTILATING, AND AIR-CONDITIONING

26.3.1 Introduction

All the recommendations provided in Chapters 1 and 2, Sections.3 and 3 should be reviewed, and those that are relevant should be implemented. Machining of some materials, such as metallic sodium or beryllium, some resins, epoxies, and plastics require special controls, atmospheres, or ventilation during processing. An industrial hygienist should be consulted for directives on special materials. Support shops may have fume hoods and a variety of local exhaust devices to contain fumes from activities such as heating resin and plastic powders and pellets, fine filament deposition, cutting certain nonmetallic materials, welding and acid etching, plus filters for dust generated at CNC milling and router machines, grinders, saws, and lathes.

26.3.2 Additional HVAC Needs

26.3.2.1 Temperature and Humidity Control. Normal comfort-level temperatures are recommended for laboratory support shop areas. In addition, machine and metal shops require control of excess humidity to reduce damage to metals and machines from rust. Relative humidity of 30% or below is recommended. When support shops have direct access to loading docks, additional heat supply units and shielding curtains are needed to avoid cold drafts in the shop area during periods when shipping doors are open in cold weather.

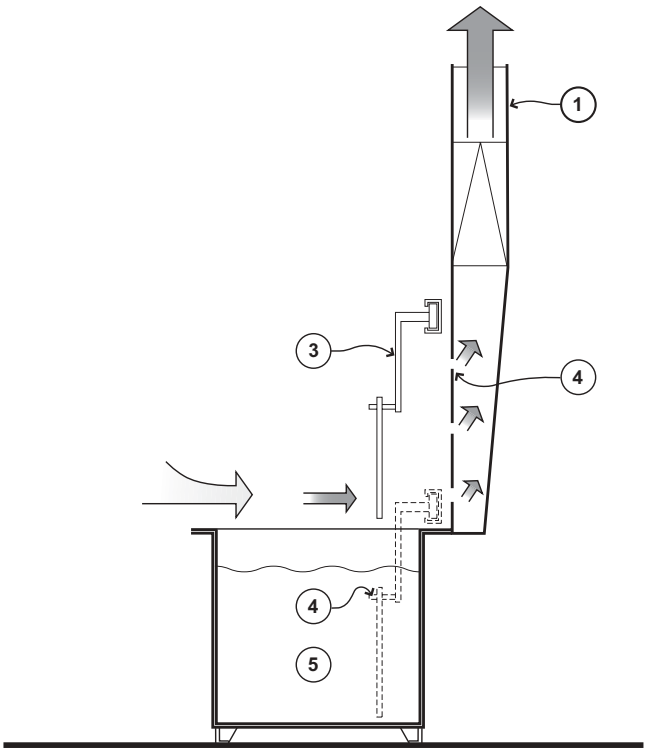
Glassblowing shops often have high heat loads from open flames and high-temperature ovens that run for long periods or shop equipment, such as industrial rotational molding chambers.

Air-conditioning is recommended, if possible, to maintain tolerable working conditions and lower humidity.

To save energy in cooling large shops, displacement ventilation delivered at low levels along walls is effective. In ambient summer temperatures, mobile water-cooled fan coil units can be moved and used where occupants work.

26.3.2.2 Exhaust Systems. Equipment manufacturers should be consulted for recommendations on the need for special local exhaust systems. Glassblowing shops require a chemical fume hood for use of solvents and strong acids. Machine and metal shops may also use strong acids (such as hydrogen fluoride) for degreasing metal parts. They often use flammable solvents for other cleaning tasks. Local exhaust hoods and fume-extraction devices are recommended at dip tanks to remove hazardous fumes or particulate matter, as shown in Figure 26-3. Welding and soldering booths require ventilated hoods to remove excessive heat and fumes, as shown in Figure 26-4. The *Industrial Ventilation: A Manual of Recommended Practice for Design, 27th Edition* (American Conference of Governmental Industrial Hygienists [ACGIH], 2010) has examples of local exhaust systems for machines and cleaning devices used in shops (see Chapter 2, Section 2.3 and Table 2-7).

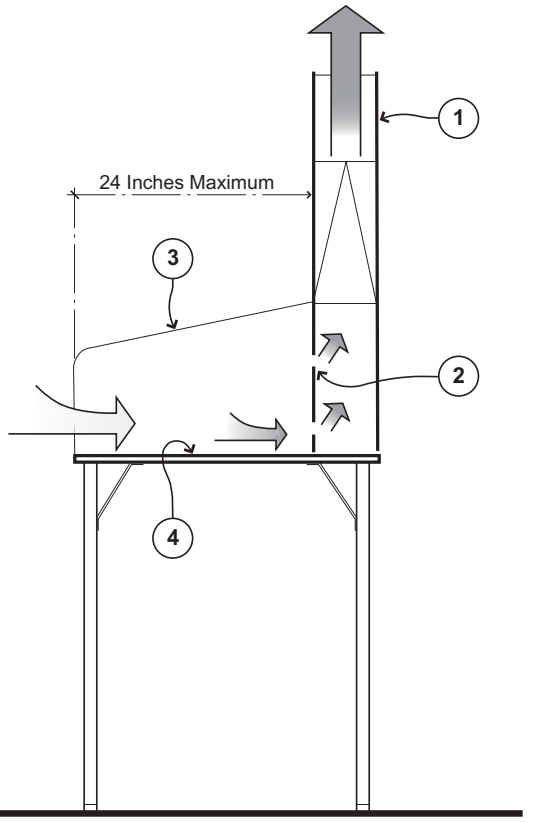
26.3.2.3 Dust Collection. Carpentry shop equipment and certain equipment in machine shops, such as grinding wheels and CNC milling/router machines, will require a dust collection system that is connected to the building exhaust system. Another option is to install separate exhaust ducts and fans with discharge directed outside at an appropriate location. Unit dust collectors



KEY

1 Exhaust Duct
2 Exhaust Slots Sized for 1000 FPM
3 Dipping Arm (Drying Position)
4 Dipping Arm (Dipping Position)
5 Dip Tank
□ Clean Air
■ Contaminated Air

FIGURE 26-3. Section through a ventilated dip tank.



KEY

1 Exhaust Duct
2 2 Exhaust Slots Sized for 1000 FPM
3 Side Baffles
4 Welding Bench Work Area
□ Clean Air
■ Contaminated Air

FIGURE 26-4. Section through a welding hood.

located beside the machines they serve can help conserve energy when wood, nontoxic metals, and plastics are used. Recirculating air cleaners take a long time to reduce particulate load in shops. They are not effective as the primary method to clean the air.

In shops using primarily resins, epoxy, and plastic materials, exhaust devices are required due to dispersion when fine particulate raw materials are loaded into machines (First & Love, 1985), or when particulate is generated during machining processes. EH&S professionals can advise HVAC engineers on the most effective collection methods and equipment for these materials.

Unit dust collectors usually leak dust back into the workroom, especially when they are not serviced regularly. Unit dust collectors require users to cleanout bins, a procedure that is messy and releases particulate back into shop environment. Procedures outlined in ANSI Z9.7 (ANSI/AIHA, 2007) should be followed. Therefore, local dust collectors at sanders, grinders, and saws are not recommended. Dust collectors for these machines should discharge to a central system with the pumps located outdoors, if possible. If accumulated waste material may burn or become explosive, it will be important to make sure the waste can be removed easily and safely.

Local dust collectors are extremely noisy, often operating between 80–90 decibels. Shop workers should wear ear protection devices with using dust collectors located within the shop. Outdoor or remote locations diminish noise levels within the shop. However, care should be taken on where dust collectors are installed, so other functions are not disrupted by their very loud noise. When a grinder is protected with a shroud enclosure that has a slot exhaust at the bottom to draw down shards and grindings into a collection box, the safety of the operator and those nearby is improved. *Industrial Ventilation: A Manual of Recommended Practice for Design, 27th Edition* (ACGIH, 2010) contains examples of recommended enclosures. These particulate collection accessories may be purchased with many machines.

26.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

26.4.1 Introduction

Laboratory support shop areas have hazards not typical of most laboratories, such as a wide variety of mechanical hazards and the heavy weight of materials handled. Other hazards are similar to those encountered in laboratories, such as chemical and electrical hazards, as well as high temperatures and high pressures. All items described in Chapters 1 and 2, Section 4 should be reviewed, and those that are relevant should be implemented. In addition, reference should be made to the National Safety Council's *Accident Prevention Manual for Business and Industry, 13th Edition (*Product #C12121-0000; National Safety Council, 2012), including *The Engineering and Technology* volume which describes the specific devices and considerations for mechanical hazards found at most machines and processes encountered in laboratory support shop areas. It also covers in detail issues concerning equipment used in materials handling. The *Administration and Programs* volume describes safety programs and procedures that should be implemented in laboratory support service areas.

26.4.2 Safety Station

In each laboratory support shop area, safety stations should be provided with safety equipment and personnel protection gear appropriate to the shop. A typical shop safety station should include a safety information bulletin board, hand-washing sink, safety glasses dispenser, emergency eyewash fountain, emergency deluge shower, an appropriate type of fire extinguisher, fire blanket, first aid kit, and chemical spill kit. Support shop safety stations should be located near the primary shop entry, where they will be visible and not easily blocked by equipment or coats.

26.4.3 Fire Protection

All laboratory support shops should be protected by a fixed automatic fire suppression system with water as the medium. Support shops need to be equipped with hand portable fire extinguishers (see Chapter 1, Section 1.4.4.2). Hand-portable fire extinguishers can be selected for each machine and types of materials used at these machines where fire or sparks may be generated.

There are special fire-safety considerations in some laboratory shops that use large volumes of fine particles, such as resins, epoxies, and plastics. There is risk of dust concentrations reaching explosive limits in some shop operations. Fire safety professionals should be consulted where this condition is possible to investigate methods to reduce concentrations and the risk of ignition.

26.5 SPECIAL REQUIREMENTS

26.5.1 Security

Security considerations are discussed in Chapter 1, Sections 1.5.4.1 and Chapter 2, Section 2.5.1. Restricted access control is highly recommended.

26.5.2 Electric Power

Laboratory support shops contain many machines connected to high-voltage and high-current outlets. Emergency shut-off boxes are highly recommended for machinery with high power requirements. These boxes should be mounted beside machines and in positions that are easily accessible to operators in emergencies.

Because many machines are operated digitally or by computers, the need for clean power to controls is essential. Separate and electrically conditioned circuits are required to operate these machines effectively and safely. See Chapter 1, Section 1.5.5 for information on effect of harmonics and Section 1.4.1.1 on the use of UPS devices.

27

HAZARDOUS CHEMICAL, RADIOACTIVE, AND BIOLOGICAL WASTE-HANDLING ROOMS

27.1 GUIDING CONCEPTS

27.1.1 Introduction

Disposing of laboratory waste is expensive, labor intensive, and heavily regulated. It requires adequate workspace and safe storage space. When adequate facilities, staffing, and programming are provided, a laboratory can save money in two ways: (1) through reduced disposal costs achieved by good material management, and (2) by maintaining strict compliance with regulatory requirements, thereby eliminating fines levied as a consequence of unsatisfactory U.S. federal and state agency inspections. Many states try to inspect every generator of hazardous material wastes on an annual basis.

27.1.2 Description

Usual waste associated with a building or a facility is commonly referred to as municipal waste or trash. This chapter considers only the following three waste types: (1) hazardous chemical waste; (2) radioactive waste consisting of radioactive isotopes, radiolabeled chemicals, materials contaminated with radioactive substances, and radioactive wastes that may be below levels of concern of NRC regulation; and (3) biological and medical waste that may be infectious or physically dangerous. Common trash or municipal waste is not discussed in this book, but will need to be considered by design teams to provide necessary space. Universal waste will be discussed along with its close relative, chemical hazardous waste. Most laboratory waste chemicals will have to be handled and disposed of as hazardous when they are spent, outdated, or no longer needed. Laws do not permit the indiscriminate disposal of such materials into sewers or landfills via trash haulers. Other types of laboratory waste that include pathological or biological, and radioactive materials will need their own special handling. Those laboratories need special attention in the laboratory design phase.

The characteristic hazards of radioactive, pathologic, and chemical wastes have few similarities; hence, the special controls for them are varied. Nevertheless, all waste types have some hazards in common, such as combustibility, and for these the controls will be the same.

Chemical waste management must deal with issues of reactivity, toxicity, flammability, explosivity, chemical compatibility, and corrosivity. Radioactive waste involves some of these same chemical hazards, but with the added dimension of exposure to ionizing radiation. Biological waste should be dealt with carefully due to its potential to spread harmful organisms. Each of these waste types must be dealt with individually, with emphasis focused on the controls for the unique hazards associated with each of them. It is seldom useful or safe to combine these wastes in one room or to handle them as a unified operation for the purpose of disposal management because comingling these wastes subjects all to the hazards and disposal requirements of the others.

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

27.1.2.1 Hazardous Chemical Wastes. Hazardous chemical waste is defined by the U.S. EPA in the Code of Federal Regulations, 40 CFR 260 Hazardous Waste Regulations (EPA, 2012), as waste that is hazardous by virtue of its flammability, corrosivity, reactivity, or toxicity (each characteristic has its own definition in the regulation) or that appears on any one of several extensive lists of pure chemicals and chemical compounds. A special category of hazardous chemical waste, universal waste, consists of mercury-containing thermostats, fluorescent lamps, batteries other than lead-acid, and pesticides. These materials contain only small amounts of hazardous chemicals and are regulated as such, but in a less stringent way.

Universal waste is regulated by the U.S. EPA's Standard for Universal Waste Management (EPA 40 CFR 273, 2008). This EPA standard was promulgated to better regulate the handling and disposal of the four materials listed above. The generators of these wastes include large and small businesses, institutions, and homeowners. The quantity of these wastes generated by laboratories is small compared to the normal amount of hazardous chemical waste, but the amount of universal waste generated by an institution that has laboratories such as a university or hospital may equal or exceed the amount of hazardous chemical waste in a given period. Space must be allocated for storage, for up to one year, of universal waste, but such space is not required to have the safety and security characteristics of a hazardous chemical waste storage facility, which will be discussed latter. For this reason, universal waste will not be discussed in detail in this chapter.

27.1.2.2 Radioactive Waste. Many laboratories produce radioactive wastes, with medical and biomedical research laboratories producing more than other labs. Worker safety and radioactive waste handling are regulated by U.S. 10 CFR 20 (NRC, 2012) or the applicable state regulations. The regulations are also enforced by the NRC. The regulations represent a performance standard insofar as the design of a radioactive waste handling room is concerned; the NRC leaves the design up to the owner as long as the facility provides adequate protection against accidents, injuries, or unauthorized releases of radioactivity to the environment. There are four types of radioactive waste to deal with in a radioactive waste handling facility: scintillation fluids (usually in small plastic or glass vials), absorbed liquids (liquids poured onto absorbent material to meet the criteria of "solid waste"), radioactive dry waste, and mixed waste. Mixed waste is defined as waste controlled by more than one agency or set of regulations. For example, a mixed waste is a highly toxic chemical waste containing an isotope of qualifying radioactivity. It comes under NRC regulations as a radioactive waste and under EPA regulations as a hazardous chemical waste. Mixed waste is very difficult to dispose of because of the many regulatory requirements imposed on the disposal facility.

27.1.2.3 Biological Waste. Biological waste is defined in state and federal regulations as

- Blood and blood products
- Pathology waste (human anatomical parts, organs, and fluid)
- Cultures of infectious agents
- Contaminated animal carcasses and waste
- Sharps (needles, scalpels, broken medical glass)
- Biotechnology by-products
- Dialysis waste
- Medical care isolation waste

Most states have, and more are implementing, regulations regarding the handling, sterilizing, and disposal of biological wastes. The U.S. federal standard covering handling and disposal of this class of waste is 40 CFR 259 (EPA, 2012). Disposal techniques for these materials include incineration, steam or gas sterilization, treatment with ionizing or nonionizing radiation followed by burial, or maceration and discharge to a sewer. Many hospitals and research laboratories do not have adequate disposal capabilities in-house and must use services provided by commercial contractors. Some institutions sterilize the waste and then have it incinerated at a commercial facility to ensure safe disposal. Handling and storage of these wastes, even for short periods calls for a special facility that must be planned carefully.

27.1.3 Work Activities

27.1.3.1 Hazardous Chemical Wastes. Activities that take place in a chemical waste management room, suite, or area vary according to the amounts and types of waste chemicals generated. Most chemical wastes are picked up for disposal by licensed waste transporters in what are known as "lab packs." These are drums, made of fiber or steel, into which are placed complete containers, such as bottles of chemicals. Packing material, such as vermiculite, is added to protect against breakage and to provide absorptive material in case of breakage during transportation. Because of the limited number of containers that can fit into a drum, this is the most expensive method of disposal available to laboratories; however, in many cases it is the only method possible under current regulations. The drums must be packed according to Department of Transportation (DOT)

shipping regulations 40 CFR 100 (DOT, 2007) requiring separate drums for each category of waste: flammable, reactive, corrosive, and poisonous. Preparation of lab packs is most frequently performed by a licensed disposal contractor to ensure DOT compliance. Because high packing density is one key to cost containment, adequate space and working accommodations must be provided to the packers so that they can have several (4–5) open drums [30- to 55-gallon (110–210 L) capacity] available for sorting and packing (refer to Section 27.2.5.1 below).

"Bulking" is the transfer of the same or like materials from small or partially filled containers to larger ones, usually 30- to 55-gallon (110–210 L) drums. A larger container can usually be disposed of at lower per-pound cost (depending on the nature of the waste material) and in some cases can return money or provide chlorofluorocarbon (CFC) credits. Some chemicals such as chlorinated hydrocarbons have a high recycle value, and CFCs will eventually be available for purchase only when a company can satisfy a justification requirement imposed by regulation or has adequate recycle credits. Bulking, however, carries the risk of incompatible materials coming together and causing ignition or explosion. Safe bulking of liquids requires maintaining small samples of the partial contents of drums and testing for compatibility before adding new materials. Bulking requires unencumbered work space with good general ventilation (see Section 27.3) and exhaust ventilation facilities; it should be carried out in a room separated from other hazardous waste activities. Some large institutions find it profitable to recycle unopened, unused, or otherwise good chemicals that have become superfluous to a given research group or purchasing laboratory. This process does not require the handling of open containers, but it does require a dedicated sorting and storage area.

Diverse activities one may observe in a hazardous chemical waste management area include filling lab packs, consolidating chemically compatible wastes into larger containers (such as combining two partially filled containers of a single chemical into one full container), consolidation to reduce bulk, transfer of toxic or flammable materials from container to container, sampling, sorting for recycling, sink disposal of nonhazardous and nonregulated waste, conducting decontamination, inventory sheet preparation, manifest and shipping document preparation, and electronic data entry of records. Universal waste only needs to be packaged to avoid breakage and subsequent release of hazardous chemistry with an identification label.

27.1.3.2 Radioactive Waste. Scintillation fluids usually enter the waste-handling facility in boxes of vials segregated by scintillation media type, activity level, and radionuclide type. The promotion of nonhazardous liquid scintillation fluids is causing a reduction in the use of hazardous scintillation materials. Scintillation vials may be packed as is into steel drums for shipment to a disposal facility, or they may be processed to reduce their volume by passing them through a vial crusher and a liquid–glass/plastic separator. The crushed glass or plastic can be washed and disposed of as trash. The bulk scintillation fluids plus rinse liquids can be poured in drums and shipped offsite for disposal as hazardous or radioactive waste. Absorbed radioactive liquids are bulked in drums and shipped for disposal by burial. Radioactive dry waste coming into the waste facility are sorted by radioactivity and type. Some can be held in storage for decay of short-half-life isotopes and then shipped off as deregulated dry waste (trash). Longer-half-life materials must be disposed of as radioactive waste. Frequently, all of these dry materials are reduced in volume using a simple drum compactor, or are shipped to a radioactive waste processor for volume reduction such as incineration. To summarize, work activities in a radioactive waste management area for laboratories include receiving, shipping, drum handling, bulking of liquids, bulking of dry materials, record keeping, labeling, surveying, volume reduction, and document preparation.

27.1.3.3 Biological Waste. When onsite disposal facilities are lacking, biological waste materials brought into the biological waste-handling facility must be segregated by waste class (U.S. 40 CFR 259; EPA, 2012 and made ready for shipment. This includes one or more of the following: autoclaving, bagging and boxing, steam and gas sterilizing, and freezing or refrigerating (to prevent putrefaction during long storage periods onsite). Other activities include record keeping, labeling, spill decontamination, and cleanup.

In-house incineration is not considered in this chapter; however, the biological waste-handling room could be used as a holding area for onsite or offsite incineration or other treatment.

27.1.4 Equipment and Materials Used

27.1.4.1 Hazardous Chemical Waste. Chemical waste handling is a support type of operation. Therefore, few laboratory equipment or supplies will be present in the waste-handling facility, with the exception of chemicals and compressed gases stored in preparation for disposal. Most of the materials listed below pertain to storing, documenting, handling, and shipping of hazardous waste chemicals needed in a hazardous chemical waste-handling area; space must be provided for them.

- Labels, forms, paper supplies
- Computer terminal, desk, chair, workbench or packaging table
- Drums—steel, fiber, plastic [5- to 55-gallon (20–200 L) sizes]
- Packing materials—vermiculite, etc.
- Wheeled carts, wheeled drum dollies
- Pneumatic or mechanical lifts
- Scales—up to 500 lb (250 kg)
- Plastic and glass containers for repacking
- Sink
- Gas cylinder rack
- pH meter, flashpoint tester
- Small wet laboratory setup
- A selection of hand tools
- Emergency equipment

27.1.4.2 Radioactive Waste. Materials needed in a radioactive waste-handling area are listed below; space must be provided for them.

- Labels, forms, pap.er supplies
- Computer terminal, desk and chair, workbench
- Steel drums [30- and 55-gallon (110 and 210 L) sizes; approximately 50 drums]
- Fiber drums [for dry waste shipping to an incineration facility]
- Packing materials (plastic bags, bottles for absorption, agricultural absorbent or as specified by waste processor)
- Spill cleanup materials
- Wheeled drum dolly
- Scales to 500 lb (250 kg)
- Sink
- Vial crusher
- Radiation-monitoring equipment
- Trash buckets
- Metal detector
- Freezer/refrigerator for "mixed" waste

27.1.4.3 Biological Waste. Materials needed in a biological waste handling area are listed below; space must be provided for them.

- Labels, forms, paper supplies
- Desk and chair
- Steam sterilizer (Autoclave)
- Boxes, fiber drums, and other containers
- Spill decontamination equipment
- Sink
- Storage cabinets
- Freezer/refrigerator

27.1.5 Exclusions

27.1.5.1 Hazardous Chemical Waste. Disposal of daily building and laboratory wastes, not otherwise hazardous, are not covered in this chapter. Chemicals not defined by the EPA or state agencies as hazardous or universal, either by being listed or possessing a hazardous characteristic, need not be handled as hazardous waste and may be disposed of through normal trash or sink disposal. The local safety or environmental specialist should be consulted to help determine these issues for any specific geographical or political area. A hazardous waste management and storage facility is not designed for treatment or destruction of hazardous waste materials by such methods as distillation, dilution, or reaction. Disposal of nonhazardous materials via the sink is an acceptable procedure.

27.1.5.2 Radioactive Waste. The radioactive waste room is not meant to handle any other types of waste.

27.1.5.3 Biological Waste. The biological waste room should not have multipurpose uses. It should be used for biological waste storage and handling only.

27.2 LAYOUT

27.2.1 Guiding Concepts

It is recommended that hazardous chemical, radioactive, and biological areas be separate rooms. These rooms should be located close to each other and a shipping dock. The quantity of waste generated will be one of the determining factors of necessary room size. Other considerations are the frequency of waste removal from the storage rooms and the sometimes higher costs of more frequent removal patterns.

27.2.1.1 Hazardous Chemical Waste. The health and safety requirements of hazardous chemical waste handling are similar to those of the laboratories using the same chemicals and compressed gases. Therefore, the provisions discussed in Chapters 1, 2, and 5, Section 2, should be reviewed for their applicability as a supplement to the recommendations discussed here. A chemical waste-handling and storage area or room should be separated from all other building occupancies by not less than 2-h fire-rated construction with 1.5-h fire-rated

door assemblies. The facility may occupy a separate, detached building removed sufficiently from other buildings or structures when required by code. Waste chemical storage containers should be protected from the weather, excessive heat, and large temperature swings. When the chemical handling and waste storage area is in a multiuse building, at least one wall of the unit should be an exterior wall above grade level and should have a pressure relief panel when it is required by local codes. The best approach to determining room size is through experience. If past records of hazardous waste activity are available, they may be referred to for an accurate determination of waste handling size requirements and room configuration. Where records do not exist, the following example can be used as a guide. For a science teaching and research complex of five buildings containing 700 or 800 individual laboratory rooms dedicated to physics, chemistry, biology, biochemistry, and geology laboratory work, approximately fifty 55-gallon (210 L) drums containing lab packs and bulk wastes will be produced each month. To handle this amount of waste, the bulking room should be separate from other activities and should consist of approximately 200 ft^2 (20 m^2) of floor space with an outside wall and no in- room storage. The remainder of the activities may be carried out in a 800- to 1000-ft^2 (100–120 m^2) room. Waste-handling areas should be located at or above grade for heat venting and loss control in the event of a fire. A sample layout for a hazardous chemical waste room can be seen in Figure 27-1.

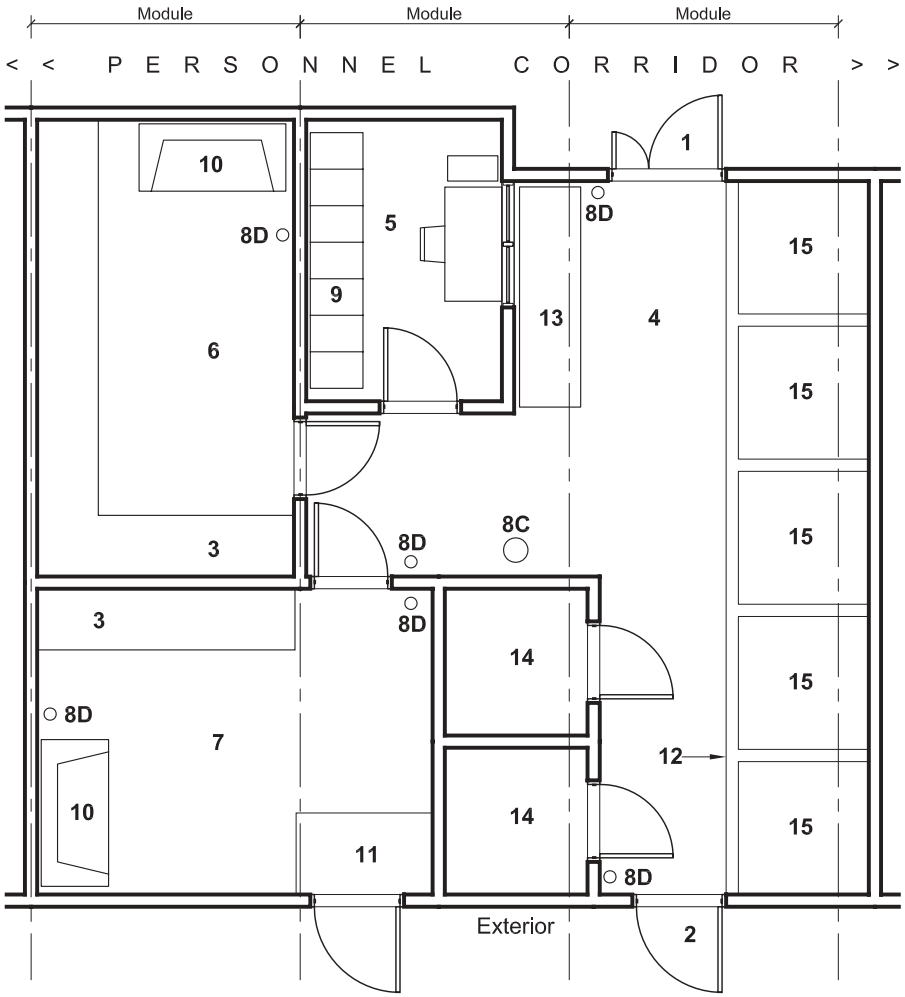
27.2.1.2 Radioactive Waste. A radioactive waste-handling facility should be separated from all other building occupancies by not less than 2-h fire-rated construction with 1.5-h rated door assemblies, or it may occupy a separate detached building removed sufficiently from other buildings or structures when required by code. Radioactive waste storage containers must be protected from the weather, excessive heat, and large temperature swings. When the radioactive waste handling and storage area is located in a multiuse building, at least one wall of the unit should be on an exterior wall above grade, to provide a location for a pressure relief panel that may be required when flammable liquids are being handled. The walls may need to be constructed of solid concrete or lined with lead sheets or other radiation shielding materials to reduce radiation levels in adjacent areas to regulatory requirements that include ALARA (as low as reasonably achievable) requirements. When selecting lead walls, consider the cost of covering the lead to minimize exposure, and the cost of removal and disposal. Adequate shielding may also be achieved by locating the room adjacent to unoccupied areas. Specific site requirements may be obtained from a resident radiation safety officer or a regional office of the NRC. For a typical teaching hospital of 500–1,000 beds, or a research building using radioisotopes, about 100 drums of waste is generated per year. To handle this quantity, one room with an area of 600 ft^2 (55 m^2) is needed for radioactive waste processing and storage. When vial crushing is conducted, a separate small room equipped for highly flammable solvent activities is required. An adjacent room for showers and clothes lockers is desirable. Space for freezer storage of mixed animal/radioactive waste should be provided in institutions generating such waste. This waste-handling and storage room should be located at or above grade for heat, dissipation venting, and fire control in the event of a fire. Spill control berms or dikes should be installed at each opening from the room. Floors should be constructed of concrete, be of low porosity, and have a continuous surface, an impervious covering, and no drains. A sample radioactive waste facility is shown in Figure 27-2.

27.2.1.3 Biological Waste. The biological waste room has potentially infectious microorganisms and sharps as primary hazards for waste handlers. There is a minimal fire hazard from the presence of stored combustible shipping boxes and packing materials. This room is a service room to the research that is carried out within the laboratory building or group of buildings. Separation from the research areas is recommended. It is desirable to have the biological waste handling room located near a loading dock to facilitate removal of material. Odor control through ventilation and air discharge away from personnel, the public, and air intakes should be reviewed in the design stage.

The amount of waste generated by a typical biological research facility can be handled and stored temporarily while awaiting shipment in a 500-ft^2 (50 m^2) room, although the generation rate of biological wastes varies greatly from laboratory to laboratory. Past waste records should be consulted when they exist, otherwise the records of similar facilities should be used for design purposes. A sample biological waste facility is shown in Figure 27-3.

27.2.2 Personnel Entry and Egress

There should be easy access to a hazardous waste room from waste-generating laboratories and easy transfer of processed wastes from the chemical, radiological, and biological waste storage areas to a shipping dock. There should be two personnel exits in each area. Emergency access should be reviewed with the local fire department



KEY

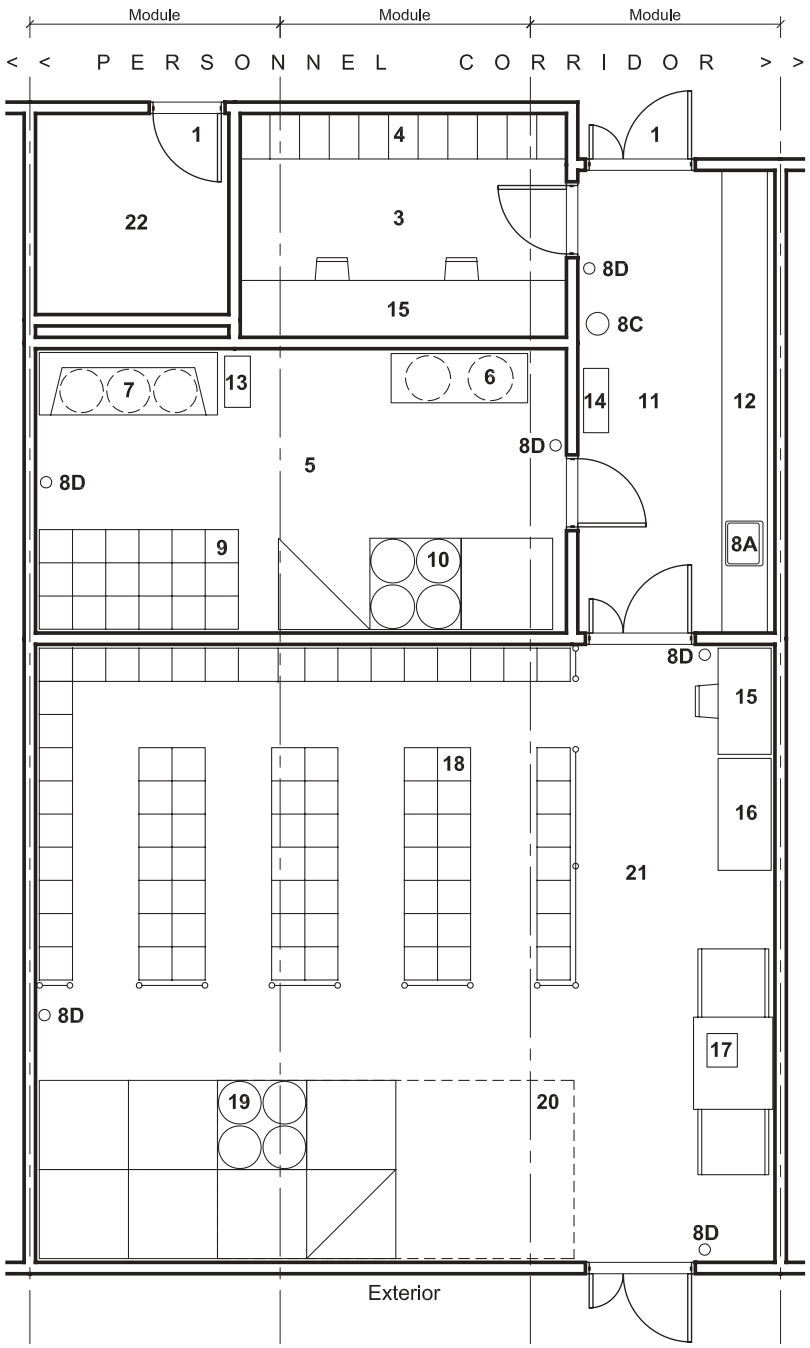
1	Primary Access/Egress	8D	Fire Extinguisher
2	Emergency Second Egress	9	Files
3	Counter	10	Fume Hood
4	Sorting Area	11	Ramped Dike to Loading Dock
5	Office	12	Curbs
6	Testing Laboratory	13	Sorting Table
7	Bulking Room	14	Primary Drum Storage
8C	Emergency EW&SS	15	Primary Shelf Storage

FIGURE 27-1. Hazardous chemical waste-processing facility layout.

for preferred entry and access by firefighters. Security requirements imposed by NCR, CDC, EPA, and some state regulations require that unauthorized personnel be unable to enter waste rooms. This is likely to require the use of a locking system with an emergency access override.

27.2.3 Materials Handling Access

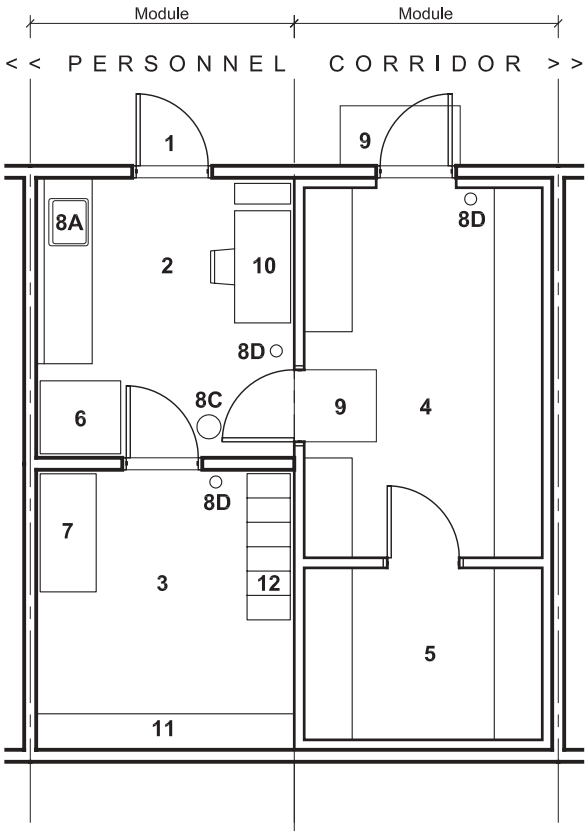
Receiving areas should be designed to accommodate incoming materials from laboratories generating waste. Shipping and receiving access is necessary for materials being received, materials being shipped, and outside



KEY

1	Primary Access/Egress	8D	Fire Extinguisher	17	Metal Detector
2	Emergency Second Egress	9	Empty 30 Gal. Cartons Storage	18	30 Gal. Cartons (stacked 4 high)
3	Office	10	Empty 55 Gal. Drum Storage (4 to a Pallet)	19	55 Gal. Drum Storage, 4 to a Pallet (Stacked 2 High), Located for 1st and 3rd Quarters of the Year
4	Record Storage	11	Sorting and Packing Room	20	55 Gal. Drum Storage, 4 to a Pallet (Stacked 2 High), Located for 2nd and 4th Quarters of the Year
5	Vial Crushing Room	12	Sorting Bench with Supply Storage Below	21	Storage Area, Varies According to Demand
6	Vial Crusher	13	Fire Extinguisher Cabinet	22	Toilet/Shower Room Adjacent to Storage Area
7	Fume Hood for Rinsing Glassware	14	Safety Station		
8A	Sink	15	Desk		
8C	Emergency EW & SS	16	Freezer Storage		

FIGURE 27-2. Hazardous radioactive waste-processing facility layout.



KEY

1	Primary Access/Egress
2	Work Room/Office
3	Dry Waste Storage/Supplies
4	Cold Room (Manufacturer Supplied)
5	Freezer Room (Manufacturer Supplied)
6	Autoclave
7	Freezer
8A	Sink
8C	Emergency EW & SS
8D	Fire Extinguisher
9	Ramp
10	Desk
11	Shelves
12	Cartons

FIGURE 27-3. Biological waste-processing facility layout.

contractor movement. A drum access ramp with a maximum slope of 8% should be provided. A separate truck-loading ramp will facilitate the long loading time usually needed to perform record-keeping requirements.

27.2.4 Furniture Locations

27.2.4.1 Desks. A desk for paperwork and data entry should be located in or immediately adjacent to the waste handling rooms. So much record keeping is required by law that a comfortable workstation is necessary. A separate, locked office provides improved security for records and data. A telephone for this area is required.

27.2.5 Work Areas

The areas described in this section relate to the facilities described previously.

27.2.5.1 Hazardous Chemical Waste. All activities except bulking operations can be performed in a 800-ft^2 (75 m^2) room. Chemicals for preparing lab packs should be stored on shelves, as detailed below. Flammable liquids should be stored in UL- or FM-approved cabinets. Lab packs prepared on a routine basis, such as once per month, should be assembled in proximity to the shelves holding the category of waste being handled. Shelves should be equipped with bookends and earthquake bars across the front, and they should be constructed of inert materials to preclude reaction with spilled acids or strong oxidizers. Storage of empty containers may be in or outside of the preparation room. Full lab packs and bulk containers should be stored in the waste storage room only temporarily before removal from the facility. Chemical wastes coming into the room from laboratories should be placed on a workbench for identification or sampling, hazard determination, containment, and labeling, and should then be moved to the bulking room or an appropriate temporary storage shelf.

27.2.5.2 Radioactive Waste. All work except vial crushing can be performed in a 600-ft^2 (60 m^2) room. Storage shelves totaling at least 15 ft (5 m) will be needed to store waste before packaging for shipment. A workbench and a writing station in the room make for efficient operations.

27.2.5.3 Biological Waste. All work can be performed in a 500-ft^2 (50 m^2) room. A desk for record keeping and refrigerators or freezers should be located in or adjacent to the room. Storage cabinets for supplies and materials are necessary.

27.2.6 Aisles

Major aisles in waste storage rooms should be a minimum of 5 ft (1.5 m) wide to allow clearance for collection carts containing laboratory wastes and for

dollies carrying heavy 55-gallon (200 L) drums. Wider aisles of 8 ft (2.5 m) will accommodate two-way circulation in busy areas. Storage aisles may be 3 ft (1 m) wide when containers stored on both sides of the aisle are no larger than 5 gallons (20 L).

27.2.7 Location of Chemical Hoods

A 4-ft or 6-ft (1.3–2.0 m) chemical hood should be located in the work zone for sorting and consolidating chemicals and for chemical testing. Leaking containers benefit from being handled in such an installation. A chemical hood may also be helpful in the radioactive waste room for special isolation control. The hood should be positioned so that it is protected from movement within the waste storage area to maintain good chemical hood containment. If the facility uses radioiodine, considerations should be made for charcoal filtration of the hood exhaust to minimize the effects of a potential release.

27.2.8 Location of Equipment and Storage Containers

27.2.8.1 Hazardous Chemical Waste. Chemical waste storage areas should be organized into a series of zones in which various types and quantities of chemicals are stored. These storage areas need only be minimally separated from work areas to reduce circulation around containers. There should be eight separate areas for classified storage of chemicals based on their primary hazard characteristic: toxicity, flammability, corrosivity, reactivity, and combinations of hazards selected with due attention to compatibility concerns. Separation of chemicals that mutually react should be accomplished by assignment of areas to keep incompatible chemicals far apart. Refer to Table 12.1 in "Storage of Laboratory Chemicals," *Improving Safety in the Chemical Laboratory, 2nd Edition* (Young, 1991). Each waste-handling area must be protected by a floor dike designed to contain a spill from the largest container stored in the area or 10% of the total stored volume. Each area should be separated and surrounded by 2-h fire-rated walls with 1.5-h rated door assemblies. A chemical waste storage area should have full-drum holding areas for each category of chemicals, with each protected from other activities. All chemical waste storage areas should be emptied on a regular schedule of no longer than 3 months for a large-quantity generator or 6 months for a small-quantity generator to comply with EPA regulations. An empty-drum storage area that can handle one cycle of empties and a few larger drums for overpacking of leaking drums in emergencies should be in, or close to, the chemical waste-handling room for immediate availability. There should be an area for storage of materials that can be recycled back to the laboratories or to chemical supply stockrooms. Some storage cabinets within each storage zone may require general room and exhaust ventilation facilities for highly toxic, not well-contained, or otherwise special chemicals.

27.2.8.2 Radioactive Waste. A storage area for about 10 empty drums (based on the example in Section 27.2.5.2) should be established. An equal number of full drums will need a temporary storage location until they are shipped. Drum tools and daily supplies should also be stored in the area. Some institutions use metal detectors, such as those used in airports, to check for lead pigs before shipping low-level solid waste for incineration. The space requirements necessary for this operation should be addressed in the design phase. These should include space consideration for the decay of very short-lived radioactive materials used in medical treatment as a significant cost-savings tool.

27.2.8.3 Biological Waste. The biological waste handling and storage room will need space for a workbench or table, for a desk, and for cold storage, as well as for an area in which dry waste not requiring refrigeration is stored. An autoclave may be located in this room.

27.2.9 Location of Safety Stations

Chemical, radioactive, and biological waste storage areas should have safety stations at each exit. At a minimum, the safety station should have a safety bulletin board, an emergency egress plan showing all pathways out of the building (if there is not a direct exit to the exterior from the waste storage area), safety glasses dispenser, fire extinguisher, fire blanket, chemical spill control kits, radioactive and biological decontamination kits, and cleaning materials.

27.3 HEATING, VENTILATING, AND AIR-CONDITIONING

27.3.1 Introduction

All the recommendations provided in Chapters 1 and 2, Section 3 should be reviewed, and those that are relevant should be implemented. Additional recommendations are given below. Industrial hygiene personnel and engineers should be consulted for unusual design conditions.

27.3.2 Heating and Cooling

The areas or rooms in which hazardous waste chemicals or radioactive materials are handled must be heated to ensure that the stored material does not freeze. Such spaces usually are not air-conditioned. However, if there is a reasonable likelihood that space temperatures would exceed 100°F (38°C) for extended periods, air-conditioning would be necessary. The overall space temperature range should be between 50°F –100°F (10–38°C), depending on the particular chemicals handled. If special chemical storage with other temperature limit requirements is anticipated, accommodations must be considered. They can include refrigerated or heated storage units placed within the normal waste room, or special temperature controlled rooms with limits set as needed.

Local cooling for personnel who may spend time at a desk may be considered for personal comfort. Open-flame heating units, direct-fired gas heaters, and electrical resistance heaters should not be used in the chemical and radioactive waste rooms where flammable liquids are handled or where explosion-proof installation is necessary (see Section 27.4.5 below). Because of the high ventilation rates described below, the humidity level in the rooms may be low, especially in colder climates. Experience has shown that humidity levels below 25–30% start to induce static charge problems that may cause explosion or fire in spilled flammables or fugitive vapors. Therefore, this minimum humidity level should be maintained.

27.3.3 General Room Ventilation Exhaust

Although the U. S. Occupational Safety and Health Administration regulations for flammable chemical storage rooms (OSHA 29CFR 1910.106; OSHA, 2012) specifies a minimum of 6 ACH, it is recommended that each waste handling and storage facility first be evaluated for its local exhaust needs. Once that is complete, calculate the actual air exchange rate. If necessary, increase to 6 with additional exhaust. Typically, the minimum general ventilation rate is 8–10 ACH [equivalent to 1 CFM per ft^2 of floor area (0.3 CMM per m^2) for rooms 8–10 ft (3–4 m) high]. The exhaust air requirements may be met by continuously operating laboratory fume hood(s), other local exhaust systems, a general room exhaust system, or combinations of the three. The cited minimum exhaust rate is required to handle small gas and vapor leaks from containers and spills during material handling. The nature and magnitude of the activities performed often necessitate the use of local exhaust ventilation in addition to the general room exhaust. To control odors from these rooms, the air pressure should be negative in relation to surrounding areas.

27.3.4 Laboratory Chemical Hood

Laboratory chemical hood space may be needed in chemical and radioactive waste handling and storage rooms. The amount of hood space required will depend on the quantity of materials handled and the amount of manipulation of small containers of materials. A 4-ft (1.3 m) hood is the minimum recommended. The hood should meet all the requirements listed in Chapter 2, Section 2.3.4.3 and Chapter 29.

27.3.5 Local Exhaust Systems

Other forms of local exhaust ventilation systems, in addition to or in place of chemical hoods, may be required, depending on the activities performed. It is essential that these systems be separate from the remainder of the building ventilation services and be discharged to the atmosphere with no recirculation. Generally, they will be low-volume, high-velocity systems or specially designed enclosures. When operations are intermittent, local exhaust system facilities can be designed so that only one local exhaust hood can be used at a time, thereby reducing the size and complexity of the local exhaust installation. Please refer to the design criteria contained in Chapter 3 of the *Industrial Ventilation: A Manual of Recommended Practice for Design, 27th Edition* (ACGIH, 2010).

27.3.5.1 Barrel Exhaust Facilities. When operations require the filling of drums, one or more barrel exhaust systems may be required (Figure 27-4). They should exhaust approximately 150 CFM (0.07 m^3/s) each. There should be enough flexible duct available to permit their use at various locations, or several permanent exhaust points should be provided. See the Industrial Ventilation Manual Design Sheet VS-15-01 (ACGIH, 2007) for design information.

27.3.5.2 Vial Crushing. This operation should be conducted in a ventilated enclosure for personal protection and fire prevention. The specific design will depend on the size of the crusher and the potential vapor release sources. The procedures outlined in Chapter 3 of the *Industrial Ventilation: A Manual of Recommended Practice for Design, 27th Edition* (ACGIH, 2010) should be followed. Some vial-crushing equipment may already be designed by the manufacturer with an enclosure and an exhaust outlet. In this case, the manufacturer should be asked to provide the required exhaust flow rate.

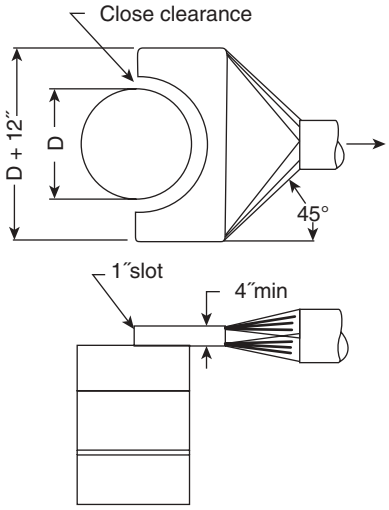


FIGURE 27-4. Hazardous waste barrel exhaust hood.

27.3.5.3 Autoclave Exhaust. When an autoclave is used in the biological waste room, local exhaust should be provided. The use of a canopy hood as described in Chapter 32, Section 32.10 would be most appropriate.

27.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

27.4.1 Introduction

Careful consideration should be given to the information contained in Chapter 1, Sections 1.4.1, 1.4.2, 1.4.4, 1.4.6, and Chapter 2, Sections 2.4.1, 2.4.2, and 2.4.6 through 2.4.8; special attention should be paid to the recommendations below.

27.4.2 Emergency Equipment Cabinets

An important element of the area design is a location near the waste-handling room for an emergency equipment cabinet containing personal protective equipment, first aid supplies, and materials related to the control and cleanup of spills and fires.

27.4.3 Water Supply

The water supply to a waste handling area should be adequate to handle the sprinkler system. A deluge shower delivering a minimum of 30 gpm (2 L/s), an eyewash fountain requiring 7 gpm (0.5 L/s), and a handwashing sink should be on the potable water system.

27.4.4 Special Fire Suppression

When water-reactive chemicals make up a substantial portion of the waste stream in the hazardous waste room, they should be segregated and confined to an area in which sprinklers are replaced by a more appropriate fire suppression system, such as a dry chemical. If needed to be stored in a room protected by a water sprinkler system, water-tight cabinets should be provided.

27.4.5 Electrical Service

Electrical services in waste-bulking rooms and vial-crushing rooms where solvents are considered flammable liquids should conform to the National Electrical Code for Class I Group C and D Division I installations. The lab pack room and all areas in which open containers of flammable liquids are handled should conform to the requirements for Class I Group C and D Division II installations. The International Electrotechnical Commission (IEC) refers to "zones" in place of "divisions." Zones are based on the length of time ignitable concentrations are present continuously. Division I would be closest to "zone" 1 and division II would be closest to zone 2.

27.4.6 Bonding and Grounding Systems

A static electricity bonding and grounding system should be installed in all areas in which flammable liquids are transferred. Bonding systems are used to equalize static electrical charges between objects such as drams and containers (safety cans). Grounding systems are used to bleed these charges to ground. Information on effective bonding and grounding systems can be found in NFPA 30 Flammable and Combustible Liquids Code (NFPA, 2012).

27.5 SPECIAL REQUIREMENTS

27.5.1 Floor Drains

No floor drains should be provided in waste-handling rooms or areas in which hazardous waste chemicals or radioactive materials are stored or processed. Nevertheless, if a floor drain is used, it should not be connected directly to the sanitary or storm sewer, but be directed to an isolated holding sump or tank. Such tanks may fall within the jurisdiction of underground storage tank regulations.

27.5.2 Security

Entry control through a locking system has been discussed earlier in this chapter. Agency regulations and

local authorities may require special equipment for this function.

Security considerations are discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1.

27.5.3 Renovations

Special consideration of decontamination is needed when rooms that have been used for waste-handling, processing, or storage are to be renovated. Some chemical contaminants, radioactive materials, microorganisms, and sludges may be so deeply imbedded in floors, benches, and walls that complete removal may be the only acceptable decontamination method. The extent of such removal will affect the cost of the project and the usability of the space. Lack of consideration of this issue could result in future illnesses and costly remediation.

28

LABORATORY STOREROOMS

28.1 DESCRIPTION

28.1.1 Introduction

Laboratory storerooms are important support facilities for laboratory buildings. Many laboratories will provide storage of commonly used chemicals and materials for daily use, but bulk volumes of chemicals and materials are better stored outside laboratories and in appropriate storerooms. Some storerooms may be dedicated to single laboratory groups; they may be shared or centralized facilities located within laboratory buildings or in separate structures.

Storerooms that have special health and safety requirements are described in this chapter. They include storerooms for the following materials: general chemicals, flammable liquids and bonded alcohol, compressed gas cylinders, biological specimens, and archaeological and geology specimens. Guidelines in Chapter 1, Section 1.2.4.2 and Tables 1-2 and 1-3 as well as Chapter 2, Section 2.4 and should be followed closely. Refer to guidelines in Chapter 27 for hazardous waste-storage facilities.

28.1.2 Work Activities

28.1.2.1 General Chemical Storeroom. General chemical storerooms can be found in most laboratory buildings; they vary in size and contents. Sizes generally are in proportion to the size, type, and number of laboratories in the building. The contents depend on the scientific disciplines served and variety of disciplines. Staff members employed by the organization or contract vendors manage and operate general chemical storerooms. In educational institutions, students may supply the labor to fill requests or orders from customers. Other chemical storerooms operate on a self-serve basis, where users enter, collect the chemicals they need, then check out. A self-serve process can be fully automated by using simple barcode tracking methods. Check-out users swipe bar codes on the containers they want in the storeroom barcode scanner. When they reach the laboratory entry, users swipe the container again at a barcode scanner there. Accounting and inventory systems are linked for billing purposes, reducing operations expense. Laboratory users may make frequent trips to chemical storerooms, if organizational policies promote and enforce limits of chemical storage in laboratories to a one-week supply, so barcode automated systems can be cost effective.

Other activities in chemical storerooms include preparation of common reagents for laboratory classes or for routine testing protocols. Storeroom workers decant large containers of chemicals into smaller containers of 1 L or less, including flammable liquids and bonded alcohol they retrieve from a separate storeroom. They place orders for new stocks of chemicals, stock the shelves and cabinets, and maintain overall safety opera-

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

tions such as checking labels for expiration dates, removing empty and old containers, and transporting used, outdated chemical containers to appropriate chemical waste facilities.

28.1.2.2 Flammable Liquids and Bonded Alcohol Storeroom. These storerooms are designed to safely hold various size containers of flammable liquids including bonded alcohol. Bonded alcohol is 97–100% pure, potable, and taxed; government agencies legally control its distribution. Chemical stockroom workers enter this room to restock and remove containers of solvents to provide to laboratory occupants. Workers may transfer liquids from 30- to 55-gal (113–200 L) drums into smaller containers. By code it is not an occupied space. Security issues must be addressed for this type of storeroom because the alcohol is a controlled substance (see Chapter 1, Section 1.4).

28.1.2.3 Compressed Gas Cylinder Storeroom. Storerooms for compressed gas cylinders are designed to safely hold cylinders of various hazardous and/or inert gases. Chemical stockroom workers or laboratory managers supervise cylinder deliveries and removals by gas vendors. No other activities are allowed in this space; by code this is not an occupied space (see Chapter 1, Section 1.4).

28.1.2.4 Biological Specimen Storeroom. Many universities, colleges, and research institutions maintain and collect many biological specimens, preserved in alcohol and formalin-containing solutions, which are kept in special storerooms. Students, faculty, and researchers temporarily occupy storerooms to make visual inspections and to compare specimens. They may also use optical microscopes.

28.1.2.5 Archeology, Paleontology, and Geology Specimen Storerooms. Storerooms for archeological, paleontological, and geological specimens can be used for teaching or for research. Students use teaching specimen storerooms for study and use optical microscopes to examine them. Students may be allowed to remove specimens for use only in the storeroom, and then they return specimens to the correct shelf or drawer. Scientists use research specimen collections in similar ways, but they may be allowed to checkout specimens and take them to their laboratories temporarily.

28.1.2.6 Laboratory Shop Storeroom. Storerooms should be planned and constructed for each type of support shop. They provide secure, locked, and safe storage for valuable materials, hardware, and tools used in support shops.

28.1.3 Equipment and Materials

28.1.3.1 General Chemical Storeroom. The categories of chemicals found in general chemical storerooms include combustible liquids and solids, organic peroxides, oxidizers, cryogenics, unstable reactive, and water-reactive chemicals. This assumes that there is a separate flammable liquid and bonded alcohol storeroom to hold all flammable liquids, and a separate compressed gas cylinder storeroom to hold an inventory of full and empty gas cylinders.

General chemical storerooms have chemical fume hoods, laboratory sinks with purified water source, hand-wash sinks, safety and emergency response equipment that health and safety professionals recommend for that particular storeroom (see Section 28.4 below). These storerooms also contain freestanding sturdy industrial shelving units, and/or wall-mounted adjustable shelves, specialty chemical storage cabinets, such as for corrosive, water-reactive, and highly reactive chemicals. Corrosive chemical cabinets may be directly exhausted into the laboratory exhaust system. There will be some laboratory benches, a customer service counter, computers, bar-code scanners and printer, laboratory-safe refrigerator(s), and possibly a glass-wash machine.

28.1.3.2 Flammable Liquids and Bonded Alcohol Storeroom. Building codes categorize flammable liquids in Classes 1A, 1B, and 1C; Class 1A is the most highly flammable. See Chapter 1, Section 1.2, and Table 1-10 for limits to volumes of flammable liquids. Liquids are classified *as flammable* when the vapor concentration above the liquid at temperatures below 100°F (38°C) forms a flammable mixture in air. The specific temperature at which this occurs is referred to as the *flash point* of the solvent. Solvents with a flash point above 100°F (38°C) are referred to as *combustible*. Table 28-1 defines the three flammable categories and two combustible categories.

Large containers may be stored on the floor; smaller containers may be arranged on freestanding, metal industrial shelving units, or on metal adjustable shelves attached to walls. OSHA prohibits opening containers to pour into other containers within this type of storeroom. Decanting activities must be done within a general chemical stockroom.

Bonded alcohol is potable grain ethanol whereas denatured alcohol has an additive that makes it nonpotable. Bonded alcohol is generally stored in a large bottle held on a special stand that protects the container from breakage and allows tipping to control decanting into other small containers. All states legally restrict access to bonded alcohol; it must be stored in a locked

TABLE 28-1. Definition of Classes of Flammable and Combustible Liquids adapted from IBC Section 307, High Hazard Group, (IBC 2012)

Flammable Liquids	Flash Point below		Boiling Point below	
	Deg. C	Deg. F	Deg. C	Deg. F
Class IA	23	73	38	100
	Flash Point below		Boiling Point at or above	
Class IB	23	73	38	100
	Flash Point at or above		Boiling Point below	
Class IC	23	73	38	100
Combustible Liquids	Flash Point* at or above		Flash Point* below	
	Deg. C	Deg. F	Deg. C	Deg. F
Class II	38	100	60	140
Class IIIA	60	140	93	200
Class IIIB	93	200	na	na

Note: na is not applicable.
*closed cup flash point.

space with no other chemicals inside the space. These are usually small, separate, and locked cages within flammable liquid storerooms.

28.1.3.3 Compressed Gas Cylinder Storeroom. These storerooms contain cylinders with a variety of gases: inert, corrosive, toxic, highly toxic, oxidizer, flammable, and cryogenic (cold temperature) gases. They are stored in a wide variety of sizes of containers, from small lecture bottles 2 in. diameter × 12 in. length (5 × 30 cm) to bulk tanks with up to 16 gal (60 L) capacity and 30 in. diameter × 82 in. height (76 × 208 cm). The most common sizes used in laboratory buildings are 9 in. × 55 in. (23 × 140 cm) and 9 in. × 51 in. (23 × 130 cm). Dewars are special insulated containers used for storage and dispensing of cryogenic liquids (liquefied gases). Gases are supplied at several levels of pressure; pressure is stamped directly on the cylinders. Gas cylinders are equipped with safety relief valves according to the type of gas in it and type of cylinder. These valves will release the contents upon overpressure or specific temperatures.

The transport of compressed gas cylinders is regulated by U.S. Dept. of Transportation (49 CFR 173; DOT, 2010). Cylinders have unique serial number identification and other critical information on the surface including: cylinder type and material of construction, registered owner symbol, date of manufacture, current owner of the cylinder, retest markings including date, location, and rating, manufacturer's inspection marking, and cylinder empty weight (Air Products, 2010). These markings are important because old tanks must be rotated out of use before they leak.

In addition to cylinders, these storerooms are equipped with racks to securely hold cylinders. There will be empty cylinders, which should be separated from full ones, for ease of removal by the vendor. See Section 28.4 below for emergency and other safety equipment recommended by health and safety professionals.

28.1.3.4 Biological Specimen Storeroom. Storerooms for biological specimens may have limited exhibit facilities within for taxidermy specimens of mammals, birds, reptiles, etc., for students and researchers to examine. Wet-preserved specimen bottles with concentrations of alcohol reaching 50% and above should be stored within OSHA-required flammable liquid cabinets. Concentrations of alcohol around 20% with water are considered combustible liquids. Jurisdictions having authority should be consulted on advisability of using OSHA-required combustible liquid cabinets for storage of those containers.

Because specimens in solution are normally not removed from their containers nor handled, risk of chemical splashes and spills is minor. If bottles break, there is risk of fire, laceration, and exposure to formalin solutions or denatured alcohol. Consult with health and safety professionals for their recommendation on installing an emergency eyewash fountain where there are containers of specimens preserved in liquid.

Dried specimens are normally stored in specially constructed metal cabinets that prevent vermin, mold, and microbes from getting inside and damaging the specimens. Materials' handling equipment may be needed in some storerooms to move large specimens, such as heavy tree trunk slices for dendrology research.

28.1.3.5 Archaeology, Paleontology, and Geology Specimen Storerooms. Archaeological and geological specimens of bone and fossil or rock and mineral are generally dry or dried, and pose few hazards. The heavy weight of geology specimen collections requires special structural evaluation. Floor load capacities of many buildings are insufficient to safely hold the weight of rock collections.

Storerooms will contain cabinets with a multitude of pullout trays or drawers to display specimens. There will be carts for transporting specimen trays or single specimens to examination tables that are equipped with good local lighting, microscopes, and computers inside the storerooms. Archaeological collections of bones or fossils from large creatures, such as dinosaurs, to small creatures, such as arthropods, and from long bones to skulls, require a wide variety and size range of storage units.

28.1.3.6 Laboratory Shop Storeroom. Materials commonly stored in shop storerooms include the following: sheet metal and metal castings; wire, rods, pipes, and extrusions; a wide variety of hardware; glass and plastic pellets, fine powders, and sheets; foam-core, wood planks, and plywood sheets; resins and resin powders; paint; glue; epoxy compounds; solvents; strong acids and other chemicals; volatile and flammable liquids; and compressed gas cylinders. Storerooms for laboratory glass blowing shops include a wide variety of tubular and sheet glass.

Hardware stored may include bolts, washers, screws, rivets, nails, staples, and many other small fasteners in a wide variety of sizes, types, and metals, such as steel, stainless steel, nickel, and aluminum. These small parts are generally stored in bins or drawers with dividers to keep each size and type separate. Tools that may be stored include small hand tools and their accessories, as well as some smaller accessories for large shop machines. Keeping small expensive tools and equipment locked in a storeroom reduces pilferage.

28.1.4 Exclusions

The storerooms described in this chapter do not contain radioactive materials, equipment emitting nonionizing radiation, explosive-category or other extremely hazardous chemicals, controlled substances, or select agents see Chapter 6, Section 6.1.2. There are no high-voltage or high-current electric services provided. These storerooms are not preparation laboratories for teaching or training purposes. This chapter excludes building office, maintenance, and supply storerooms, or storerooms for not-in-use laboratory equipment. See Chapter 18, Sections 18.1.2.4 and 18.1.2.5, organ and glass slide storage rooms.

28.2 LAYOUT

28.2.1 Introduction

Common goals for layout of storerooms are to maximize the storage capacity and to organize stored materials so users can find what they need and have the space to work safely. Layouts also need to ensure safe emergency exit for storeroom occupants in case there is a chemical spill, fire, or other type of accident. Normally very few persons occupy storerooms for general chemical or specimen storage. Other storerooms are not occupied and used strictly for storage, such as those for flammable liquids and gas cylinders.

28.2.2 Common Elements

All the recommendation provided in Chapters 1 and 2, Section 2 that are applicable to storerooms should be implemented. Layouts of work areas within storerooms should be arranged as those in basic laboratories (see Chapter 5, Section 5.2). The concept of hazard zoning pertains to all storerooms (see Chapter 2, Section 2.2.4); low hazard activities and materials are located near the primary entry and higher hazard activities and materials are located away from the primary entry. Two exits are desirable; in some storerooms building codes (IBC, 2012) and national safety standards, such as NFPA 45 (NFPA, 2011), require two exits.

28.2.2.1 Aisle Layouts and Requirements. Shelving storage units can be arrayed as islands, with circulation pathways on all sides, or as peninsulas, where aisles end at walls and storage units flank both sides. Island arrangements allow workers with lab carts to circulate down one aisle and come up another. Aisle widths under an island arrangement can be no less than 3 ft (1 m) if aisle lengths are 20 ft (6 m) or more and materials stored on flanking shelves and cabinets are narrower than the 3 ft (1 m) dimension. Aisles also must be wider than the width of cabinet doors or drawers that open into aisles.

Peninsula arrangements with dead-end aisles require workers to turn their carts around to exit. Consider providing additional aisle width to do this safely; 5 ft (1.5 m) is recommended for this arrangement. Peninsula aisles should be no longer than 20 ft (6 m). The furthest point of the storeroom should be on a pathway 50 ft (15.24 m) or less to the nearest exit (Section 1003; IBC, 2012).

28.2.2.2 Storage Units. All storerooms require storage units: floor-mounted shelving units or cabinets and wall-mounted shelving systems. Some shelving may be used for general display. Shelving units, floor and wall-mounted, should be able to hold the load expected to be placed upon them. Heights of shelving units are limited to reach no higher than 18 in. (0.46 m) from the ceiling, so that building fire protection system sprinkler heads can operate properly. The following are guidelines on common loads (Adapted from Safety Fact Sheet; MIT, 2009).

1. General display	15 psf (76 kg/m^2)
2. General storage	25 psf (126 kg/m^2)
3. Books	40 psf (202 kg/m^2)
4. Water (liquid)	62.4 lb/ft^3 (1,000 kg/m^3)

Wall-mounted shelving systems can fail, such as pulling off the wall or deflecting shelves to the point where they drop the materials placed upon them. These systems may have limitations on load capacities based on several factors (MIT, 2009): (1) overloading, (2) improper installation because of lack of adequate structure or blocking inside walls, (3) use of wrong type of anchor or anchors of insufficient strength, (4) insufficient number of brackets or standards installed to keep shelves from bowing or buckling. These cautions also apply to shelves provided with and installed in floor-mounted cabinets.

28.2.2.3 Seismic Zone Requirements. In geographic regions that experience seismic activity, all shelves should have seismic restraint bars or barriers on the front, back, and sides of each shelf. Seismic restraint bars can hold chemicals, bottles, containers, and materials that could break if dropped to the floor during seismic events. In addition, all floor-mounted shelving units and cabinets should be anchored to the wall behind the unit, at the top edge and close to the bottom to restrain units from moving and tipping over during a seismic event. If there is no suitable wall upon which to anchor the units, secure them to the structure overhead and to each other. This method can prevent tipping.

In addition, all shelves holding chemicals or other liquids should have raised front edges (spill lips), approximately 0.25 to 0.5 in. high, to capture small spills from containers that have leaks or are tipped over accidentally. These spill lips delay the time that it takes for most liquids to drip down and adversely affect materials stored below or drip on the floor causing a slip hazard.

28.2.3 Individual Storeroom Layouts

28.2.3.1 General Chemical Storeroom. The area where users or customers will arrive to request, purchase, and pick-up chemicals should be maintained as a low-hazard zone. Here storeroom workers will work with computers, converse with customers, and bring them materials requested. As workers move back into the storeroom, hazards may increase, with the materials stored and basic laboratory procedures that will be conducted there. Processes and materials that require use of chemical fume hoods such as decanting of chemicals from one container to another, preparing solutions, or collecting waste chemicals, should be in the rear of the storeroom. It is highly recommended that a second, emergency exit is located toward the rear, so storeroom occupants can move immediately away and escape from a spill, fire, or accident.

For security, provide locked doors into chemical storerooms and lockable shutters at customer counters. Doors may have emergency exit hardware on them so workers can exit at any time.

28.2.3.2 Flammable Liquids and Bonded Alcohol Storeroom. Because flammable liquids and bonded alcohol storerooms are not occupied spaces, storeroom workers must have their computer and other workstations outside this storeroom or use intrinsically safe computers. Intrinsically safe electronic devices provide no ignition source. Only the chemicals and the storage units that hold the containers are in this room. According to the volume of flammable liquids held, containers may be on open shelves or in OSHA-required flammable liquid storage cabinets. National and some local building codes have limits on the volume of flammable liquids allowed in storerooms (see Section 28.4.1). Single fire-control zones require 2-h fire-rated construction surrounding each room in walls, ceilings, and floors. Doors must be rated for 1.5-h fire resistance. Doors must have locks.

Bonded alcohol must be in a separate, locked area. This area can be within a flammable liquid storeroom, but a full-height security fence with a gate that can be locked must separate the area. An alternate method is to construct a room with standard walls and a locking door.

28.2.3.3 Compressed Gas Cylinder Storeroom. All compressed gas cylinder storerooms are equipped with cylinder racks attached to walls or the floor to keep them stable, even under seismic events. The distance between rows of cylinders should be maintained at 5 ft (1.2 m) to provide sufficient area in front for delivery persons to safely use tank carts or other materials' handling equipment. Rotation of cylinders also requires space between rows.

There are manufactured cylinder racks to secure small numbers of cylinders, or racks may be assembled from sturdy steel components to accommodate a large

number of cylinders. Racks are equipped with heavy-duty industrial straps or with metal chains to tie-down each cylinder to a rack. Some tall cylinder types, such as A, AA, and B require restraints near the tops and the bottoms to keep cylinders from either tipping or sliding out. If gases are piped into the laboratory building, each cylinder requires a place to mount the regulator, shut-off valves, and excess-flow check valve, if required. Boards mounted on walls or above rack systems work well to attach this apparatus.

Cylinders are arranged in storerooms by hazard type, separating incompatible hazards. Cylinders of incompatible gases must be stored specified distances apart in the same storeroom. For example, cylinders of flammable and oxidizer gases should be separated by a minimum of 10 ft (3 m) or by a solid wall that extends floor to ceiling. Arrange these storerooms with additional area and racks to store empty cylinders, convenient to the primary entry, along with a counter for a computer and paperwork, applying the hazard-zoning concept (see Chapter 2, Section 2.2.4).

There are several options for the location and construction of compressed gas cylinder storerooms. Central storerooms may be in separate open-air sheds or in manufactured structures near, but outside laboratory buildings. Gas cylinder regulators at cylinders can be installed to gas piping that enters the building and is distributed to fixtures installed in specific laboratories. Sheds or buildings separated from laboratory buildings reduce risks by putting all the hazards of the gases and operations of this facility outside. Sheds are appropriate structures to protect compressed gas cylinders in areas with temperate climates, where inclement weather does not affect valves and regulators or interfere with operations. Shade compressed gas cylinders from direct sun with a roof or canopy. Provide a dry floor, or if it is an open shed, floor drains to remove standing water that corrodes bottoms of cylinders. Corrosion makes cylinders unsafe if they have stood in water for long periods.

Protected and secured areas on laboratory building receiving docks can be used for gas cylinder storage, but only if there are very limited numbers of gas cylinders. Installation of chain link fencing with a sunshade canopy and a locked gate can suffice as the enclosure, if the receiving dock is in a secure area of a site or a campus.

When central compressed gas cylinder storerooms are within laboratory buildings, they should be located at grade level and close to a receiving dock, if possible. National and some local building codes and fire codes regulate allowable limits of hazardous gas. (see Section 28.4.1). A fire-control zone requires 2-h fire-rated construction surrounding the room in walls, ceilings, and floors. Doors must be rated for 1.5-h fire resistance. The door must have a lock.

Satellite compressed gas storerooms may be located on laboratory floors above grade level if gases stored there are primarily inert and/or nonflammable. Allowable volumes of flammable and oxidizer gases decrease the higher the level above grade they are located. Satellite storerooms are desirable to keep many cylinders out of laboratories. Piping connects tanks to laboratory fixtures and equipment on the same floor. For equipment that needs a continuous flow of gas, such as CO_2 to cell culture incubators or high purity noble gases to analytic chemistry instruments, satellite compressed gas cylinder storerooms work very well. Jurisdictions having authority may require construction of a fire-rated enclosure and locked doors for satellite compressed gas cylinder storerooms.

28.2.3.4 Biological Specimen Storeroom. There are a wide variety of specialty cabinets manufactured for biological specimens. For those preserved in alcohol solutions, according to the concentration of alcohol OSHA-required flammable liquid and combustible liquid storage cabinets are highly recommended. Dry specimens are best stored in insect and mold-proof cases. At minimum, aisles must be wider than cabinet doors to open fully. If cabinets have drawers or trays that are removable, aisles must be wider than the dimension of cabinet front to back, plus the width of a person(s). In dry-preserved specimen storerooms, there are no restrictions for locations of work areas. However, in wet-preserved storerooms, work areas should be located close to primary exits.

28.2.3.5 Archaeology, Paleontology, and Geology Specimen Storerooms. Because most bones, fossils, rock, and mineral specimens are generally not flammable (coal and elemental sodium are exceptions), storage cabinets and shelves may be manufactured in conventional construction materials. Aisles widths and configurations should be as described in Section 28.2.2.1. Work areas are not restricted to near exits.

28.2.3.6 Laboratory Shop Storeroom. Racks, shelves, and cabinets should be structurally sound and adequate to support the weight and sizes of materials for which they are intended (see Section 28.2.2.2). Storage units should be anchored to a wall or to the building structure above to prevent tipping, not just during seismic events, but also on a daily basis when workers pull heavy or bulky materials off of shelves. Industrial and extra heavy-duty-grade materials should be used as storage components. Standard commercial-grade storage units should be avoided because they may fall apart or deflect under loading with heavy metal shop materials.

Many shop storerooms require wider aisles widths than those described in Section 28.2.2.1 and wide double-leaf access doors to safely move materials in from the loading dock and then out to the shop (see Chapter 26, Figure 26-2).

28.2.3 Egress

Storerooms that do not contain flammable and combustible liquids may have one exit if the maximum distance to an exit door is 50 ft or less. Two exits are strongly recommended in storerooms containing flammable or combustible liquids, or those with a chemical fume hood. Follow the guidelines in Chapter 1, Section 1.2.3 and Chapter 2, Section 2.2.2 as applicable for storeroom use.

28.2.4 Floors, Ceilings, and Walls

Because materials' handling equipment carrying heavy boxes of chemicals, specimens, bulky gas cylinders, or shop materials can knock into walls and scrape floors, sturdy materials should be used to construct walls and floors. Walls of concrete masonry units, reinforced with steel, or walls of heavy-gauge steel studs with high-impact gypsum wallboard surfaces are acceptable. If working conditions are expected to be really rough, wall bumper guards are effective in protecting walls exposed to materials' handling equipment. Floors of sealed concrete are generally serviceable and durable under normal storeroom conditions. If mechanized materials' handling equipment and/or very heavy loads are predicted, structural engineers should be consulted on recommendations of floor loading capacity. In these conditions also consider installing an industrial monolithic floor coating to protect the concrete. Fire-rated assemblies for storerooms can be made from these materials where required by building codes and jurisdictions having authority. Finished ceilings are optional in storerooms. Ceilings may be installed for aesthetic and acoustical reasons. Solid gypsum wallboard assemblies can provide fire-rated ceilings where required by building or fire codes.

28.2.4.1 Flammable Liquids and Bonded Alcohol Storeroom. Explosion venting or prevention is required in these storerooms when volumes of flammable liquids for Class IA reach 90 gal (341 L) or for Class IB, 360 gal (1,363 L). Bonded alcohol "vapor forms explosive mixtures with air at concentrations of 4.3–19% (by volume)" (Prudent Practices, 2010). Vapors from extremely flammable liquids, such as diethyl ether, can form explosive mixtures with air at concentrations of 1.9–36 % by volume (Prudent Practice, 2010). Structural engineers calculate the wall or roof area required for explosion venting. See NFPA Standard 68, *Explosion Protection by Deflagration* (NFPA, 2007). Explosion venting is a mechanism to relieve excess build-up of pressure, fire, or explosion in rapidly expanding gases from an explosion.

In flammable liquid and bonded alcohol storerooms, generally one exterior wall of the storeroom is constructed with pressure relief panels that pop open when pressure rises above the limit. If flammable liquid and bonded alcohol storerooms are in single story structures, panels can be in the roof assembly and open up to the atmosphere. Panels are tethered, attached with a strong cable or chain to the building, so they will not become projectiles if an explosion takes place.

28.2.4.2 Compressed Gas Cylinder Storeroom. Explosion venting is required in gas cylinder storerooms when volumes of flammable gases reach over 1,000 ft^3 (93 m^3) and for liquefied flammable gas reach 30 gal (114 L). See Section 28.2.4.1 for guidelines on location, and NFPA Standard 68, Explosion Protection by Deflagration (NFPA, 2007).

28.3 HEATING, VENTILATING, AND AIR-CONDITIONING

28.3.1 Introduction

All the recommendations provided in Chapter 1, Sections 1.3.9 and Chapter 2, Section 2.3 that are applicable to laboratory storerooms should be implemented. Additional recommendations are given below. Industrial hygiene personnel and engineers should be consulted for unusual design conditions.

28.3.2 Individual Room Requirements

28.3.2.1 General Chemical Storeroom. A general chemical storeroom requires ventilation systems and criteria similar to that for a general chemistry laboratory, as described in Chapter 5, Section 5.3. This storeroom may require local exhaust devices and vented corrosive chemical storage cabinets.

28.3.2.2 Flammable Liquids and Bonded Alcohol Storeroom. Details of ventilation requirements from the flammable liquid waste storage guidelines that are applicable to this storeroom are shown in Chapter 27, Section 27.3.3. See Chapter 2, Section 2.4.6.3 for a discussion on the venting of flammable liquid storage cabinets.

28.3.2.3 Compressed Gas Cylinder Storeroom. The areas or rooms in which compressed gas cylinders are stored normally do not need to be heated, even when ambient temperatures reach freezing. Such spaces usually are not air-conditioned. However, if there is a reasonable likelihood that enclosed space temperatures would exceed 100°F (38°C) for extended periods, air-conditioning should be considered. In open-air sheds or on loading docks ambient air temperatures are acceptable because normal air currents dissipate any leakage. Indoor space temperature range should be between 50°F and 99°F (10–37°C), depending on the particular gases handled. If special gas storage with conflicting temperature limit requirements is anticipated, accommodations must be considered. Bulk cryogenic gases should remain stored outdoors.

28.3.2.4 Biological Specimen Storeroom. Because room air is not exposed to preservative chemicals, biological specimen storerooms require normal laboratory ventilation. See Chapter 1, Section 1.3.9 and Chapter 2, Section 2.3 for guidelines.

28.3.2.5 Archeology, Paleontology, and Geology Specimen Storerooms. Because room air is not normally exposed to chemicals, these specimen storerooms require normal laboratory ventilation. See Chapter 1, Section 1.3.9 and Chapter 2, Section 2.3 for guidelines.

28.3.2.6 Laboratory Shop Storeroom. Laboratory storerooms may contain small volumes of solvents, strong acids, paints, varnishes, flammable and oxidizing gas cylinders, and possibly other hazardous chemicals and coating materials. These should be stored in appropriate chemical cabinets, so that these storerooms require normal laboratory ventilation. See Chapter 1, Section 1.3.9 and Chapter 2, Section 2.3 for guidelines.

It is critical that air in storerooms, where metals, metal hardware, and tools are stored, should be kept in very low humidity conditions, less than 20% RH to retard rust formation.

28.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

Careful consideration should be given to the information contained in Chapter 1, Sections 1.4.1, 1.4.2, 1.4.4, 1.4.6, and Chapter 2, Sections 2.4.1, 2.4.2, and 2.4.6 through 2.4.8. Special attention should be paid to the recommendations below. National building codes and fire codes such as IBC (IBC, 2012; IFC, 2012) have limits on volumes of flammable liquids allowed in buildings. In a single fire-control zone located at grade level, 30 gal (114 L) of Class IA, 120 gal (454 L) of Class IB, and 120 gal (454 L) Class IC flammable liquids are allowed on open shelves. This volume increases by 100% if they are stored in appropriate chemical cabinets, and another 100% if the storeroom is in a fully sprinklered, fire-protected building. If the need requires, the flammable liquid/alcohol storerooms, located on the ground level, can be designed and designated as one fire-control zone to maximize the volume that can be legally stored (see Chapter 1, Section 1.2.4.2).

According to the volume of hazardous compressed gases held, the IBC (IBC, 2012) shows allowable limits per fire-control zone located at grade level 1,000 ft^3 (93 cu m^3) for flammable gases, and 1,500 ft^3 (139 m^3) for oxidizing gases. This volume increases by 100% if the storeroom is in a fully sprinklered, fire-protected building. If the need requires, compressed gas cylinder storerooms can be designed and designated as an entire fire-control zone at ground level to maximize the volume that can be legally stored (see Chapter 1, Section 1.2.4.2).

28.4.1 Personal Protective Equipment

Normal laboratory PPE should be available for persons working in general chemical storerooms, in flammable liquid and bonded alcohol storerooms, and in wet-specimen biological storerooms. Because no chemicals are normally used in flammable liquid and bonded alcohol or in wet-specimen biological storerooms, no eyewash or safety shower is required, unless recommended by the organization's health and safety professionals. Both eyewash and safety shower are required in general chemical storerooms.

For compressed gas cylinder storerooms containing large volumes of oxidizing gases, consider provision of special nonflammable, flame-retardant protective suits, gloves, and other PPE to protect workers.

28.4.3 Electrical Service

Electrical services in flammable liquid and bonded alcohol storerooms should conform to the International Electric Code or National Electrical Code for Class I Group C & D Division I installations. All areas in which open containers of flammable liquids are handled should conform to the requirements for Class I Group C & D Division I installations. The International Electrotechnical Commission (IEC) refers to "zones" in place of "divisions." Zones are based on the length of time ignitable concentrations are present continuously. Division I would be closest to "zone" 1 and division II would be closest to zone 2. Division II is required if there is an existing ignition source.

28.4.4 Bonding and Grounding Systems

A static electricity bonding and grounding system should be installed in all areas in which flammable liquids are transferred (see Chapter 27, Section 27.4.6). Information on effective bonding and grounding systems can be found in NFPA 30, Flammable and Combustible Liquids Code (NFPA, 2012).

28.4.3 Fire Protection

Water-reactive chemicals in the general chemical storeroom should be segregated and confined to an area in which sprinklers are replaced by a more appropriate fire suppression system, such as a dry chemical. If needed to be stored in a room protected by a water sprinkler system, watertight cabinets should be provided.

28.5 SPECIAL REQUIREMENTS

28.5.1 Security

Security considerations are discussed in Chapter 1, Section 1.5.4.1 and Chapter 2, Section 2.5.1.

28.5.2 Floor Drains

No floor drains should be provided in general chemical, flammable liquid, and bonded alcohol storerooms or areas in which hazardous chemicals are stored or processed. Nevertheless, if a floor drain is used, it should not be connected directly to the sanitary or storm sewer, but be directed to an isolated holding sump or tank. Such tanks may fall within the jurisdiction of underground storage tank regulations (see Chapter 1, Section 1.5.3.3).

PART IV

HVAC SYSTEMS

Well-designed and well-operated heating, ventilating, and air-conditioning (HVAC) systems are essential for laboratory health and safety protection, as well as for an environment that promotes comfort, productivity, and good work practices. In some laboratories, such as cleanroom and microelectronics laboratories, the HVAC system contributes importantly to the functionality of the facility. This part of the book is concerned with the design of satisfactory HVAC systems for laboratories in general and for a number of specific applications. It is also concerned with the selection and installation of HVAC equipment that is specifically designed for laboratory use, i.e., equipment that has been found to be reliable, long-lived, and efficient for the task. Energy conservation is addressed to aid building owners, operators, and design engineers to evaluate conservation strategies and systems that maintain health and safety of occupants. Energy conservation is a significant factor in achieving sustainable design (see Chapter 38).

Some general information on the nature of HVAC systems and equipment has been included to assist those not professionally involved with HVAC matters to understand the issues and to be prepared to assist in reaching critical decisions on cost and function.

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29

HVAC SYSTEMS

29.1 DESCRIPTION

This chapter is intended to provide a general background for those less familiar with the terminology used in describing heating, ventilating, and air-conditioning (HVAC) systems. It is by no means an exhaustive discussion of HVAC systems. For more detailed information, see the current series of *ASHRAE Handbooks* on *Fundamentals*, *HVAC Systems and Equipment*, and *HVAC Applications* (ASHRAE, 2009–2012). Additional reference sources include classic works (Stoeker, 1958), as well as recent discussions by Kavannaugh (2006), Sauer and Code (2005), and Butterworth at al. (2007), and the *ASHRAE Laboratory Design Guide* (McIntosh, Dorgan, & Dorgan, 2001).

To meet design conditions in all laboratory areas, several independent control variables must be satisfied simultaneously under all conditions of operation. They are (1) temperature, (2) differential space pressure, (3) humidity, and (4) air exchange rate.

29.2 AIR-CONDITIONING SYSTEMS

29.2.1 Introduction

Air-conditioning is commonly understood to mean the supply of tempered (heated or cooled) air into a room to offset heat losses or heat gains, but air motion, relative humidity, and air purity controls are also included in a fully implemented system. A conditioned zone is a boundary inside the conditioned space that is controlled by a single control point or thermostat.

To a remarkable degree all warm-blooded animals, including humans, are able to maintain a constant internal environment, called *homeostasis*, while living in a changeable external environment characterized by extremes of temperature and humidity. Humans, however, are unique in having the ability to regulate the external environment in accordance with their own ideas. Warming the interior of buildings during cold weather has been carried on since time immemorial, but cooling is a 20th century phenomenon, initiated for factory production of heat- and humidity-sensitive items, adopted on a large scale in the United States for commercial properties during the 1930s, and adopted for residential use after 1950. Although the original objective in cooling commercial and residential properties was to provide a lower indoor temperature during hot weather, it was soon learned that the moisture content of the cooled air and its rate of motion over the body were additional factors in regulating human comfort in air-cooled spaces.

Heat energy flows from a region of higher temperature to one of lower temperature, meaning that building interiors lose heat when the weather is cold and gain heat when the weather is hot. The rate at which heat flows from the interior to the exterior, or vice versa, is variable and depends partly on the conductivity of the structure and partly on the amount of air exchange

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between inside and outside. Outside unconditioned air is brought into the structure in two ways: purposefully for ventilation supply air and inadvertently as infiltration air that enters through open doors, windows, and structural cracks under the influence of an inside pressure that is lower than the pressure outside the structure. Wind action has an important influence on infiltration rates as well as on heat conductivity. Recently, energy conservation measures have been influential in substantially decreasing the heat conductivity of new and old structures by the addition of heat insulation materials and by reducing building porosity to decrease infiltration. Both measures have been effective in reducing building air-conditioning costs; it is unlikely that this trend toward energy efficiency will be reversed in the foreseeable future.

Heat gains by insolation are welcomed during cold weather, but they are guarded against during hot weather by window and structural shading, reflective roof and wall treatments, and building orientation relative to the sun. Heat gains by insolation are generally neglected when calculating heating requirements, but must be carefully accounted for when calculating cooling loads. A similar comment applies to outside air humidity. Together, heat gains from insolation and the need to reduce the moisture content of outside air entering the air-conditioned spaces through mechanical ventilation and infiltration often represent a major fraction of the total summer cooling load. Heat sources within the building itself from lighting, equipment, and personnel decrease the winter heating load, but increase the summer cooling load. In many laboratories, the heat generated internally by equipment, people, and lights may be greater than the summertime heat gains from the sun and by conduction through the building's structure. It is critical, therefore, to inquire closely into the nature and amount of laboratory equipment that emits heat when designing the HVAC facilities that will be included in the building design. Maximum population density should also be estimated to calculate internal heat gain by personnel in the space. This information can be very important in designing teaching laboratories. In extreme cases, a cooling capability may be required year round, even in cold climates, and this requirement must be provided for when the heat load from equipment is unusually large. These issues are illustrated in Table 29.1, Equipment Plug Load Estimates. This chart is an actual example of calculations for a specific client.

29.2.2 Temperature /Humidity interaction Psychometric Chart

The psychometric chart can be used to calculate and understand humidity and temperature interaction. It graphically represents the thermodynamic properties of moist air. The coordinates for the chart can be different. A commonly used chart (Figure 29-1) is illustrated with enthalpy (Btu/lb dry air [da]) and humidity ratio (lb water/lb da).

29.2.3 Comfort

A definition of thermal comfort is the "condition of mind that expresses satisfaction with the thermal environment." This can be very subjective and one laboratory worker can be comfortable when another is not. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers has published a standard Thermal Environmental Control Standard 55 (ASHRAE, 2004) and provides an excellent source of information on this subject. The feeling of comfort may be different than summer than winter as the clothing worn is different. This difference is shown as different clothing and thermal insolation (Clo) values. For example, a winter business suit has approximately 1.0 Clo (0.88 ft^2/h °F/Btu), whereas summer trousers and short sleeve shirt has 0.5 Clo (0.44 ft^2/h °F/Btu); Figure 29-2 shows the new ASHRAE summer and winter comfort zones using different Clo numbers. In the middle of the zone, a typical person wearing the prescribed clothing should be comfortable. At near the boundary, the person may feel slightly cooler or warmer.

Figure 29-3 shows the number of individuals who are predicted to experience discomfort annually over a range of mean temperatures under operating conditions per 100,000 ft^2.

Humidity levels are less precise and Standard 55 prescribes no upper or lower limits for humidity (for more details, refer to Section 29.5).

Even though it is not a design issue, education of occupant may be helpful in their feeling of comfort. Warm clothing worn by occupants in winter can allow lower temperatures in the space and conserve energy.

29.2.4 Air-Conditioning Load

The air-conditioning or heating and cooling loads are laboratory (space) or building energy gain or loss requirements to achieve comfort or desired space temperature and humidity conditions.

29.2.4.1 Internal Loads. The internal loads in a laboratory building have a significant impact on the HVAC requirements. Two major items are lighting and plug loads. The lighting design for buildings has significantly advanced over the years. The fixture design has improved

TABLE 29-1. Example of Laboratory Plug Load Estimate

Heat Gain Calculations: range is 4 to 20 W/NSF, average is 8 W/NSF	Lab Anteroom	DNA Sample Prep Lab	Sample Holding Room	DNA Sample Accessioning Room	DNA High Sensitivity Accessioning Room	Casework Examination Lab	Exemplar Examination Lab	Examination Anteroom	Rape Kit Examination Lab	Alternate Light Source Lab	Casework Confirmation Lab
Number of Rooms	3	1	1	1	1	1	1	2	1	2	1
Type of Major Equipment											
Refrigerator - standard	0	1	4	0	0	4	2	0	0	0	2
Refrigerator - u.c.	0	0	0	0	0	32	0	0	0	0	8
Freezer - standard -4°C	0	1	4	0	0	0	0	0	0	0	2
Freezer - ultra cold -80°C	0	0	8	0	0	0	0	0	0	0	1
Liquid-handler - robot	0	1	0	0	0	4	1	0	0	0	8
Hand dryer - automatic	4	0	0	0	0	0	0	2	0	0	0
Power Calculations											
Total Net Area (NSF)	823	1,540	1,558	1,142	663	4,663	1,716	464	185	180	1,323
Connected W/NSF	25.30	28.70	15.30	3.68	1.88	48.26	16.24	10.00	0.00	4.41	18.96
Diversity Factor	20%	75%	45%	75%	75%	60%	60%	20%	60%	80%	50%
Lighting W/NSF	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
Heat Gain W/NSF	7,941	4,859	12,338.00	6,757	3,731	45,277	15,750	3,260	648	4,158	14,111
Environmental Factors											
Temperature/ Humidity	std	std	std	std	std	std	std	std	std	std	std
Pressurization to corridor	negative	positive	negative	negative	positive	positive	negative	negative	negative	negative	negative

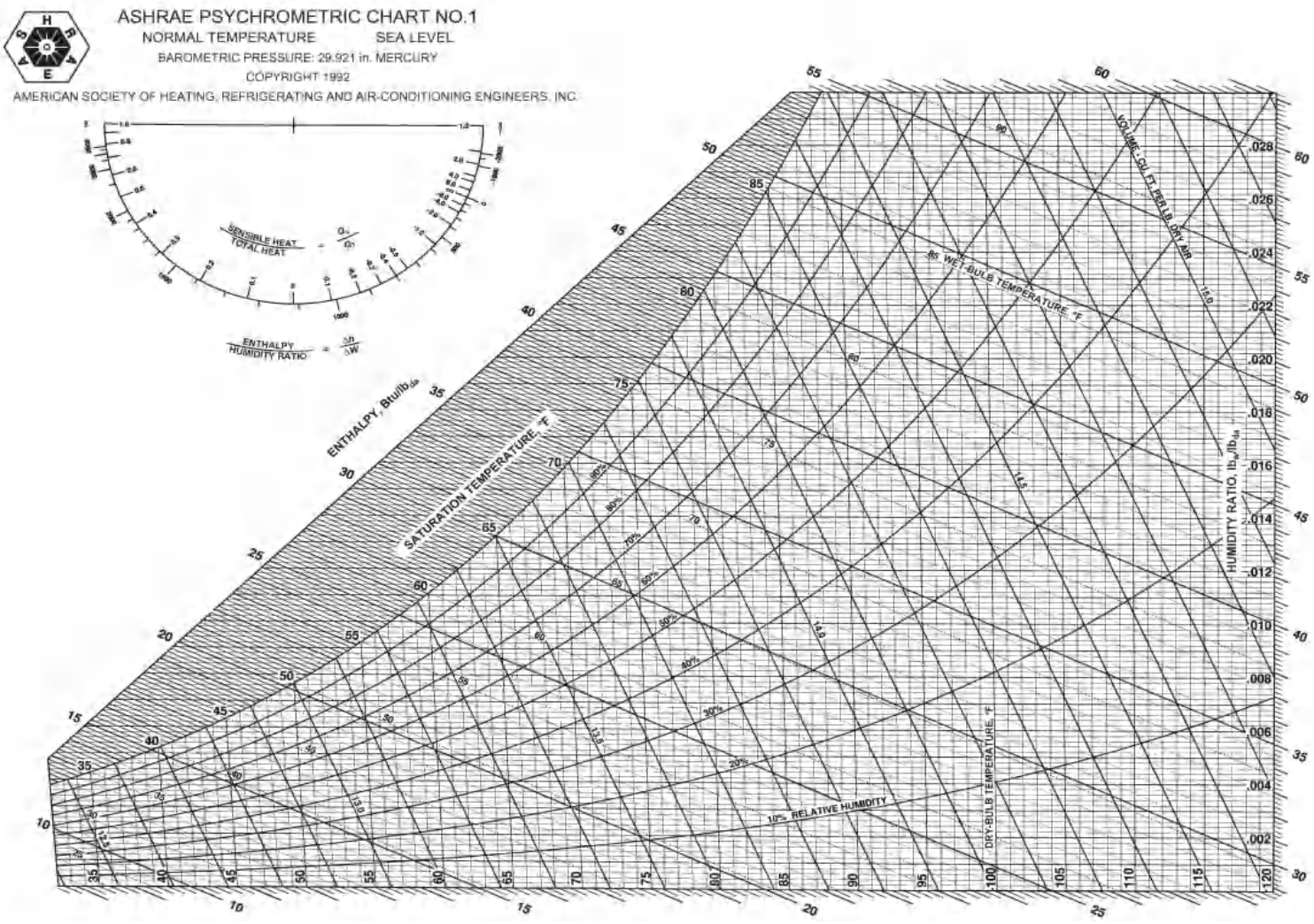
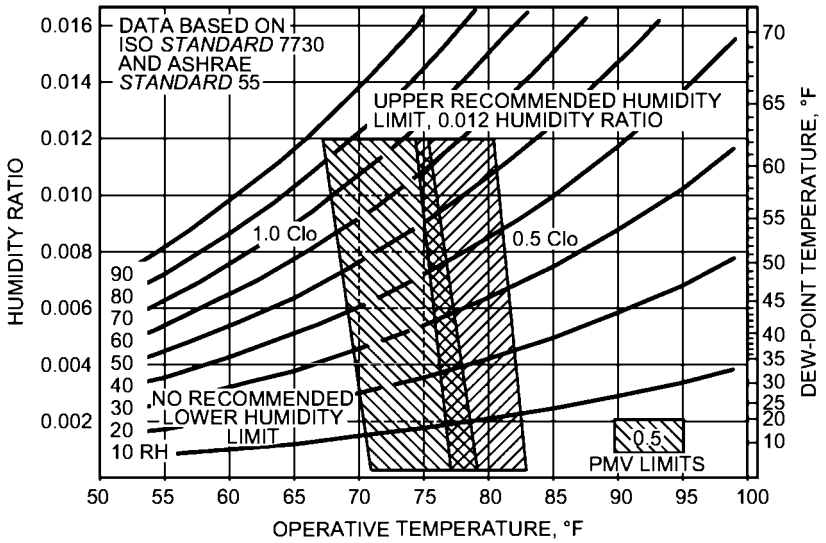


FIGURE 29-1. Psychometric chart.



[Acceptable ranges of operative temperature and humidity with air speed ≤ 40 fpm for people wearing 1.0 and 0.5 clo clothing during primarily sedentary activity (≤1.1 met).]

FIGURE 29-2. ASHRAE Comfort standards.

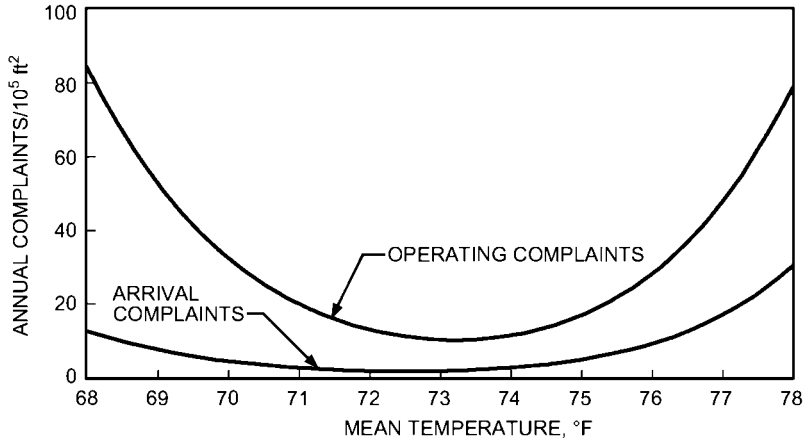


FIGURE 29-3. ASHRAE predicted rate of unsolicited thermal operating complaints.

and more energy efficient light sources are available. In many cases, energy-efficient lighting design is required by regulators, as well as the laboratory's goal to be more sustainable. More information on lighting design is provided in Chapter 1. Plug loads are those electrical loads inside laboratory where the equipment is either plugged in the wall receptacles or hard wired. This equipment emits heat and this heat energy becomes part of the HVAC room load, adding to the cooling requirements and subtracting from the heating requirements.

Tables 6 and 7 of Chapter 18 in the *ASHRAE Handbook of Fundamentals* (ASHRAE, 2011) provide some examples of typical heat gains provided by Hosni et al. (1999). Further work by ASHRAE and other agencies is ongoing. As more information is being gathered on a regular basis, the designers should attempt to collect the best information possible. Manufacturers may also be a good source. In calculating internal loads from equipment, consider that all equipment may not operate simultaneously.

29.3 HVAC SYSTEM DESIGN AND DESCRIPTION

The usual design procedure is first to establish extreme operating conditions to select equipment capable of satisfactory full-load operation. Next, decisions must be made regarding (1) the type of system required (e.g., multiple zones, individual room controls), and (2) the nature of the equipment that will be selected to deliver the preselected design conditions (e.g., central heating, humidifying, and cooling systems, or modular systems to provide final temperature control).

In a *central system*, cooling and heating are performed with central chillers and boilers connected to large air-handling equipment that serves the whole or a major part of the building. The heating or cooling sources may be remote from the buildings they serve.

In a *modular system*, heating and cooling are done locally, sometimes room by room. Central and noncentral cooling systems used in modern buildings are described below.

29.3.1 Cooling Systems

The most commonly used cooling system, referred to as *mechanical cooling*, uses a thermodynamic process called *direct expansion*. A gaseous heat-transfer medium (commonly called refrigerant) is compressed to a state of high temperature and pressure by a compressor. Freon and ammonia were the most common of refrigerants. Use of ammonia in commercial applications is problematic. Freon due to its adverse greenhouse gas effect has been replaced by other refrigerants. The refrigerant is then transformed into a cool liquid in a condenser, which may be air- or water cooled. The cooled liquid, a refrigerant under high pressure, is allowed to flow to a low-pressure region through an expansion valve where the refrigerant evaporates. The latent heat of evaporation is extracted from the fluid (air or water) being cooled, thereby producing the temperature-reduction step. The warm evaporated refrigerant gas is drawn next into the suction side of a compressor, and the cycle is repeated. This most basic of thermodynamic cycles is the heart of all direct expansion, or DX, refrigeration cooling systems. Some of the components are described below.

29.3.1.1 Compressors and Prime Movers. There are many types of compressors in use for air-cooling systems. Compressors can be hermetic or semihermetic. In hermetic compressors, the electric motor windings are cooled by the refrigerant suction gas. This prevents overheating; at the same time, it increases efficiency by heating up the cool suction gas, evaporating any liquid droplets that may be in the stream. A true hermetic compressor is integrally sealed. In smaller sizes, it is called a "tin can." A semihermetic compressor is similar to a hermetic one, except that it can be taken apart for maintenance. For larger systems, it is almost mandatory that a semihermetic compressor be used. Another classification is an open compressor where the prime mover operating the compressor is separate from it. Although there is more flexibility in the choice of prime movers, the most frequent choice is an electric motor. Other kinds of prime movers, such as gasoline engines and steam or gas turbines, are also used.

In large systems, the voltage to the electrical motor may be substantially higher than usual to avoid unusually large wire sizes and motor windings.

29.3.1.2 Reciprocating Compressors. The most common compressor is a reciprocating one in which the gas is compressed in cylinders by pistons operated by an electric motor.

29.3.1.3 Centrifugal Compressors. This machine compresses the refrigerant gas by centrifugal action rather than by reciprocal piston action, but is otherwise similar to a reciprocal pump in its function. It is used primarily in systems having more than 100 tons of refrigeration capacity because it provides a more efficient ratio of energy consumption.

29.3.1.4 Screw Compressors. In this type, the refrigerant gas is compressed between two turning helical screws. The system is generally used from medium to high refrigeration tonnage because the energy ratio (i.e., kilowatts of electricity expended per ton of refrigeration produced) is attractive and the system offers a very reliable alternative to reciprocating and centrifugal compressors. The choice of prime mover is predominantly electrical, but others have been used.

29.3.1.5 Coils. Coils are inherently heat transfer devices and are the fundamental part of an air-conditioning system. Traditionally, a coil is composed of tubes connected to each other in which a fluid flows. A change of temperature or phase or both, occur inside a coil. To improve heat transfer efficiency, fins are provided on the outside surface.

A *heating* coil placed in a supply air system will raise the temperature of supply air. Similarly, a *cooling* coil will reduced the air temperature. When the coil surface temperature is less than surrounding air dew point condensation will occur. For cooling coils drain pans and drain needs to be provided to deal with condensate. This condensate can be recovered and reused.

A *refrigerant* coil provides heat exchange by phase change.

29.3.1.6 Condensers. The system is named according to the heat-transfer medium, either air or water. An air-cooled condenser, as the name implies, cools the hot compressed gas phase by forced air around the refrigerant heat exchanger (a collection of coils). In a water-cooled system, the refrigerant condenser is cooled by water. The water can be sent directly to waste or recycled after being cooled in a direct or indirect water cooler. In a water-cooling tower, hot condenser water is sprayed, or otherwise distributed, over packings or pans that allow the water to trickle downward in thin films countercurrent to a rising airflow. Some of the heated water evaporates, extracting the heat of vaporization from the water and transferring it to the ambient air. The water returns to the condenser cooler than when it left. In an evaporative cooler, water from a secondary source is sprayed over a closed loop coil in which the hot condenser water flows. Air is forced over the outside wet coil surfaces to evaporate the secondary water, which in turn cools the primary condenser water inside the coil. One of the advantages of this system is that the primary condenser water is not contaminated, but this system is slightly less efficient than the cooling tower configuration.

29.3.1.7 Expansion Devices. There are two commonly used expansion devices: thermostatically controlled expansion valves and capillary tubes. Thermostatically controlled expansion valve provides better control.

29.3.1.8 Evaporators. The liquid refrigerant at low temperature is drawn into a low-pressure region by compressor suction where it evaporates, withdrawing the heat of vaporization from the air being cooled or from water used to cool the ventilation air. There are various kinds of evaporators in use, but the most widely used are refrigerant-to-air or refrigerant-to-water types.

29.3.1.8.1 Refrigerant-to-Air Evaporators. The liquid refrigerant is evaporated directly into a coil located inside an air handler that supplies cool air directly into conditioned spaces. In this case, a thermostatically controlled expansion valve is normally used.

29.3.1.8.2 Refrigerant-to-Water Evaporators. In this type of equipment, the liquid refrigerant is evaporated into a coil that cools water surrounding the coil. The cooled water is then pumped through cooling coils located in the space to be cooled. This system is normally referred to as a "chiller." It is commonly used for large, widely distributed areas or buildings and when close control of environmental conditions is required.

29.3.1.9 Evaporative Cooling. Evaporative cooling is another energy-conserving process (for more details, see Chapter 51, ASHRAE, 2010).

29.4 SYSTEM DESCRIPTIONS AND STRATEGIES

29.4.1 Introduction

After the cooling and heating equipment selection is made, the distribution system must be selected. There are three possible combinations: an all-air system, an all-water system, or a combination of the two. Depending upon the inside temperature and humidity requirements and outdoor design wet bulb or dry bulb temperature each of the systems described below will have different coefficient of performance (COP). Sometimes, this efficiency information is also presented in kw/ton.

Some commonly used combinations are

- A *reciprocating-type direct expansion system* consists of a reciprocating hermetic or semi-hermetic compressor connected to an air-cooled condenser followed by an expansion device that discharges directly into a refrigerant-to-air coil in an air handler. A small version of this system is the common window air conditioner. Large systems of this nature are known as "package units" or "rooftop package units" because they are often installed there. A variation of this system is a *split system*, in which some of the components of the refrigeration cycle are inside and the heat rejection, or condenser, parts are outside.
- A *chiller/cooling tower combination* is the most popular of the central refrigeration systems. A complete reciprocating or centrifugal compressor system is used to chill a secondary cooling medium (water) that is then pumped throughout the spaces to be cooled.

In general, water-cooled chillers have a better COP than air-cooled systems. The chilled water is incorporated into air handlers that consist of large housings containing fans, cooling coils, and filters. They cool the air and move it into the conditioned spaces. Heating coils are usually installed for winter heating and to reheat air for summer air-conditioning that has been cooled below the comfort level for the purpose of condensing excessive water vapor. These air handlers can

be either low-pressure or high-pressure systems. A low-pressure system has less than 3 in. w.g. static pressure capability, whereas a high-pressure system exceeds this value. It takes more fan energy to operate a high-pressure system. Nevertheless, high-pressure systems usually operate at higher velocities so the duct sizes can be smaller.

29.4.2 All-Air Systems

In all-air systems, one or several air handlers are used to condition the entire building. A further classification can be made among the following:

1. In *constant temperature systems*, air is cooled to a constant discharge temperature. Reheat coils to temper the air to any desired temperature are installed downstream to accommodate variations in requirements.
2. In *dual-duct systems*, a single air handler—or a cluster of air handlers—has a split air system consisting of a *hot deck* and a *cold deck*, which simultaneously produces separate hot and cold airstreams. Both are distributed to each conditioned zone where a preset thermostatic controller positions dampers in a mixing box to mix the hot and cold airstreams to produce the desired air temperature in the room.
   - *Multizone systems* are similar to dual-duct systems in that the air handler has a hot and a cold deck. However, the mixing zone dampers are located at the air handler.
   - *Variable-volume systems* supply air at a constant temperature into the conditioned space where the zone thermostat controls a volume box that reduces or increases the amount of air supplied to the conditioned space to satisfy the thermostat setting.

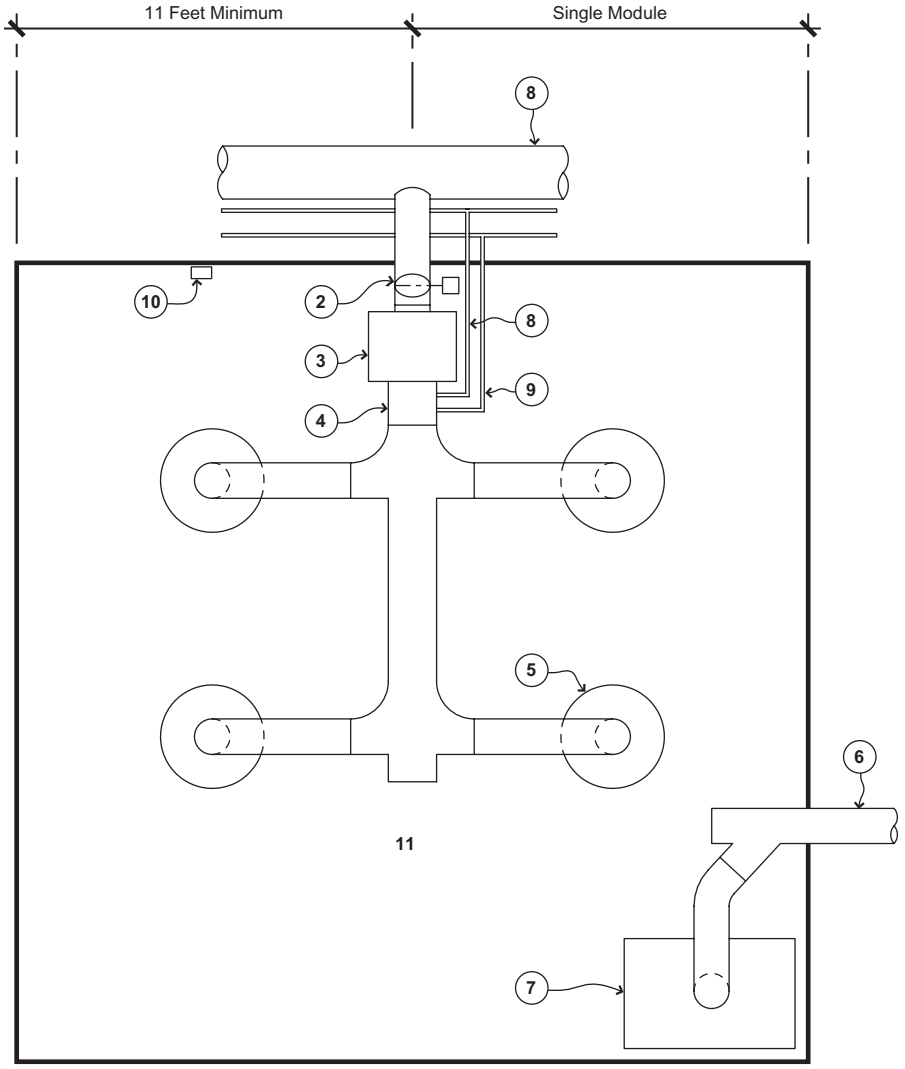
     Different system approaches are usually considered in the design stage. They differ significantly with respect to system configuration, space requirements, control psychometrics, first cost, operating cost, and flexibility. Types of systems include a constant-volume terminal reheat (TRH) system, a variable-volume terminal reheat (VVTRH) system, and a dual-duct (DD) system.

29.4.2.1 Constant-Volume Terminal Reheat Systems. A constant volume of air is supplied to the ventilated laboratory space through a high- or low-velocity ductwork system. The air is introduced into the laboratory through an air-volume-regulating device and a reheat coil. The air-volume-regulating device may be as simple as a manual balancing damper (in low-velocity systems) or as complex as a pressure-independent terminal box (in high-velocity systems). The reheat coil tempers the supply air when cooling requirements and internal heat gains are less than design conditions. Building cooling loads and internal heat gains do not normally peak simultaneously; therefore, reheat is needed most of the time. Because a constant volume of air is supplied to a laboratory using the TRH system, a constant volume of air must be exhausted to maintain design pressure relationships. Air may be exhausted through a central system, through individual exhaust hoods, or through a combination of both.

The TRH system is relatively simple in concept. When it is used to meet all requirements for ventilation, heating, cooling, and space pressurization, it must be designed and operated to meet full-load climatic design conditions even though it seldom operates under this condition. Therefore, it calls for a large system, high design load conditions, and high operating costs that together result in an inefficient use of system capacity. In addition, TRH systems tend to be inflexible and to have limited ability to support expansion without significant cost penalties. When the terminal equipment does not use pressure-independent volume control regulators at each space, a change in flow conditions in one space will normally cause a deviation in another, resulting in a need for frequent, costly system balancing. A TRH without a pressure independent terminal boxes therefore are not recommended for laboratories. A diagram of a TRH system is shown in Figure 29.4.

29.4.2.2 Variable-Volume Terminal Reheat Systems. This is an all-air system that uses a central air-handling system to meet all facility needs for ventilation, heating, cooling, and space pressurization. However, VVTRH systems use variable-volume-regulating devices as terminal equipment instead of a constant-volume-regulating device to control the introduction of air into each space. A VVTRH system is similar in configuration to a TRH except for the use of an air volume controller. A VVTRH system can allow significant variation in supply air and correspondingly reducing the supply fan energy usage. Note that the supply air volume may not be reduced below a minimum needed to maintain laboratory temperature, humidity, and pressure differential. A typical room terminal system is illustrated in Figure 29.5.

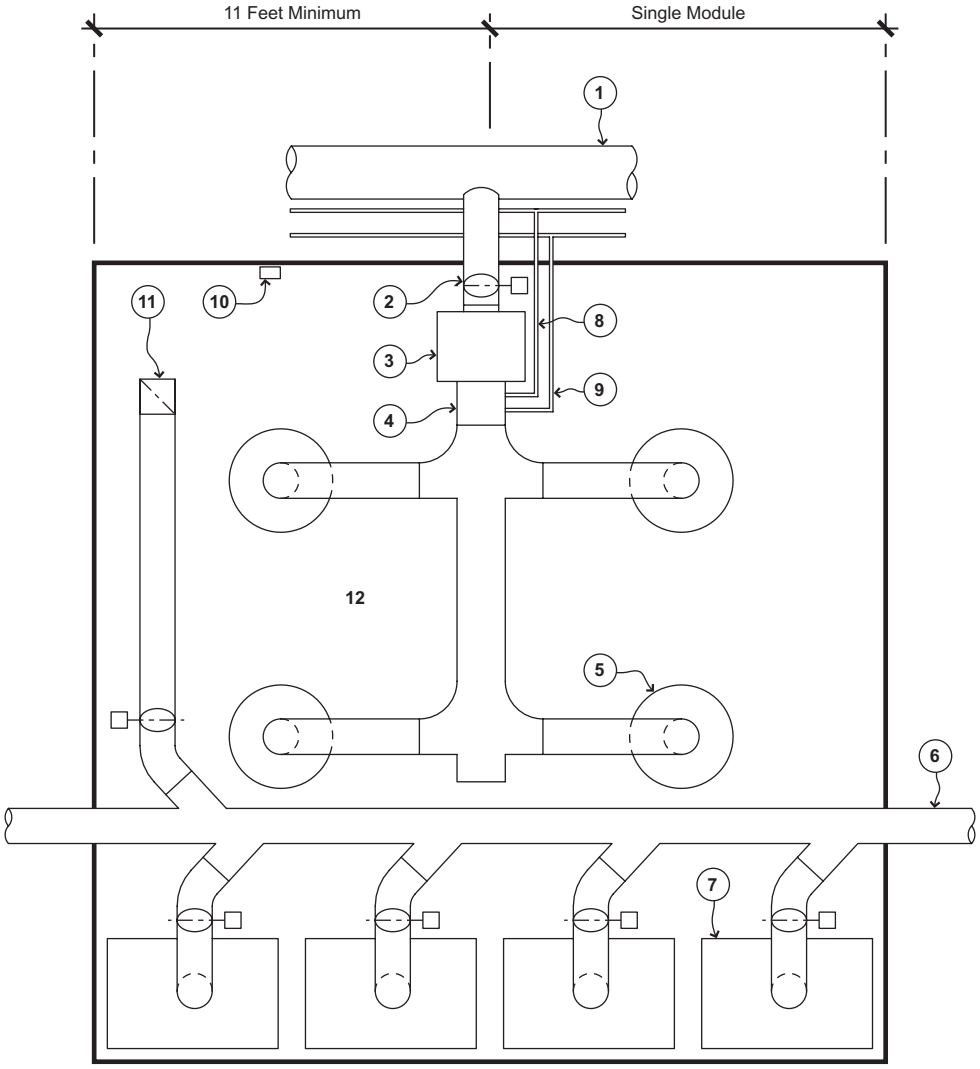
29.4.2.3 Dual-Duct Systems. In DD systems, two sets of ducts are needed: one carrying cold air and the other carrying hot air to terminal boxes that mix hot and cold air to satisfy the preset room thermostat and regulate total volume to satisfy a room differential pressure



KEY

1 Primary Air Supply
2 Damper
3 Terminal Reheat Box
4 Reheat Coil
(Typically Located in Reheat Box)
5 Diffusers
6 Central Exhaust System
7 Fume Hood
8 Hot Water Supply
9 Hot Water Return
10 Thermostat to Reheat Coil
11 Typical Laboratory

FIGURE 29-4. Constant volume terminal reheat system (TRH).



KEY

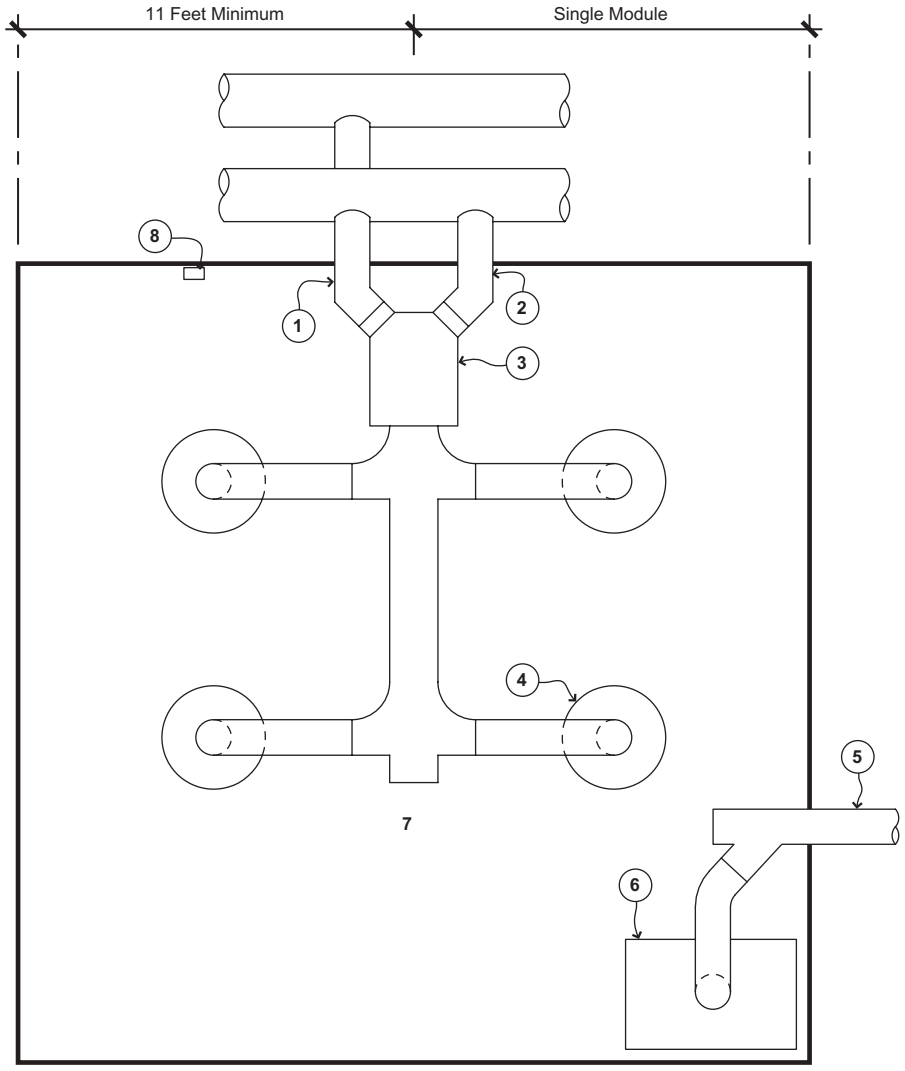
1 Primary Air Supply
2 Damper
3 VAV Box
4 Reheat Coil
(Typically Located in Reheat Box)
5 Diffusers
6 Central Exhaust System
7 Fume Hood
8 Hot Water Supply
9 Hot Water Return
10 Thermostat to Reheat Coil and Econmizer
Exhaust Damper
11 Economizer Exhaust Duct
12 Typical Laboratory

FIGURE 29-5. Variable air volume (VAVTRH).

controller. The two airstreams used for temperature control are referred to as the hot deck and the cold deck. DD systems may be constant-volume or variable-volume systems. In variable-volume systems, there is a minimum turndown level at the terminal box to maintain temperature and pressure control at all times. A DD system is illustrated in Figure 29.6.

29.4.3 Displacement Ventilation Systems

The natural buoyancy of warm air is used to provide improved ventilation and comfort in displacement ventilation (DV) systems. Initially used for heating industrial buildings, displacement ventilation has now become a very attractive alternative for providing



KEY

1 Hot Air Supply Duct
2 Cold Air Supply Duct
3 Dual Duct Mixing Box
4 Diffusers
5 Central Exhaust System
6 Fume Hood
7 Typical Laboratory
8 Thermostat

FIGURE 29-6. Dual-duct system (DD).

heating, cooling, and ventilation in several types of office and classroom buildings.

In a DV system, conditioned supply air is introduced to the space at or near the floor level at a low velocity and at a temperature only slightly below the desired room temperature. The cooler supply air "displaces" the warmer room air, creating a zone of fresh cool air at the occupied level. Heat and contaminants produced by activities in the space rise to the ceiling level where they are exhausted from the space.

DV systems are typically more energy efficient and quieter than conventional overhead systems. They also provide better ventilation efficiency, and thus improve indoor air quality.

A DV system with underfloor air supply distribution (UFAD) for laboratory applications can be problematic due to possible spills of hazardous materials and subsequent contamination of the supply air. For proper operation and reducing the loss of conditioned air, the underfloor space should be "tight." The underfloor space may also require a good pest control program to prevent contamination. In some cultures, a conditioned air supply from the floor is unacceptable.

Wall-mounted DV systems are also possible by installing supply air devices low on the wall. To connect these devices to the supply air duct system, duct risers may need to be installed on the wall (see Figure 29.7). This duct layout may restrict overall laboratory layout (refer to Chen, 2003) for an excellent discussion of a DV system).

A DV system can be appropriate in classrooms and conference rooms with high ventilation requirements as well as for the office space. However, in an actual laboratory a DV system may limit the amount of wall space for laboratory equipment.

29.4.4 All-Water Systems

Chilled water for cooling, and in some cases hot water for heating, is piped throughout the conditioned building. In each conditioned space, there are fan units to blow air over the coils to condition the area. The terminal fan-coil units are small, unitized cabinets with filters, a small fan, and coils for cooling and/or heating. All-water systems of this type are classified as

1. *Two-pipe systems*—a single set of water-containing pipes is distributed to each of the fan coils. The circulating water may be cool or hot, depending on the season. Changeovers from hot to cold water and vice versa are conducted as the seasons require.
2. *Four-pipe systems*—hot and cold water are supplied to each fan-coil unit through a separate set of pipes for instantaneous heating or cooling at each fan-coil unit as needed.

Whenever a terminal fan-coil unit is used, a condensate drain is normally needed to remove water that condenses on the outside of the cooling coil during humid weather. Figure 29.8 illustrates a typical fan coil unit.

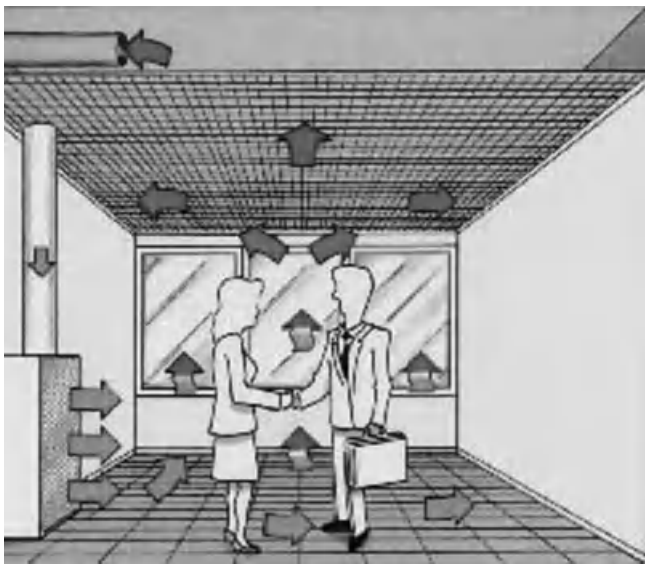


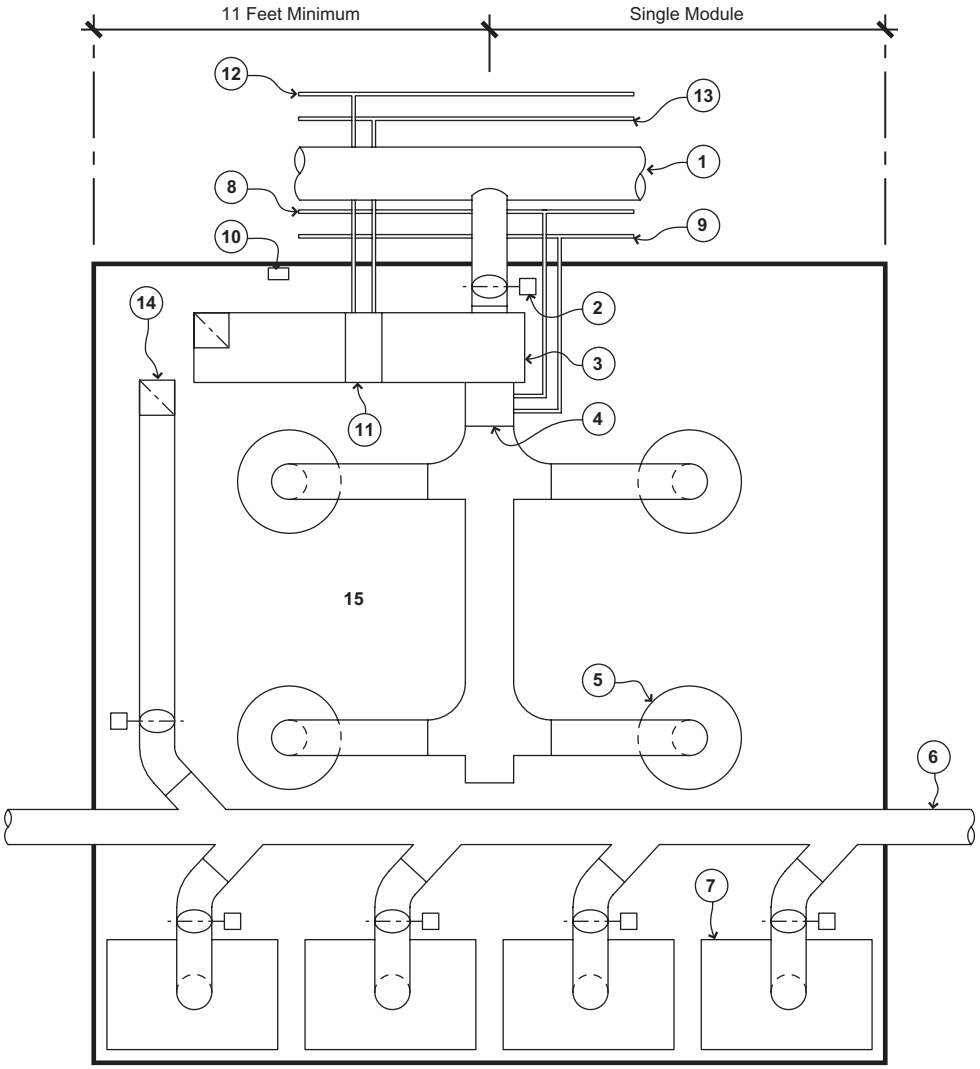
FIGURE 29-7. Displacement ventilation (DV) diagram. (Courtesy Argon Air.)

FIGURE 29-8. Fan coil unit.

29.4.5 Combined Systems

Mixed air-and-water systems are also common. They are described below.

29.4.5.1 Fan-Coil Variable-Air-Volume Systems. A fan-coil variable-air-volume (FCVAV) system differs from TRH and VVTRH systems in system function and the configuration of the terminal unit. A typical room FCVAV system with economizer exhaust is illustrated in Figure 29.9. FCVAV systems use a central variable-volume air-handling system that distributes tempered air through supply ductwork and returns it for recirculation through exhaust ductwork. Alternatively, heating



KEY

1	Primary Air Supply	9	Hot Water Return
2	Damper	10	Thermostat to Reheat Coil and Economizer Exhaust Damper
3	Fancoil VAV Box	11	Recooling Coil
4	Reheat Coil (Typically Located in Reheat Box)	12	Cold Water Supply
5	Diffusers	13	Cold Water Return
6	Central Exhaust System	14	Economizer Exhaust Duct
7	Fume Hoods	15	Typical Laboratory
8	Hot Water Supply		

FIGURE 29-9. Fan-coil variable-air-volume with economizer exhaust system (FCVAV).

and cooling functions may be provided in each space with fan-powered VAV units serving as fan coils. By separating heating and cooling functions from space pressurization and ventilation functions, outside air requirements are reduced; this results in a major reduction in operating costs. The FCVAV system design results in the smallest possible central HVAC unit and primary distribution ductwork, but requires more ceiling space in the served areas. Heating and cooling are accomplished by the sequential operation of hot water and chilled water control valves at the fan-coil unit. Ventilation and space pressurization functions are provided by a controller located at the room boundary, which regulates the rate of air introduced into each space to maintain a preset pressure relationship relative to contiguous spaces. When air is exhausted from a pressure-regulated space, the pressure controller senses an imbalance and compensates for it by increasing the supply air flow rate. Space pressurization control is recommended over other methods for reasons of responsiveness and minimum cost.

29.4.5.2 Fan-Coil Constant-Volume Systems. Fan-coil constant-volume (FCCV) systems differ from terminal reheat and variable- volume systems in terminal unit configuration and system function. A typical FCCV system is illustrated in Figure 29.10. Just as for FCVAV systems, the separation of heating and cooling from space pressurization and ventilation functions results in a major reduction in outside air requirements and operating costs. The result is a small central system and a reduced air distribution network, but greater use of ceiling space in the served areas. Heating and cooling are accomplished by the sequential operation of hot water and chilled water control valves at the fan-coil unit. The ventilation and space pressurization functions are provided by a controller located at the room boundary.

29.4.6 Radiant Heating and Cooling System

A radiant system uses the radiation from a hot or a cold surface to provide heating or cooling. A common example is radiators used for perimeter heating in many types of buildings where hot water or steam circulate, thereby warming the outside surface. This warm surface "radiates" to the occupants providing comfort. Similarly, a colder surface can provide comfort cooling. Radiant heating and cooling panels have been in use for many years.

Early applications of the radiant cooling panels were problematic. As the temperature controls systems available to control the water temperature flowing inside the panel were not sophisticated; wide fluctuations of water temperature and consequently the surface of the panel also varied. If the temperature of the surface was less than the dew point of surrounding air, unwelcome condensation of water vapor from surrounding air occurred on the surface. There have been occurrences of radiant cooling panels or surfaces in the laboratories "raining." No such problem has occurred with radiant heating panels and they have been in wide use.

With the advent of better temperature control technology, the water temperature inside the cooling panel can be better controlled and one can ensure that the surface temperature will not be less than the surrounding air dew point. In some applications where the walls are radiantly cooled, the air temperature can be warmer to achieve the same level of comfort. The cooled wall approach is probably not useful for laboratories as it inhibits laboratory layout.

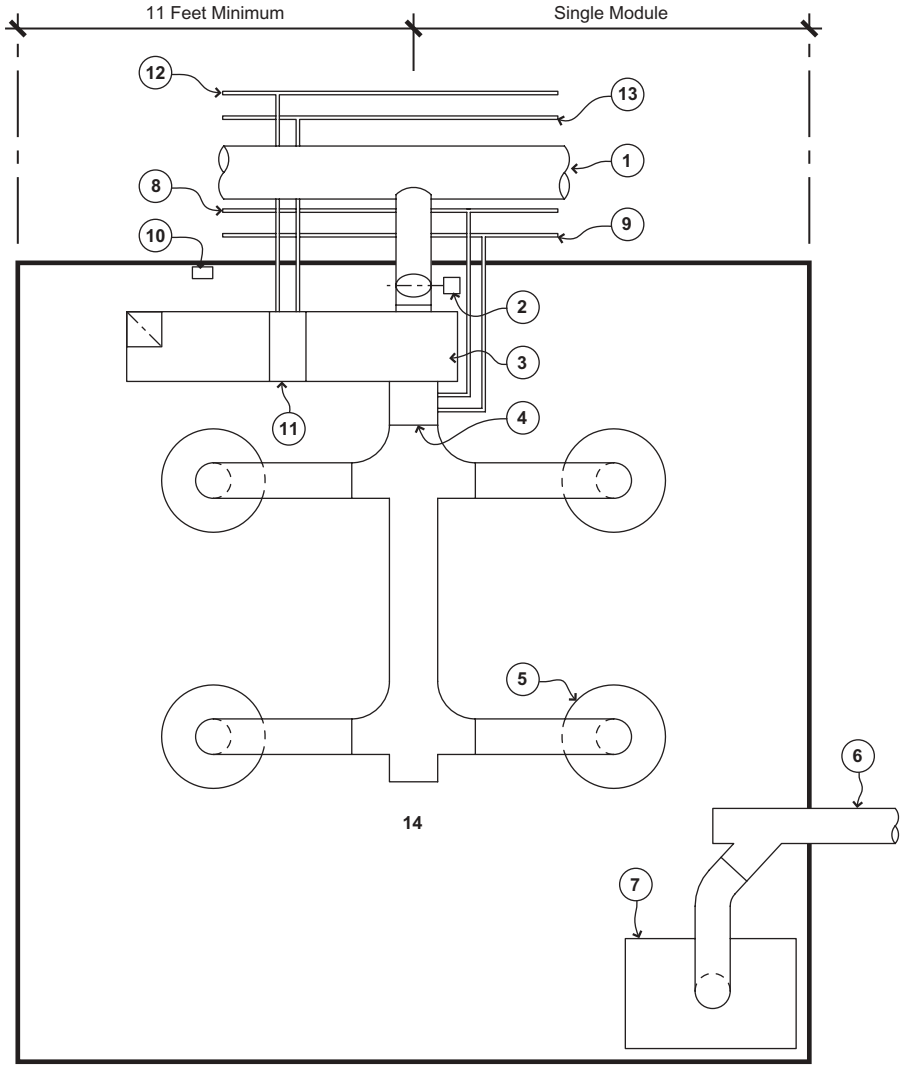
29.4.6.1 Chilled Beam System. A chilled beam system is essentially a radiant cooling system. These systems were developed in the 1980s; they resemble a structural beam. This system is very popular in Europe where it is used to provide comfort cooling. Chilled beam systems are illustrated in Figure 29.11.

There are two basic types of chilled beams: active and passive (Sutter, 2007). *Passive beams*, rely entirely on the natural convection process with chilled water coils, and provide no air supply to the unit. Room air supply is provided separately.

Active beams have chilled water coils and an air supply (called *primary air*) connection. Primary air supply causes induced convection over the water coils and results in an increased cooling capacity; the primary airflow required for fresh air supply is discharged into a mixing zone via nozzles. The induced air is drawn from the room through a water coil. In the mixing section, the induced air is mixed with primary air and the total discharged into the room via slots as shown in Figure 29.11.

Chilled beams combine the airflow characteristics of ceiling diffusers with the benefits of load dissipation using water. Active chilled beams can provide cooling, heating, and ventilation.

Chilled beam technology may be used in BSL-1 and some BSL-2 laboratories. The advantage of a chilled beam system is its ability to provide sensible cooling capacity in the laboratory. This way the ventilation requirements and the cooling requirements can be decoupled. Costs can be reduced. As there is no fan, fan energy is saved as well. Chilled beams are therefore a very energy efficient method of providing cooling in laboratories. An example of possible savings of chilled beam systems is illustrated in Figure 29.12.



KEY

1 Primary Air Supply
2 Damper
3 Fancoil VAV Box
4 Reheat Coil
(Typically Located in Reheat Box)
5 Diffusers
6 Central Exhaust System
7 Fume Hood
8 Hot Water Supply
9 Hot Water Return
10 Thermostat to Reheat Coil and Economizer
Exhaust Damper
11 Recooling Coil
12 Cold Water Supply
13 Cold Water Return
14 Typical Laboratory

FIGURE 29-10. Fan-coil constant volume system.

The disadvantage of a chilled beam system is that there is no filtration in front of the coil. As the cooling process includes induced air, any particles in the air can get attached to the coils. A non-laboratory example of this phenomenon is seen in hospital patient rooms where floor-mounted induction units are used. Many times a thin coating of lint from patient linen is found on the induction unit coils, creating operational problems. Similarly, in some labs (e.g., model shops or foundries) where particles may be in the air, the use of chilled beams is not appropriate.

Another disadvantage of a chilled beam system is that it required close control of chilled water temperature. As mentioned above, if the chilled water temperature is too low it will cause the surface temperature of a chilled beam system to drop below the dew point. Surface condensation then will occur; this water will eventually fall in the laboratory. To address this problem many manufacturers have started to provide a drain pan, which adds to the upfront cost and provides installation challenges. For example, this drain pan must be pitched and piped appropriately to drain properly.

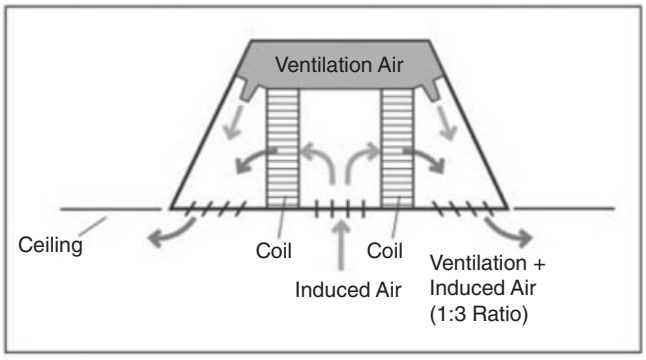


FIGURE 29-11. Section through a chilled beam device Taken from *PG&E High Performance Laboratories, Design Guidelines* source book (http://www.energydesignresources.com/media/2396521/Labs_BestPractices.pdf?tracked=true).

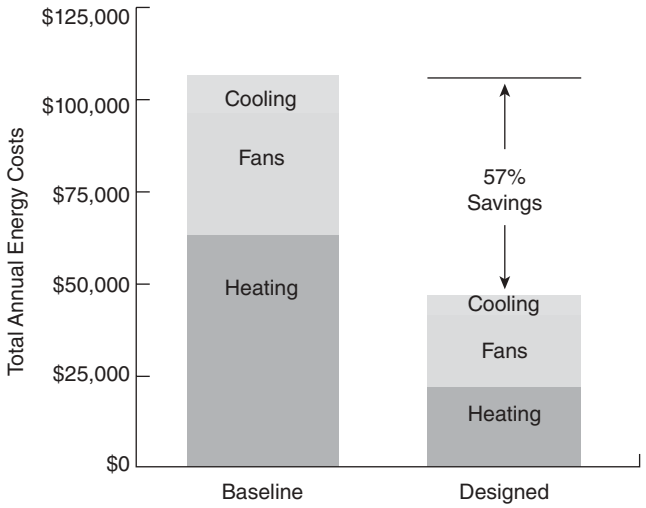


FIGURE 29-12. Energy savings of chilled beams.

29.5 HUMIDIFICATION AND DEHUMIDIFICATION

29.5.1 Humidity

Humidity is an ambient air condition that affects human comfort and environmental control in laboratories. Water vapor is usually present in the air. Chapter 1, Section 1.5.6—Steam Quality—should be consulted.

Relative humidity (RH) is the amount of water vapor present in the air compared to the maximum amount it could hold at the same temperature expressed as a percentage. Air at 100% RH is saturated. In general, indoor relative humidity should not exceed 60% or be less than 30% (Sterling, 1985). ASHRAE (2009) describes some of the research conducted in support of establishing the high and low points of humidity levels. ASHRAE Standard 55 recommends that the dew point of occupied spaces be not less than 36°F (2.22°C) nor exceed 62.2°F (16.78°C) at standard pressure.

The need for humidity control should be considered carefully to avoid condensation during cold weather. It will require the control point to be lowered in some cases (Hermans, 2000), although it is desirable to maintain conditions as close as possible to 30–40% RH. Should extensive condensation occur, there is a potential for mold growth and damage to the building structure. The American Architectural Manufacturers Association (AAMA) has established condensation resistance factors (CRF) for newly manufactured windows that seek to limit RH in cold climates. Recommended levels of RH are listed in Table 29.2 and are

TABLE 29-2. Recommended Condensation Resistance Factors (CRF) (courtesy of the American Architectural Manufacturers Association)

	Recommended CRF				
Location	ASHRAE 99.6%	Relative Humidity			
		20	30	40	50
Atlanta	18.8	16	36	50	62
Washington DC	15.9	21	39	53	64
Boston	7.7	31	47	59	69
Chicago	–5.0	43	56	66	74
Minneapolis	–14.9	49	61	70	77

Examples of Major U.S. Cities (assuming an Indoor Air Temperature of 70°F)

based on a tight, well-insulated multipane window with a CRF of 54 (Hermans, 2000). The RH setpoint for the space should be reset to this schedule when windows with a CRF rating higher than 54 are used; set points can be raised. For winter temperatures above 20°F (–7°C), spaces should be maintained between 30 and 40% RH.

29.5.2 Humidification Systems

Humidification can be accomplished by local or central systems. Central systems are recommended for laboratories. Special humidity control systems may be needed for very precise humidity regulation. Chapter 21 in the *ASHRAE Systems Handbook* (ASHRAE, 2012) describes various system options. Some are illustrated in Figure 29.13.

29.5.2.1 Direct Steam Injection. Steam at relatively low pressure and temperature is introduced directly into the air to be humidified without affecting air temperature significantly. This is the most popular system. The control system can be a modulating or an on-off type. The following are the most frequently recommended options.

1. *Enclosed Steam Grid Humidifier*: A grid containing one or more steam injection tubes is installed in supply ducts. A steam control valve driven by a laboratory humidity sensor provides RH control. Prevention of steam condensate splash-over inside the duct requires careful steam trap installation design.
2. *Jacketed Steam Humidifier*: An integral steam control valve with a steam-jacketed tube that disperses steam into the supply duct. It contains a separator to prevent water from being introduced into the airstream.
3. *Self-Contained Steam Humidifier*: Converts water directly to steam by an electric heating device.

29.5.2.2 Water Atomization. Atomizing humidifiers introduce a fine mist of water directly into the air, where the water evaporates. The ability of air to evaporate all the mist depends on air temperature, air velocity, and entering RH. One of major questions regarding water atomization is potential risk of bacteria growth in the supply water reservoir and the nozzle itself. A UV filtration system is suggested (Spengler, Samet, & McCarthy, 2001).

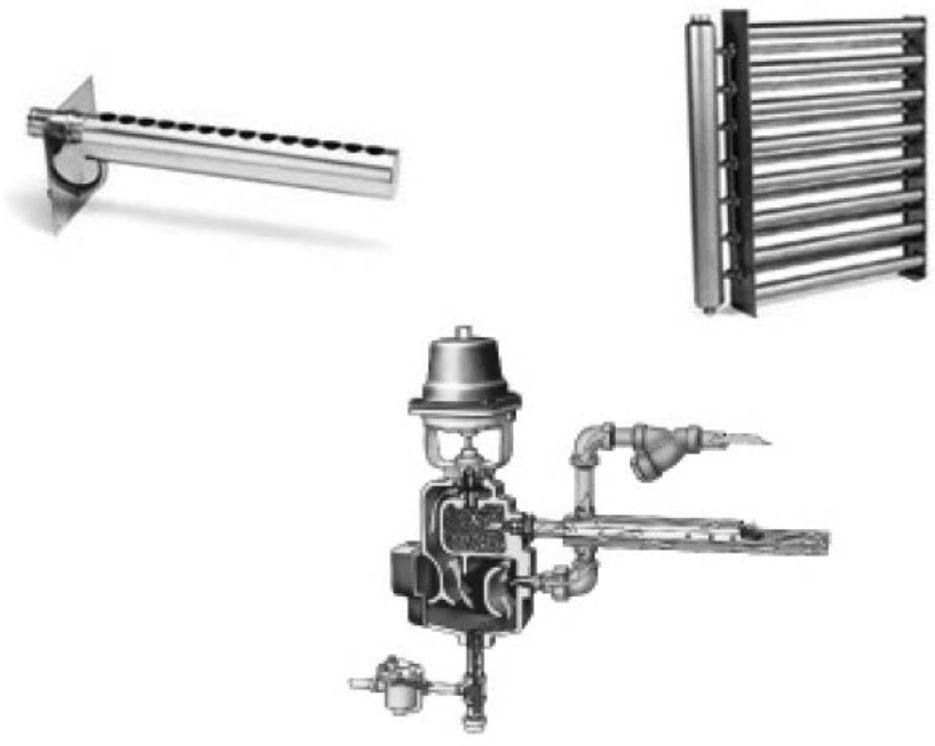


FIGURE 29-13. Types of humidification equipment. (Copyright © 2013, Armstrong International, Inc. Reproduced with permission.)

29.5.3 Duct-Installed Humidifiers

Care must be taken to avoid water condensation inside ducts because the persistent or intermittent presence of liquid water can initiate and sustain the growth of fungi and bacteria that degrade air quality. When condensation is persistent, water may drip out of air outlets. The location of a humidifier installation is critical for optimum safe performance; manufacturers' recommendations should be followed.

29.5.4 Humidifiers Installed in Laboratories

Devices are available for direct humidification of the laboratory space. These are especially applicable in humidification of greenhouses. Care must be taken in their selection and placement because uniform dispersion of water vapor is sometimes difficult to achieve.

29.5.5 Dehumidification

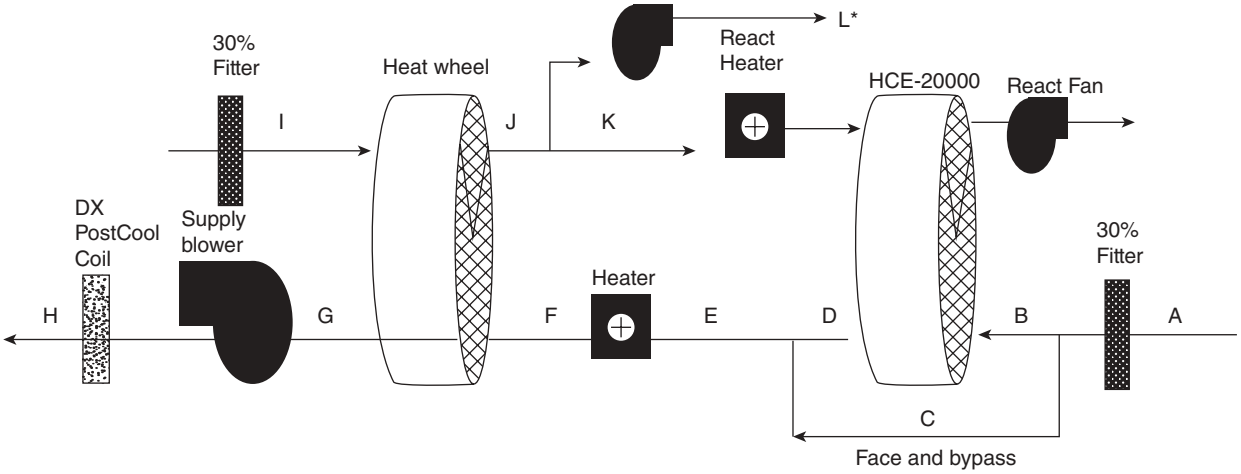
As the name implies, dehumidification is removal of humidity or water vapor from the air. Hermans (2000) recommends an upper limit of 60% RH. This is below the 70% level considered optimum for the growth of fungi, but it favors the growth of dust mites. Maintenance of extremely close humidity tolerances or exceptionally low humidity in summer means intensive use of the air-conditioning system.

Two of the common systems are described below.

29.5.5.1 Subcooling the Air. The air is cooled below its dew point. This allows water vapor in the air to condense. The resultant moisture is collected and removed from the conditioned space.

29.5.5.2 Need for Reheat. The designers should carefully review the researchers' requirements before setting the humidity level. When the need for reheat energy cannot be totally eliminated, the use of waste heat should be considered. Waste heat from an engine-driven device, an engine-driven chiller, or electrical generator can be a good source. In winter, the rejected heat from a cooling system can be used

29.5.5.3 Desiccant Systems. Another way to dehumidify is to use desiccant systems. An example is shown in Figure 29-14. The airstream is first filtered; then a portion of the airstream passes through the desiccant. The remainder of the airstream bypasses the desiccant and is mixed with the dehumidified airstream. The mixed air is drier, but is at a higher temperature. The



		Process											
		A	B	C	D	E	F	G	H	I	J	K	L
SUMMER	FLOW [CFM]	30000	20000	10000	20000	30000	30000	30000	30000	30000	30000	10000	20000
	Temp [°F]	90	90	90	168	142	142	106	70	90	127	127	127
	Moisture [gr/lb]	120	120	120	35	65	65	65	65	120	120	120	120
WINTER	FLOW [CFM]	30000	30000	0	30000	30000	30000	30000	30000	0	0	0	0
	Temp [°F]	0	0	0	0	0	70	70	70	0	0	0	0
	Moisture [gr/lb]	5.5	5.5	0	5.5	5.5	5.5	5.5	5.5	0	0	0	0

FIGURE 29-14. Desiccant system detail. (Courtesy Munter Corp. Amesbury, MA)

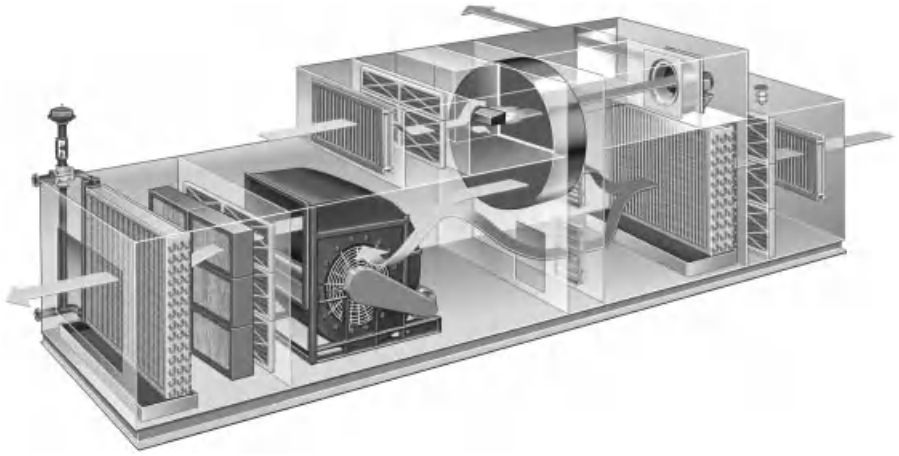


FIGURE 29-15. Desiccant system typical package unit detail. (Courtesy Munter Corp., Amesbury, MA)

airstream is then cooled or heated to the desired temperature for the space. The desiccant is reactivated by another heated airstream. Figure 29-15 shows a cutaway of a commercially available packaged rooftop unit.

29.6 SPACE PRESSURE CONTROL

29.6.1 Introduction

Laboratory HVAC systems must be ventilated and designed to satisfy space pressure needs under all conditions of operation.

There are four pressure control strategies that can be used:

1. Space pressure control
2. Flow totalization
3. Flow synchronization
4. Constant-volume reset control

Each strategy has advantages and limitations, but when correctly applied, each can result in satisfactory facility performance at reasonable installation and operational costs. Any of the strategies can be applied to existing facilities using constant-volume systems to correct operational deficiencies and can support a moderate degree of expansion without necessarily increasing physical plant or primary air-handling system requirements. A combination of more than one strategy is possible.

When the maximum exhaust air requirements of all variable-volume hoods in a laboratory exceed 100% of the normal room air supply volume and the laboratory is designed for controlled air exchange between adjacent spaces, automatic flow control should be provided to modulate the supply air volume.

29.6.2 Pressure Control Systems

Pressure control systems use velocity or differential pressure sensors at the boundary of the room to control the introduction of air into the space. In addition to the hood exhausts that are normally served by the air supply system, an economizer exhaust device is needed to make sure that space heating and cooling requirements are met whenever hood exhaust air quantities are inadequate to induce sufficient tempered air flow.

29.6.2.1 Space Pressure Control. Pressure control systems have the following advantages:

- They are the simplest type of control.
- They provide positive separation of environments from room to room because they require compartmentalization.
- They easily support system expansion and contraction of facilities without the addition or modification of controls.
- They are not limited in turndown except by the leakage rate of the volume regulators used.
- They eliminate a need to place sensitive control instruments in corrosive environments, resulting in a high degree of reliability.
- They require only one supply system per regulated space.
- They require a minimum of supply air to meet the changing pressure needs of the space, thereby conserving primary air use.
- They measure differential pressure (the control variable) directly. Therefore, they are self-balancing and accommodate external disturbances such as stack effects and air infiltration from wind.
- They are the least costly control method to implement.

Pressure control systems have the following disadvantages:

- They require maintenance of laboratory compartmentalization.
- They are highly dependent on (1) the continuous sensitivity of the pressure sensor to small pressure changes that directly affect infiltration and exfiltration between compartments, and (2) how the system responds to transient disturbances such as traffic through the pressure-controlled boundary.
- Their response to pressure disturbances can call for sudden supply air increases that may cause localized air turbulence that affects fume hood performance adversely.
- Establishing minimum ventilation rates is difficult.

29.6.2.2 Flow Totalization Control of Space Pressure. Flow totalization pressure control systems use a Pitot tube or hot-wire anemometer velocity sensor in the airstreams entering and leaving the controlled space. The signals received from these sensors are processed by a square root extractor (pneumatic systems), a pressure/electric transducer (pneumatic/digital system), or an analog-digital processor to provide a signal that is used to regulate the total pressure-controlled laboratory supply air and exhaust air volumes. The physical configuration of the air distribution system will be the same as for the space pressurization approach. Flow totalization systems with differential pressure control require a high order of complexity with high initial cost and high maintenance requirements.

Flow totalization control systems have the following advantages:

- Do not require compartmentalization of the facility or maintenance of compartmentalization for system control. Infiltration and exfiltration rates are a matter of system balance and are not subject to transient disturbances in maintenance or compartmentalization (i.e., traffic through doors).
- Only one supply system is required to support a space.
- Minimum ventilation rates are easily established.
- Disturbances do not cause localized air turbulence that affects fume hood performance adversely.

Flow totalization systems have the following disadvantages:

- Sensitive control instruments are placed within corrosive environments, thereby reducing reliability.
- May be limited to a 4:1 turndown before the ability of the equipment to measure air velocity is affected adversely.
- Do not readily support the addition or removal of exhaust systems without the addition or modification of system controls.
- Technically complex
- Expensive
- Are not self-balancing because the control method does not directly measure the important control variable.
- Subject to degradation of balance from control drift and sensor fouling; require regular rebalancing.
- Air balancing is difficult and expensive. The system must be balanced throughout its entire range of modulation.
- Insensitive to non-quantifiable disturbances such as infiltration and building stack effect.

29.6.2.3 Flow Synchronization Control Systems. Flow synchronization control systems to control laboratory differential pressure differ from space pressurization and flow totalization control methods in physical configuration. Each system is served by dedicated air ducts that use Pitot tube or hot-wire anemometer velocity sensors in every airstream entering and leaving the controlled space. The signals received from the sensors are fed into a proportional plus integral laboratory differential pressure controller to eliminate output signal offset error. Controllers providing derivative functions are useful in eliminating control system transients.

Flow synchronization control systems have the following advantages:

- Do not require compartmentalization of the facility.
- Room infiltration and exfiltration rates are a matter of system balance and are not subject to transient disturbances such as from door traffic in the maintenance of compartmentalization.
- Minimum ventilation rates are easily established.
- Pressure transients do not cause localized air turbulence that affects fume hood performance adversely.

Flow synchronization systems have the following disadvantages:

- Sensitive control instruments are placed within corrosive environments, thereby reducing reliability.

- May be limited to a 4:1 turndown ratio before the ability of the equipment to measure air velocity is affected adversely.
- Do not permit easy addition or removal of exhaust system components.
- Complex
- Expensive
- The control system does not respond directly to the control variable, namely, pressure differential. Therefore, the system is not self-balancing, is subject to degradation from controller drift and sensor fouling, and requires regular maintenance and repeated air balancing.
- Air balancing is difficult and expensive because the system must be balanced through its entire range of modulation.
- More than one air supply system may be required for each regulated space because every exhaust system, such as fume hoods, requires a separate supply system.
- Insensitive to non-quantifiable disturbances such as infiltration and the building stack effect.

When correctly designed, installed, and calibrated, space pressurization, flow synchronization, and flow totalization systems are as effective as variable-air-volume systems for laboratories, and each improves hood efficiency.

29.6.2.4 Constant-Volume Reset Control Systems. Laboratory pressure control is maintained by volume control alone. Unlike other methods, volume control does not require the installation of mechanical or electronic devices. Instead, for negative-pressure spaces, the volume of exhaust air is kept larger than the supply volume by the preset amount, and as long as the preset air balance is maintained, the laboratory will remain at the correct differential pressure. For laboratories that must be kept at a positive pressure relative to adjacent areas, the pressure relations will be reversed.

29.6.2.5 Directional Air Flow. The intent of pressure controls systems described above is primarily to ensure that directional air flow exists from a less contaminated to a more contaminated area. A typical pressure gradient that ensures such directional air flow is 0.015 in. w.g. pressure difference (NIH, 2012). Large pressure gradient can cause excessive air leakage, noise and sometime make door opening or closing difficult.

29.7 AUTOMATIC CONTROL SYSTEM

Automatic control systems for temperature and humidity control are vital for laboratories. These control systems have significantly advanced over the years. Until recently, large and small laboratory buildings were controlled by pneumatic controls, where control air pressure variations caused the valves to operate, dampers to open, etc. Today electronic controls or direct digital controls offer tremendous opportunity for close temperature and humidity control, but also remote monitoring. The subject is much too specialized to discuss here; however, when possible, provide individual temperature control capability, and general humidity control. Special purpose rooms may have other needs in relation to humidity control and pressure control.

30

FANS

30.1 FAN TERMINOLOGY

The following definitions have been adapted from *Fan Engineering, An Engineer's Handbook on Fans and Their Applications* (Buffalo Forge, 1999).

Axial-Flow Fan: A fan contained in a cylindrical housing and characterized by flow through an impeller that is parallel to the shaft axis.

Blades: The principal working surfaces of the impeller (also called vanes, paddles, floats, or buckets)

Blower: A fan used to supply air or gases to a thing or a place

Centrifugal fan: A fan contained in a scroll-shaped housing characterized by radially inward and outward flow through the impeller.

Cutoff: The point of the housing closest to the impeller (also called the tongue)

Diffuser: A device attached to the outlet of a fan to transform kinetic energy to static energy (also called a discharge cone or evasé)

Exhauster: A fan used to remove air or gases from a thing or a place

Fan: *Generally*, any device that produces a current of air by the movement of a broad surface

Housing: The stationary element of a fan that guides the air before it enters the impeller and after it leaves the impeller (also called a casing, stator, scroll, scroll casing, ring, or volute). Centrifugal fan housings include side sheets and scroll sheets. Axial fan housings include the outer cylinder, inner cylinder, belt hiring, guide vanes, and tail piece.

Hub: The central part of the impeller that attaches to the shaft and supports the blades directly or through a shroud to the shaft

Impeller: The rotating element of a fan that transfers energy to the air (also called a vane, paddle, float, or bucket).

Inlet box: A device attached to the inlet of a fan to make it possible to use a side entry into a centrifugal fan (also called a suction box)

Inlet: The opening through which air enters the fan (also called the eye or the suction)

Outlet: The opening through which air leaves the fan (also called the discharge)

Propeller fans are pedestal or panel-mounted low-static-pressure axial-flow fans.

Shroud: A portion of the impeller used to support the blades (also called a cover, disk, rim, flange, inlet plate, back plate, or center plate)

Specifically, a turbo machine for the movement of air having a rotating impeller at least partially encased in a stationary housing.

Tube axial fans do not have stator vanes.

Vane axial fans have stator vanes.

Vanes: Stationary blades used upstream or downstream of a fan to guide air flow (When used upstream,

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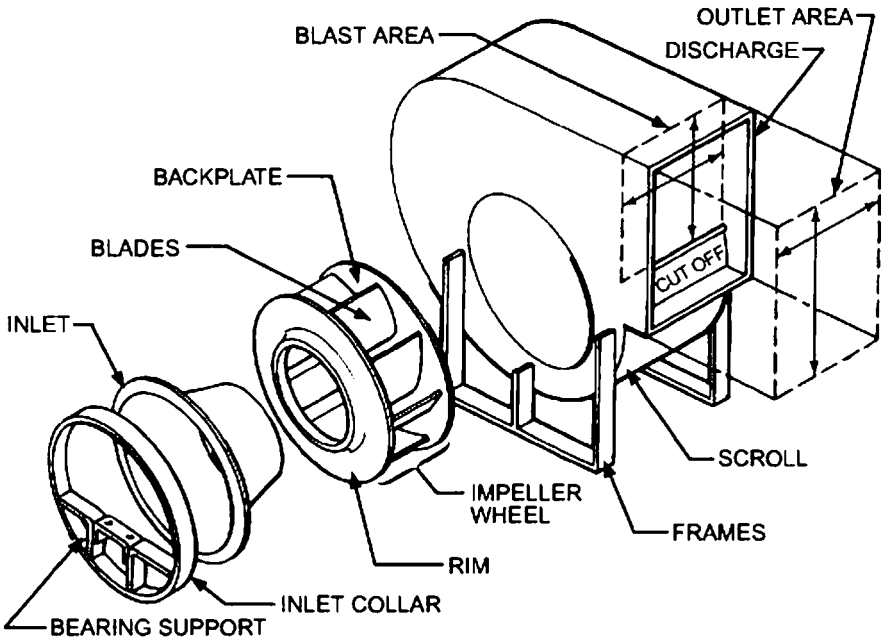


FIGURE 30-1. Exploded view of centrifugal fan. Courtesy ASHRAE.

they are also called inlet guide vanes; when used downstream they are also called straightening vanes or discharge guide vanes.)

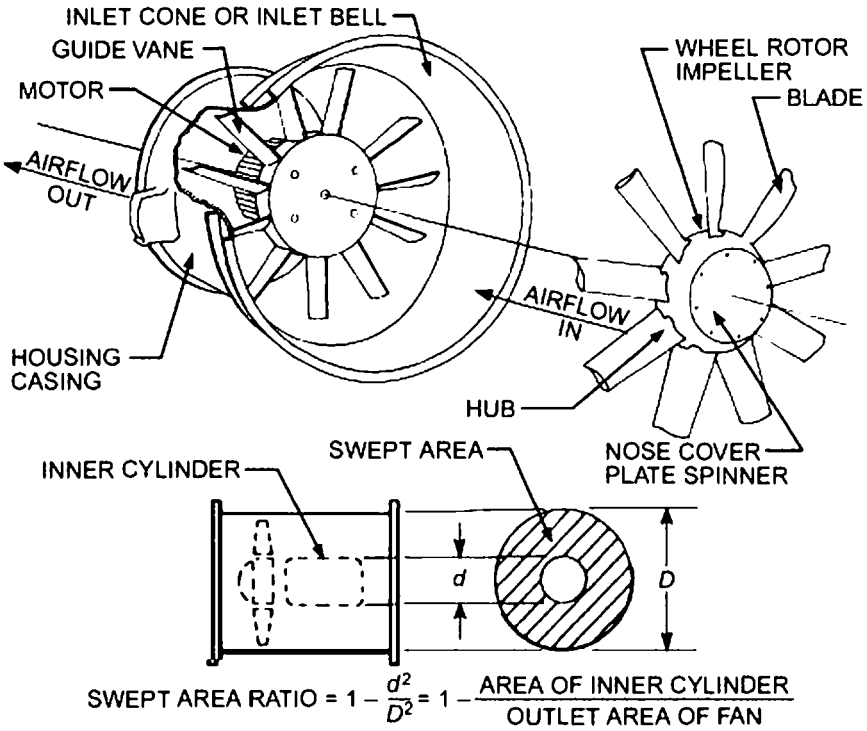
Ventilator: A very-low-pressure-rise fan

Typical centrifugal and axial-flow fans are illustrated in Figures 30-1 and 30-2.

30.2 EXHAUST FAN SPECIFICATIONS

Centrifugal fans, complete with motor and drive, should be used for general exhaust service and can also be used for exhausting fume hoods. They should be of Class I construction, in accordance with the standards established by the Air Moving and Control Association (AMCA, 2012). The fan impeller should be backwardly inclined and should have a true self-limiting horsepower characteristic. The fan should be single width, single inlet with ball bearings with an overhung pulley for a V-belt drive. In some cases, the fan-motor drive combination should be a nonsparking type. Fan housing should be constructed of steel, and all parts should be bonderized and then coated with baked primer-finisher especially formulated to meet stringent corrosion-resistance standards. The coating should have a thickness of at least 1–2 mils without voids. The fan housing should be weatherproof for protection of motor and drive when located on the roof, and a drain connection should be provided in the fan housing. When used for chemical fume hood service, centrifugal exhaust fans can be directly connected to the motor to avoid failures caused by slipping or loss drive belts. An illustration of a typical direct-drive roof installation is shown in Chapter 2, Figure 2-18 and described in the accompanying text.

An alternative exhaust fan system designed specifically for chemical fume hood service uses one or clusters of three or more fan units designed to handle multiple hoods in a manifold system that may induce some building exhaust air when insufficient hoods are in full operation to maintain a strong stack discharge velocity for good atmospheric dispersion purposes. The fan uses a mixed-flow impeller mounted directly to the motor as shown in Figure 30-3, a diagram of a single fan-unit. Air flows upward into the impeller and then flows upward through stationary vanes to a nozzle that discharges a jet of mixed hood exhaust plus dilution air at high velocity inside a windscreen and induces additional mixing with outside air. Multifan units can be modulated to accommodate VAV systems and maintain discharge velocities of active units. These fans can also be manifold together with a common factory-built plenum to increase the exhaust capacity and provide redundancy. Manifold hood exhaust systems are now being selected over single-hood-dedicated systems more frequently than formerly because of lower initial cost and potential energy savings.



Note: The swept area ratio in axial fans is equivalent to the blast area ratio in centrifugal fans.

FIGURE 30-2. Cutaway view of vane-axial fan. Courtesy ASHRAE.

30.3 ATMOSPHERIC DISPERSION

The common solution for getting laboratory exhaust fumes out of a laboratory building's recirculation zone has been to extend the exhaust fan's discharge stack above the boundary layer of the recirculation zone. In most cases, a 10-ft (3-m) height is sufficient (see Chapter 2, Figure 2-18). However, depending on the building configuration, this boundary layer can be higher, sometimes even 20–30 ft (6–9 m) above the roof. Such high stacks sometimes are not acceptable to architects, owners, or the community on aesthetic grounds. An alternative option described by Goode (2000) is as follows.

The recirculation zone boundary layer can be penetrated with a shorter stack by discharging the exhaust air with high momentum, that is, a large mass of exhaust at a high velocity. At least two manufacturers (Strobic Air, Harleysville, PA; M.K. Plastics, Montreal, Canada) have developed rooftop exhaust fans that increase the mass flow of the exhaust stream by inducing air from the recirculation zone to mix with the primary exhaust airstream from the laboratories. The result is a discharge flow rate that is 1½–2½ times the flow being extracted from the inside of the building. The higher flow rate coupled with a discharge velocity of 3,000–6,000 ft/min is claimed to achieve the same effect as a higher physical stack height. The fan manufacturers' performance claims and warranties must be analyzed carefully.

30.4 FAN LAWS

Knowledge of what are known as "the fan laws" is important for selecting equipment to serve current needs and being available for projected future needs. The fan laws interrelate fan size, impeller rpm, air volume, air pressure, input power, efficiency, and fan noise and vibration. A consideration of the fan laws is simplified by considering air to be incompressible, which is approximately correct for usual ventilation air pressures. Detailed quantitative discussion of all the fan laws may be found in publications by ASHRAE and others. Here we will select only some for brief discussion.

- *Fan size and air volume.* For fans of the same series or of closely similar design and equal rpm, the air volume rate varies as the cube of the size ratio. For example, doubling the size of a fan results in an eightfold increase in volume rate ($2^3 = 8$).

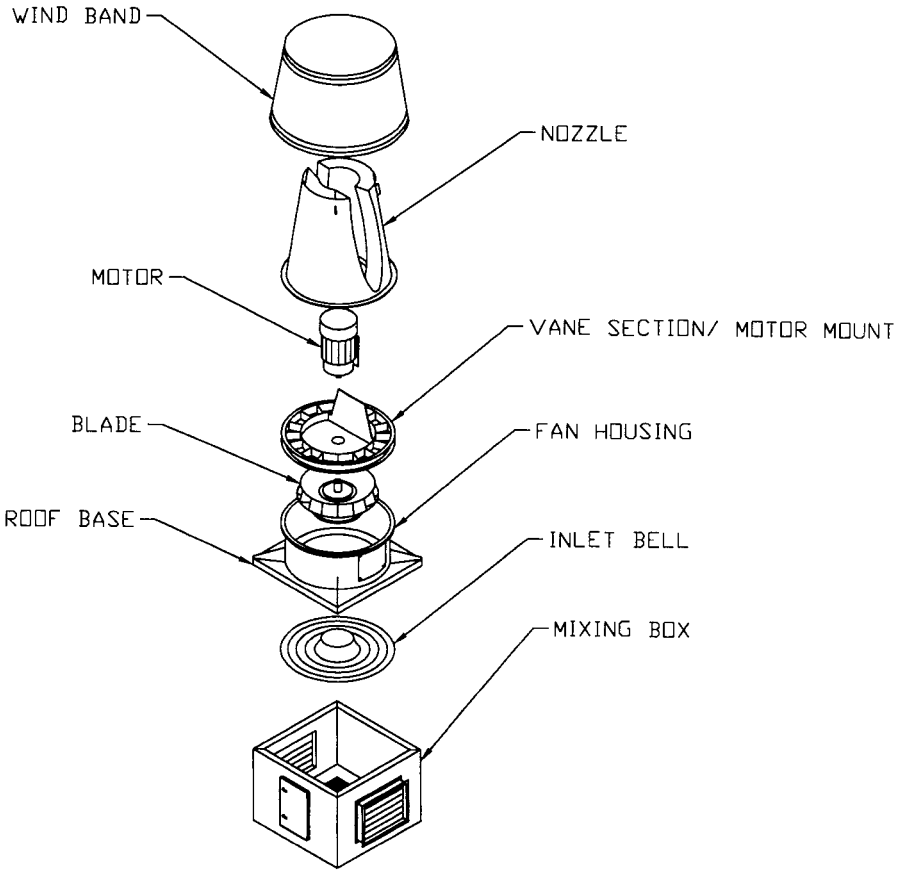


FIGURE 30-3. Tri-stack fan exploded assembly. Courtesy Strobic Air Corp.

- *Fan rpm and air volume rate*. Air volume delivery rate of a fan is directly related to fan rpm. For example, changing the sheave ratio of a fan drive mechanism to increase fan rpm 20% will increase air delivery by 20%. A caution here is that the fan impellor must never be sped up beyond the safe rpm published by the fan manufacturer.
- *Fan rpm and air pressure*. The air pressure developed by a fan increases as the square of the fan rpm. For example, to increase fan total pressure 10% calls for increasing rpm by a factor of 21%.
- *Fan rpm and the development of fan noise (sound power level) and vibration*. Sound power level increases as the cube of the rpm. For example, when fan rpm is increased 10% fan noise may be expected to increase 33%.
- *Fan rpm and power*. Fan power requirements are related to the cube of the change in fan rpm. For example, increasing air delivery 10%, i.e., increasing rpm 10%, calls for an increase in power requirements, motor size, of 21%.

These simple relationships provide a reliable guide when selecting fans for a new installation and for adapting existing fans to changing requirements. Selecting fans of small size and high rpm will be likely to result in excessive noise being conducted through the ducts and into the laboratory. This would be especially intolerable in teaching laboratories. Such a minimum fan size selection would not provide the prudent selection of equipment for a foreseen future expansion of facilities. The fan laws provide practical guidelines for the amount of excess fan capacity that can be provided without running into excessive noise difficulties or inadequate power resources.

30.5 FAN SELECTION

Volume-pressure curve high on the steeply rising portion and this point will be the maximum efficiency operating point. Using the fan laws and either the tables or the diagram in *ASHRAE HVAC Systems and Equipment*, Chapter 21 (ASHRAE, 2012), it is a simple matter to

convert the data to different types of fans. Fan selection begins after requirements have been refined. Many different types of fans are available, each in a large spread of sizes, so that the selection task is largely one of choosing those that will perform the needed task at lowest cost considering purchase, operating, and maintenance costs. The very long service life of fans makes fan efficiency (operating cost) a major consideration in the cost analysis. The major industrial fan manufacturers have staff engineers who are available to offer help in fan selection after system designers have established air flow and pressure requirements. The fan laws play an important role in the selection process. The leakage rate associated with the selected duct construction method and their length will play a part in calculating the total volume of air reaching the fan, especially for exhaust systems. This makes it necessary to select duct construction methods, as well as to know flow volume and pressure needs before selecting fans.

Ventilation fans are assumed to be handling clean air at normal temperatures and no special construction materials or internal protective coatings are needed. Fans on laboratory exhaust systems may be exposed to elevated temperatures and to highly corrosive gasses and vapors. The latter class of contaminants is especially troublesome when they evolve from an elevated temperature process in the laboratory and condense in a cooler fan. These operating conditions call for industrial quality fans with factory-applied internal protective coatings. Rotor rpm may be limited to prevent interference with the adhesion limits of the plastic coatings. For this consideration to be resolved satisfactorily, exact knowledge of laboratory operations is a preliminary step in fan selection.

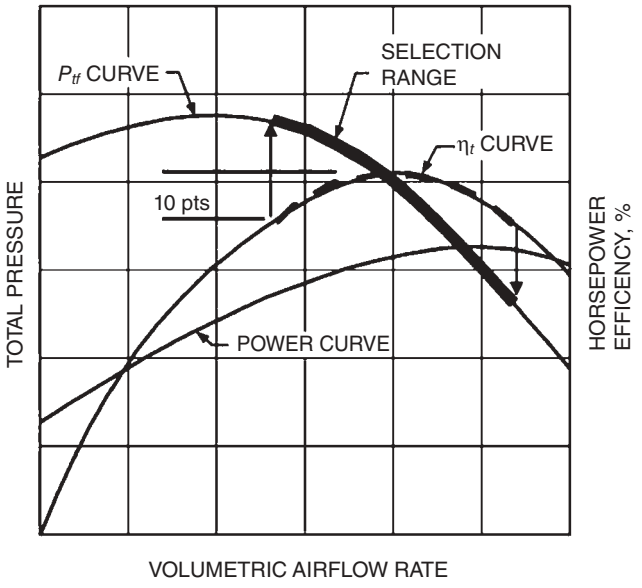


FIGURE 30-4. Fan Selection. Courtesy ASHRAE.

30.6 FAN PERFORMANCE

Fan performance data are contained in tables in manufacturers' catalogues that give rpm and corresponding airflow rate, air pressure, motor size, and efficiency for each type and size of fan. A certified sound power level for specified operating conditions will also be included. Performance data for a specific type and size of fan at a single rpm may also be available from the fan manufacturer with related air volume and pressure development for the full range of the fan's capability. Figure 30.4 is a typical diagram. In addition to the volume-pressure curve, it shows horse power efficiency. The volume-pressure curve rises steeply from a condition of free flow (no system resistance) to a peak, the maximum pressure the fan produce at that rpm when handling ventilation air. When air is further restricted, pressure falls off, indicating unstable conditions caused by insufficient air flow to fill the volume of the fan (a bad operating point). The power curve crosses the size or rpm curves.

31

AIR CLEANING

31.1 INTRODUCTION

The outside air supplied to all laboratories is usually treated to remove some or all of the particulate matter naturally present. In some laboratories, such as clean rooms and microelectronic processing laboratories, it is essential to remove all particles, large and small, from the air supply to preserve the essential functions of the facilities that call for a dust-free environment. Other laboratories that call for a contamination-free air supply are analytical chemistry and biology laboratories engaged in measuring trace quantities of microorganisms and chemicals that occur in air, water, and tissues. Other types of laboratories, because of the nature of the activities conducted in them, require all effluent air to be decontaminated. Such laboratories include high-toxicity (Chapter 6), radiation (Chapter 13), and biosafety laboratories (Chapter 14).

Ventilation supply air is characterized by low concentrations of particulate matter (50–200 $\mu g/m^3$) and gaseous contaminants such as SO_2 (0.02–0.08 ppm), NO_2 (0.01–0.05 ppm), and volatile organic compounds of all species (0.5–1.0 ppm). Particles in outside air are characterized by small average size (median aerodynamic diameter ~0.5 μm), but a very wide size range. Pollens and spores range from 10 to 40 μm in diameter; soot and wind-blown soil particles range from 1 to 20 μm. Sulfate and nitrate salts formed by reactions in the atmosphere between SO_2, NO_2, and ammonia are less than 0.5 μm. The importance of airborne dust sizes is related to the fraction(s) that must be removed before introducing ventilation air to the laboratory. As a general rule, the smaller the particle sizes that must be removed from the air, the more difficult and more costly it becomes. Therefore, there is a wide selection of air-cleaning devices to respond to a wide range of needs for air purity, from removal of pollens and large soiling particles to removal of all particles down to molecular size. The particle size and concentration of toxic dusts produced by laboratory operations are harder to characterize because they reflect the nature of the operations being conducted and the effectiveness of the containment facilities. Just as it is customary to provide efficient filtration of supply ventilation air to such laboratories, it is essential to decontaminate exhaust air. Supply air filtration is also important to prevent back-flows of toxic or infectious materials. Considering the usual care exercised when handling highly toxic and infectious materials, it is expected that exhaust air contamination concentrations will not differ significantly from outside air concentrations. Therefore, no distinctions will be made between influent and effluent air cleaning devices and technology in the discussions that follow. Exceptions to this premise may occur in pilot plant laboratories (Chapter 9) and engineering laboratories (Chapter 8) when semi-industrial-scale operations are being conducted. Industrial stack-gas cleaning systems should be investigated for these operations.

Removal of gas-phase contaminants is difficult because of the low concentrations that are normally

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present in the atmosphere and in the laboratory exhaust air. This is because gas-phase air cleaning is accomplished by devices that remove the undesirable components from air by methods that depend for effectiveness on the differential concentration (in units of partial pressure) of the compounds to be removed in the sorbent and in the air being treated.

31.2 AIR-CLEANING EQUIPMENT FOR LABORATORIES

Filters, which are porous beds of glass or plastic fibers that separate particulate matter, solid, or liquid, from the air passing through them, are widely used for cleaning ventilation air. Contrary to what many believe, filters do not function like sieves, which are made up of holes smaller than the particles to be retained. Instead, the pores in fibrous filters are many times larger than the size of the particles they retain. Particles flowing through a porous bed of small-diameter fibers deposit on the fibers by forces known as diffusion (for particles smaller than 0.5-μm aerodynamic diameter), inertia (for larger particles), and interception (simply bumping into a fiber) for all particle sizes. This particle separation scenario leaves a gap between small particles retained by diffusion and larger particles retained by inertial forces whereby each is at its lowest effectiveness. In high-efficiency filters, this particle size is known as "the least filterable size" (also known as "the most penetrating particle size"). Particles of smaller size and particles of larger size are both retained at higher levels.

Particles may also be removed from ventilation supply air by electrostatic precipitators. These are two-stage devices that first charge all airborne particles as they pass through a zone containing high-voltage discharge wires. In the second stage the charged particles are attracted to charged collecting plates of opposite sign. For ventilation air, particles are given a positive charge and attracted to negatively charged collecting plates. This arrangement produces less ozone than negative particle charging and positive collecting plates. Electrostatic precipitators are subject to electrical supply interruptions. When this occurs, the collecting plates lose their charge and the accumulated dust has a tendency to blow off. Therefore, it is usual to install filters downstream of electrostatic precipitators to catch the released dust and prevent it from traveling further downstream into the ventilated laboratories. Two-stage electrostatic precipitators are capable of excellent atmospheric dust collection. Unlike filters, they do not experience continuously increasing airflow resistance with service. However, they require considerably more servicing than the usual ventilation filters.

Neither filters nor electrostatic precipitators are effective for the removal of gas and vapor contaminants. For the class of contaminants that are commonly found in ambient air, the use of adsorbents (rather than absorbents) is the air-cleaning method of choice because they are effective for low gas concentrations and are easy to service. Activated carbon (activated charcoal) is widely used to remove organic vapors from air. Other adsorbents are available for removing inorganic gases and vapors such as ammonia, hydrogen sulfide, mercury, and a large number of acid gases. Granular adsorbent beds are poor particle collectors, but they do collect some particles that progressively degrade adsorbent effectiveness. Therefore, activated carbon and other adsorbent beds must be preceded by moderately high-efficiency particulate filters to protect them from rapid inactivation by dirt accumulation.

31.2.1 Ventilation Air Filters

Air filters are rated by the amount of particulate matter they are designed to remove from air. For many years, ratings were conducted with clean, new filters and expressed as percent efficient for a specified test aerosol. Filter ratings have a wide range: 5–10% for warm air residential heating systems; 35–45% for ventilation systems of schools, stores, and restaurants; 85–95% for fully air-conditioned modern hotels, hospitals, and office towers; 99.99+% for air supplied to clean rooms, microelectronic laboratories, and hospital operating rooms. Filter efficiency of 80% is recommended for hospital laboratories (ASHRAE, 2011).

ASHRAE Standard 52.2, "Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size" (ASHRAE, 2007) provides complex testing and rating procedures. Test results are reported as the minimum efficiency reporting value (MERV) in 20 grades grouped into four categories. Tested filters are referred to by MERV number, MERV 1 being the least efficient.

Briefly, efficiency by particle size is measured with an optical particle counter and size recorder or by a time-of-flight instrument that measures aerodynamic size and counts the number of particles in each size group. The specified aerosol is prepared by aerosolizing an aqueous solution of potassium chloride with a nebulizer and then drying the particles and neutralizing any charge on the test particles. A wide spectrum of particle sizes is produced.

Particle-size efficiency data are collected in three size ranges: 0.3–1 μm, 1–3 μm, and 3–10 μm. Four measurements, more or less equally spaced, are made in each size group for a total of 12 particle-size efficiency measurements. The four measurements in each size range

TABLE 31-1. Minimum Efficiency Reporting Value (MERV) Parameters (Adapted from ASHRAE 52.2)

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, μm			Average Arrestancc, %, by Standard 52.1 Method	Minimum Final Resistanc	
	Range 1 0.30–1.0	Range 2 1.0–3.0	Range 3 3.0–10.0		Pa	in. of water
1	n/a	n/a	$E_3 < 20$	$A_{avg} < 65$	75	0.3
2	n/a	n/a	$E_3 < 20$	$65 \le A_{avg} < 70$	75	0.3
3	n/a	n/a	$E_3 < 20$	$70 \le A_{avg} < 75$	75	0.3
4	n/a	n/a	$E_3 < 20$	$75 \le A_{avg}$	75	0.3
5	n/a	n/a	$20 \le E_3 < 35$	n/a	150	0.6
6	n/a	n/a	$35 \le E_3 < 50$	n/a	150	0.6
7	n/a	n/a	$50 \le E_3 < 70$	n/a	150	0.6
8	n/a	n/a	$70 \le E_3$	n/a	150	0.6
9	n/a	$E_2 < 50$	$85 \le E_3$	n/a	250	1.0
10	n/a	$50 \le E_2 < 65$	$85 \le E_3$	n/a	250	1.0
11	n/a	$65 \le E_2 < 80$	$85 \le E_3$	n/a	250	1.0
12	n/a	$80 \le E_2$	$90 \le E_3$	n/a	250	1.0
13	$E_1 < 75$	$90 \le E_2$	$90 \le E_3$	n/a	350	1.4
14	$75 \le E_1 < 85$	$90 \le E_2$	$90 \le E_3$	n/a	350	1.4
15	$85 \le E_1 < 95$	$90 \le E_2$	$90 \le E_3$	n/a	350	1.4
16	$95 \le E_1$	$95 \le E_2$	$95 \le E_3$	n/a	350	1.4

are then averaged to derive what are referred to as "average minimum efficiencies." This series of tests is conducted on the clean, new filter and repeated five times; each of these tests being preceded by a fixed course of filter loading with a special loading dust consisting of a mixture of Arizona road dust, carbon black, and cotton linters. In addition to particle size and number measurements, pressure drop increase is noted after each loading event and limits are placed on total increase for acceptance. From this data set each ventilation filter is assigned a MERV number from 1–16 according to the criteria in Table 31-1 adapted from ASHRAE 52.2. Figure 31-1 shows a panel-type filter representative of those that qualify for Group 1 classification in Table 31-1. Figure 31-2 illustrates a type of filter that would be classified in Group 2. It is pleated to provide a larger amount of filter medium to maintain pressure drop within prescribed limits. Figure 31-3 shows a pleated ventilation filter that qualifies for a Group 3 MERV Number. It differs from the filter shown in Figure 31-2 by having finer filter fibers and more of them in the filter structure to improve collection for the smallest particles.

FIGURE 31-1. Group 1 panel type filter: A 25–35% dust spot efficiency filter. (Courtesy of Flanders Filters)

31.2.2 High-Efficiency Filters

High-efficiency filters are a critical component of many laboratories. High-efficiency filters have a minimum retention of 99.97% for a monodisperse test aerosol containing 0.3-μm particles (HEPA). Filters used for 0.1-μm particles are known as *ultra-low penetration air (ULPA)* filters. They have efficiencies of 99.99–100%.

High-efficiency filters were developed by the U.S. military during WWII for the gas mask. The filter was so highly efficient it was dubbed the "absolute filter." Its military procurement designation is "filter, high efficiency particulate air" (to distinguish it from

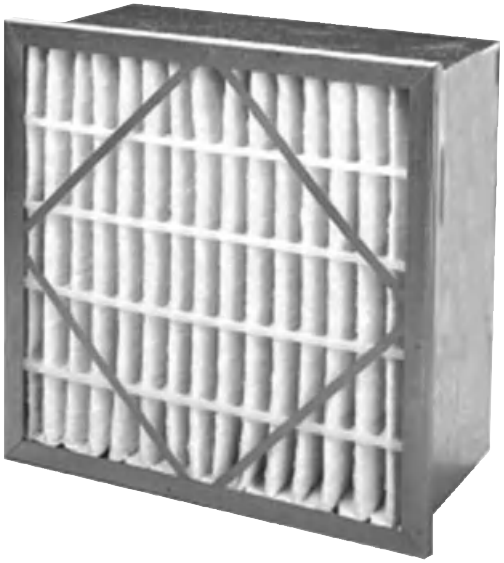


FIGURE 31-2. Group 2 filter: A 55–70% dust spot efficiency filter. (Courtesy of Flanders Filters)

FIGURE 31-4. HEPA filter. (Courtesy of Flanders Filters)

FIGURE 31-3. Group 3 pleated ventilation filter: A 80–95% dust spot efficiency filter. (Courtesy of Flanders Filters)

high-efficiency liquid filters) and the commonly used designation gradually changed to HEPA filter. Filling a war-time need for protecting command and communication facilities, the U.S. military expanded the gas mask filter to a size that would handle 1,000 CFM (0.3 m^3/s). A picture of a typical HEPA filter is shown in Figure 31-4. This filter was adopted by the nuclear industry worldwide. The ASME Nuclear Air Cleaning Code, AG-1 (ASME, 2009) details filter construction, certification, installation, and in-service leak testing. This same filter was also adopted by the biological safety establishment, differing only by omission of the radiation tolerance requirement. Designation, installation, and in-service testing appear in the ANSI/NSF Standard 49 for Class II biosafety cabinets (NSF) and in the CDC/NIH publication on biological safety (CDC, 2012).

Other standards organizations in Europe (i.e., for filters, BS-EN-1822-1, 2009; for application to cleanrooms, ISO 14644, 2012) and the United States (i.e., ASHRAE Standard 52.2; ASHRAE, 2007) and Institute for Environmental Safety and Testing [IEST]) have published standards for HEPA and ULPA filters. Table 31-2 has been adapted from ASHRAE's "Application Guidelines" for filters designated by MERV numbers 1–20. The additions are four grades of HEPA filters and ULPA filters accompanied by their test method and acceptance criteria. In addition, this section of Table 31-2 mentions equivalent designations in the IEST Standard. It will be clear from the descriptions in Table 31-2 that the test methods for ventilation filters (MERV 1-16) are unrelated to the test methods cited for MERV 17–20 filters. For the latter type of filter tests, efficiency is related to a single particle size (0.3 μm or 0.1 μm), and except for the military/nuclear dioctyl phthalate (DOP) test, all measurements are made with single particle counters tuned to a specified particle size.

A question often asked by people working with hazardous microorganisms is "Will my laboratory be safer if I specify ULPA filters for biosafety cabinets and supply and exhaust ventilation air, instead of HEPA filters?" The general answer is no because microorgan-

TABLE 31-2. Application Guidelines (Adapted from ASHRAE's "Application Guidelines," Filters Designated MERV No. 17–20)

Std. 52.2 Minimum Efficiency Reporting Value (MERV)	Approx. Std. 52.1 Results		Application Guidelines		
	Dust Spot Efficiency	Arrestancc	Typical Controlled Contaminant	Typical Applications and Limitations	Typical Air Filter/Cleaner Type
20	n/a	n/a	**≤0.30 μm Particle Size**	Cleanrooms	**HEPA/ULPA Filters**
19	n/a	n/a	Virus (unattached)	Radioactive materials	~99.999% efficiency on 0.10–0.20 μm particles, IEST Type F ~99.999% efficiency on 0.30 μm particles, IEST Type D ~99.99% efficiency on 0.30 μm particles, IEST Type C ~99.97% efficiency on 0.30 μm particles, IEST Type A
18	n/a	n/a	Carbon dust	Pharmaceutical manufacturing	
17	n/a	n/a	Sea salt All combustion smoke Radon progeny	Carcinogenic materials Orthopedic surgery	
16	n/a	n/a	**0.3–1.0 μm Particle Size**	Hospital inpatient care	**Bag Filters** Nonsupporied (flexible) microfine fiberglass or synthetic media. 300 to 900 mm (12 to 36 in.) deep, 6 to 12 pockets. **Box Filters** Rigid style canridge filters 150 to 300 mm (6 to 12 in.) deep may use lofted (air laid) or paper (wet laid) media.
15	>95%	n/a	All bacteria		
14	90%–95%	>98%	Most tobacco smoke	General surgery	
13	80%–90%	>98%	Droplet nuclei (sneeze) Cooking oil Most smoke Insecticide dust Copier toner Most face powder Most paint pigments	Smoking lounges Superior commercial buildings	
12	70%–75%	>95%	**1.0–3.0 μm Particle Size**	Superior residential	**Bag Filters** Nonsupported (flexible) microfine fiberglass or synthetic media. 300 to 900 mm (12 to 36 in.) deep, 6 to 12 pockets. **Box Fillers** Rigid style cartridge filters 150 to 300 mm (6 to 12 in.) deep may use lofted (air laid) or paper (wet laid) media.
11	60%–5%	>95%	Legionella	Better commercial buildings	
10	50%–55%	>95%	Humidifier dust		
9	40%–45%	>90%	Lead dust Milled flour Coal dust Auto emissions Nebulizer drops Welding fumes	Hospital laboratories	
8	30%–35%	>90%	**3.0–10.0 μm Particle Size**	Commercial buildings	**Pleated Filters** Disposable, extended surface, 25 to 125 mm (1 to 5 in.) thick with cottonpolyester blend media, cardboard frame. **Cartridge Filters** Graded density viscous coated cube or pocket filters, synthetic media **Throwaway** Disposable synthetic media panel filters
7	25%–30%	>90%			
6	<20%	85%–90%	Mold	Better residential	
5	<20%	80%–85%	Spores Hair spray Fabric protector Dusting aids Cement dust Pudding mix Snuff Powdered milk	Industrial workplaces Paint booth inlet air	
4	<20%	75%–80%	**>10.0 μm Particle Size**	Minimum filtration	**Throwaway** Disposable fiberglass or synthetic panel filters **Washable** Aluminum mesh, latex coated animal hair, or foam rubber panel filters **Electrostatic** Self charging (passive) woven polycarbonate panel filter
3	<20%	70%–75%	Pollen	Residential	
2	<20%	65%–70%	Spanish moss	Window air conditioners	
1	<20%	<65%	Dust mites Sanding dust Spray paint dust Textile fibers Carpet fibers		

Note: A MERV for other than HEPA/ULPA filters also includes a test airflow rate, but it is not shown here because it has no significance for the purposes of this table.

isms, including virus particles, are of sizes that are equally well handled by HEPA filters. ULPA filters are especially useful for microelectronics laboratories where elimination of inert particles smaller than airborne microorganisms is of critical importance. What is important for critical laboratory operations is to order "certified filters" that conform to all of the size, construction, and sturdiness criteria contained in a code such as AG-1 and have efficiency and pressure drop measurement results noted on the side of the filter case.

31.2.3 Facility Preparation, Installation, and In-Service Testing of HEPA and ULPA Filters

Decisions to include facilities that require high-efficiency air cleaning devices should be made early in the design process because these facilities have design requirements that will be difficult and costly to implement late in the design process. Of critical importance for many of these special laboratories is the requirement—legal or recommended—for certification by an accredited specialist prior to initiating work, and periodically for the life of the facility. High-efficiency air cleaning systems loom large in these certification protocols.

Preoperation and periodic high-efficiency filter leak testing calls for easy access to ducts upstream and downstream of the filters. There should be straight duct runs of at least six duct diameters on each side of the filters. An entry port at least six duct diameters upstream of the filters is needed to introduce the challenge aerosol for the leak test. A second port is needed close to the upstream face of the filters to measure the uniformity of the challenge aerosol. The AG-1 nuclear air-cleaning code calls for the challenge aerosol to be distributed across the entire face of the filters so that no reading is more than 20% higher or lower than the average concentration. Another sampling port is needed 4–6 duct diameters downstream of the filters to measure the concentration of the challenge aerosol in the filtered air. The AG-1 code accepts a leakage rate that is not more than 0.05%.

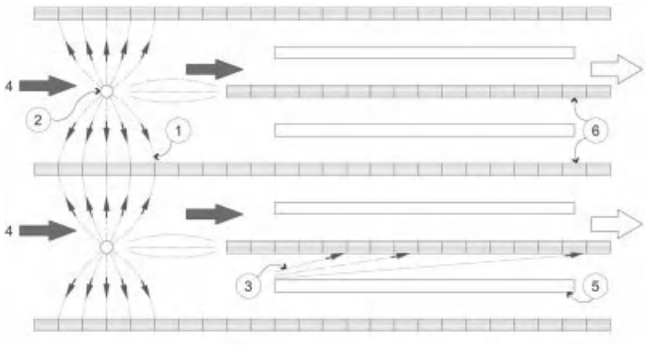
The biological safety code calls for a leakage rate not greater than 0.01% for the same test protocol. The preferred test for biological service is a filter scan test described in Standard NSF 49 (NSF, 2007). It calls for passing a sampling probe across the entire downstream face of the filters and gaskets in overlapping strokes at a rate of 2 inches per second (5 cm/s). The acceptance criterion is "no reading higher than 0.01% of upstream concentration." All ULPA filters (and some HEPA filters) are both filter efficiency and filter leak tested with single particle counters focused on particles of 0.1 μm. For many microelectronics and clean room laboratories, minimum filter efficiency for this particle size is 99.9995%. Another procedure for measuring the efficiency of ULPA and HEPA filters is to plot a particle size-efficiency curve for particle sizes less than 0.1–1.0 μm and report the percent penetration (1-efficiency) at the most penetrating particle size.

The foregoing discussion of filter installation leak testing protocols should have made it clear that similar leak testing procedures are used at prescribed intervals over the entire service life of the filters. Filter-efficiency testing is conducted and results published by the filter manufacturer. Leak tests are performed by the user. The leak test is not another filter efficiency test; it is designed to detect the presence of a damaged filter as well as leaky mounting racks and poorly installed filter cartridges. To avoid installing damaged filter cartridges, they should be examined on all sides after removal from the shipping carton. Tears deep in the filter can be detected by looking for bright spots from the opposite side while someone scans the entire filter with a bright light in a darkened room.

All high-efficiency filters are single-use disposable filters. As a general rule the higher the efficiency rating of filters, the greater will be their cost, airflow resistance, and energy consumption.

31.2.4 Electrostatic Precipitators

Electrostatic precipitators are used in office buildings and a variety of commercial properties for cleaning ventilation air. They are less frequently used in laboratory air systems. They are rated for efficiency by a discoloration method using atmospheric dust and comparing up- and downstream air samples. Commercial units are usually rated 85% or 95% dust-resistance efficiency. The 95% efficient unit differs mechanically from the 85% efficient unit in having a longer retention time of the air within the charging and precipitating stages resulting in higher efficiency. Figure 31-5 is a diagram of a two-stage electrostatic precipitator for ventilation air cleaning. The ionizing stage usually operates at 12,000 volts, whereas the collecting stage operates at 6000 volts. The ionizing stage contains a series of fine-diameter, highly charged wires that continuously ionize the air molecules close to them and propel clouds of positive air ions across the air gap to ground. During the passage, they collide with dust particles and give them a unipolar positive charge. In the collecting stage, the positively charged dust particles deposit on grounded plates of opposite charge by electrostatic attraction. From time to time, the collecting plates must be cleaned by washing with a detergent to prevent collected dirt from building up to the point where it tends to become reentrained in the flowing airstream.



KEY

1 Path of Ions
2 Wires at High Positive Potential
3 Theoretical Paths of Charged Dust Particles
4 Air Flow
5 Intermediate Plates Charged
6 Alternate Plates Grounded
□ Clean Air
■ Contaminated Air

FIGURE 31-5. Diagram of a two-stage electrostatic precipitator for ventilation air cleaning.

31.2.5 Adsorbents for Supply and Exhaust Ventilation Air

Adsorbent materials are characterized by their extremely porous structures, which provide internal surface areas many times larger than the external surface. Adsorption of a gas or vapor on a solid is a spontaneous process. Vapors diffuse into the pores of the adsorbent and are bound to the internal surface in various ways. Adsorption can be likened to the condensation of a vapor to form a liquid. Adding heat can cause reevaporation.

High-grade gas adsorbents have surface areas of 1,100–1,600 m^2/g. The capacity of an adsorbent is measured in several ways. The "retentivity point" is the quantity of adsorbate that will be retained by the adsorbent no matter how much clean air is passed through the bed. It is about 30% of the quantity of adsorbate contained in the adsorbent at the "breakpoint." This is the first detectable quantity of adsorbate to appear in the gas leaving the adsorber. Prior to the occurrence of the breakpoint negligible or no adsorbate leaves the adsorber bed. After the breakpoint, the concentration of the adsorbate in the gases leaving the adsorption bed gradually increases until the concentration of the adsorbate in the leaving gases is equal to the quantity entering. This is called saturation. The breakpoint marks the normal capacity of an adsorption bed and is a critical point for gas mask cartridges. Absorptive capacity varies greatly depending on the nature of the gas, but usually it increases with increasing molecular weight and sometimes can reach values as high as one gram of solvent per gram of absorbent, although adsorptive capacities only 1/10th or 1/20th of this value are considered satisfactory.

Activated carbon is the usual adsorbent used in ventilation air systems to remove organic vapors, sulfur dioxide, nitrogen oxides, and ozone. It is purchased for service in the form of .25- to 2-in. deep panels containing a packing of 80- to 120-mesh-activated coconut-shell carbon. The panel sizes usually match the cross section of the particulate filters installed ahead of them. Filters impregnated with carbon granules are sold as combination particulate filters and gas adsorbers, but anything less than a 1/4-in. thickness of well-packed granules is useless as an adsorber stage. Granules of 1/2-in. thickness and greater are likely to give much more satisfactory service. Activated coconut-shell gas activated carbon can give 95–99% removal of most organic compounds.

Activated carbon, as well as other adsorbents, ultimately reaches the breakpoint and then becomes saturated with the vapors it is installed to remove. It must then be replaced by fresh carbon. For large installations, the spent carbon may be returned to the supplier for reactivation and reuse. For small operations, disposal may be more cost effective.

Activated carbon gives no discernible signal when it reaches the breakpoint or saturation. The air coming out of the carbon bed can be monitored for unacceptable gas penetration. Alternatively, the recommendations of the supplier or manufacturer for routine replacement may be followed.

32

LABORATORY HOODS AND OTHER EXHAUST AIR CONTAMINANT-CAPTURE FACILITIES AND EQUIPMENT

32.1 INTRODUCTION

Frequent references have been made throughout this book to laboratory hoods of various designs and to alternative exhaust systems that provide control of toxic, corrosive, combustible, and reactive gases, vapors, and aerosols originating from the materials being used and the processes employed. Assembling information on each of the options into a single chapter should help make those with design responsibility for these items better informed and thereby improve selection of this class of equipment. Because most of this equipment is built in during construction or renovation, selection errors tend to become chronic sources of complaint after the facility is put into service and unusually costly to remedy. Therefore, thorough familiarity with laboratory hoods and all manner of laboratory contamination-control exhaust systems is essential for everyone involved in the laboratory design process. Laboratory workers are trained from their earliest introduction to experimental science to regard their laboratory hood as their principal and all-purpose safety device. Therefore, they tend unquestioningly to accept the efficacy of all such facilities. When the safety devices do not perform their intended function adequately, serious harm is likely to result. The laboratory designer's responsibility for providing facilities adequate to safeguard laboratory workers' health and safety is a heavy burden that cannot be delegated or evaded. The sections that follow describe each of the exhaust ventilation contamination-control devices that are commonly found in laboratories. Despite significant differences in design, they perform an equivalent function. Therefore, selection is generally guided by tradition, type of activity, cost, energy consumption, and similar factors, each of which may receive a more or less important rating by different laboratory users, designers, and owners. It is incumbent upon the designers to understand the equipment to be used and the operations to be performed that will need contaminant control. In this way, the most efficient device can be selected as well as one that will have the optimal benefit to the user. Regardless of the selection criteria used, it should be kept in mind that correct selection of fans and duct construction materials and methods of construction are essential for a full measure of safety and user satisfaction. The latter topics are treated in other chapters: Chapter 30 for exhaust fans and Chapter 33 for exhaust ducts and accessories.

32.1.1 General Types of Containment Control Hoods

Hoods used for contaminant control are classified into three broad categories based on their primary method of control: enclosures, exterior hoods, and receiving hoods. All of these types of hoods are found in laboratories. Enclosure hoods, sometimes referred to as containment hoods, prevent release of contaminants by enclosing the process or source of generation and transporting them out of the laboratory in the exhaust air stream. Examples include full enclosures, e.g.,

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

gloveboxes and partial enclosures, e.g., laboratory fume hoods and biological safety cabinets. Exterior hoods, sometimes called *capture hoods*, are used when the process or source cannot be enclosed; sufficient air velocity must be generated outside the opening of the hood to "capture" the contaminants at the source and transport them into the exhaust system before escape into the laboratory. Examples include bench top slot hoods. Receiving hoods take advantage of the process or source generation that results in air movement in a specific direction. Examples include canopy hoods above hot operations (e.g., autoclaves, glassware and cage washers) and downdraft tables used for odor control.

32.1.2 Guidelines for Hood Selection

The general concept is to attempt to enclose the process or generation of the source whenever feasible because complete enclosure is the best way to contain the contaminants and prevent escape into the laboratory. This idea needs to be balanced with the need for laboratory workers to access the process and space, and for energy conservation. For example, large equipment may have a single source of generation that then may be controlled by an exterior or canopy hood without the need to completely enclose the process, e.g., atomic spectroscopy units.

32.2 CONVENTIONAL BYPASS CHEMICAL FUME HOODS

Bypass chemical fume hoods constitute one of the most widely used types of laboratory hood and are familiar to all laboratory workers. They are an improved version of an even older type that used to be referred to as *a fume cupboard* (a term still used in Britain), and, true to its name, the fume cupboard was an open-faced wood and glass boxlike enclosure connected to an exhaust fan, usually located at the top rear. Many important modifications have been made to the early design to improve airflow characteristics for the purpose of achieving greater containment efficiency, and reducing energy requirements. Note that although they are commonly referred to as "fume" hoods, they are not designed to capture or contain fumes or dusts. They are primarily used for control of vapors and gases generated inside the hood.

The most important modification to the old-fashioned fume cupboard was the addition of a vertical sliding sash covering the open front. The sliding sash made it possible to expose the entire open front for full access, but also made it possible to lower the sash to provide a safety shield between the experiment and experimenter. Lowering the sash during dangerous experiments also decreased the open-face area; this served to increase the inflow velocity through the remaining opening, thereby providing greater protection for the worker against an outflow of contaminants. However, when the sliding sash was lowered beyond a certain point, the inflow velocity (for the same air volume required to exhaust-ventilate the hood when the sash was in the full open position) became so great that air turbulence effects at the edges of the opening caused backflow inside the hood and leakage outside the hood, decreasing safety rather than enhancing it. In addition, excessively high velocities sweeping across the work surface of the hood disrupted experiments by extinguishing burners, scattering powders, and cooling constant-temperature flasks.

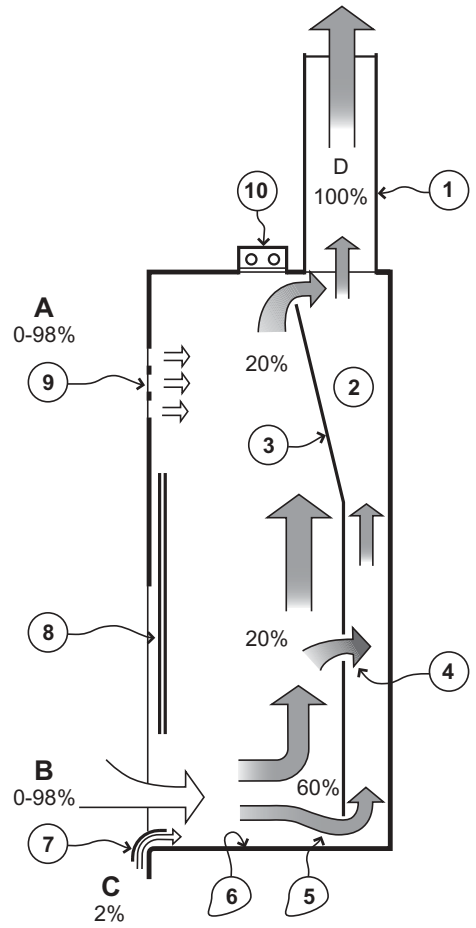
32.2.1 Important Features of Constant-Volume Bypass Chemical Fume Hoods

To correct the several deficiencies of the old-fashioned fume cupboard, the following features were developed and are found in modern, efficient bypass chemical fume hoods:

1. Bottom and side airfoils around the open face produce nearly turbulence-free airflow into the hood.
2. A mechanism to minimize excessive velocities (300 fpm, 1.5 m/s) when the total opening is 6 in. (0.15 m) or less. This may be accomplished by an air bypass at the hood or by switching the fan to a lower speed. A typical bypass hood is illustrated in Figure 32-1.

Other important characteristics of acceptable bypass chemical fume hoods are the following:

- The sash is constructed of shatterproof material.
- The material of construction of the hood is resistant to damage by the materials used in the hood and from potential fires.
- Nonasbestos-containing materials are used.
- The hood provides adequate containment. This can be evaluated by setting off a 30-s smoke candle or other heavy smoke generator inside the hood with the sashes in the fully open and then in the fully closed position. The smoke must be totally and quickly removed, and there should be no reverse flow out of the hood. Refer to Section 32.12 for other details on evaluating hood performance.
- There is an inward airflow across the entire opening. Reverse flow can be detected by passing a smoke



KEY

1	Exhaust Duct
2	Exhaust Plenum
3	Rear Baffle
4	Fixed Center Slot
5	Adjustable Bottom Slot
6	Work Surface
7	Airfoil Sill
8	Vertical Sliding Sash
9	Room Air Bypass, Does Not Open Until Sash Is 75% Closed.
10	Lights
□	Clean Air
■	Contaminated Air

AIR FORMULAS

A + B + C = D

B + C = D (Sash Fully Open)

A + C = D (Sash Fully Closed)

FIGURE 32-1. Bypass chemical fume hood: Section. (Approximate percentages shown for descriptive purposes only.)

stick or equivalent smoke generator across the entire perimeter of the face opening and looking for flow out of the hood.

- No velocity measurement across the hood face with the sashes positioned to provide the maximum opening is less than or greater than 20% of the average face velocity.
- The airflow through the hood provides an average face velocity of 80–100 fpm (0.4 to 0.5 m/s) at the maximum face opening.
- The airflow through the system is monitored by an in-line measurement device (e.g., pitot tube, orifice or venturi meter) or by static pressure measurements in the duct just downstream of the hood and calibrated to the specific hood system. The display of the measurement instrument will be visible to the hood user.
- During renovations, when existing fume hoods are inadequate but are to remain, an attempt to modify them should be made, when necessary. This would include providing a bottom airfoil (if missing), providing some means of controlling face velocity at all sash positions by means of a bypass or variable air volume control, and providing an airflow monitoring system.

32.2.2 Model Hood Specification

To further illustrate the important characteristics of an acceptable chemical fume hood, the *Laboratory Fume Hood Specifications and Performance Testing Requirements*, published by the National Institute of Health (NIH, 2012), have been adapted as model specifications and are provided for use below in developing a specification for fume hood purchase. Note that some of the construction sections (e.g., materials of construction, dimensions, etc.) are not directly related to containment ability and can be changed depending on the user's needs.

32.2.2.1 Standard Bypass Fume Hood.

1. All fume hoods should be of the airfoil design, with foils at the bottom and along both vertical sides of the face opening. The bottom airfoil can be raised approximately 1–1.5 in. (25–40 mm) to allow air to pass under the foil and across the work surface and to serve as the terminus for vertical sliding sash(es). The vertical foils should be flush with the hood interior surface to minimize turbulence as air enters the hood.
2. The superstructure construction for all hoods should be counter-mounted and not more than 65 in. (1.6 m) high, 36 in. (0.9 m) deep, outside

dimensions, and of length indicated. The interior clear working height should not be less than 47 in. (1.2 m) above work surface for full depth of hood from interior of lintel panel to face of baffle plenum. Double side-wall construction is to enclose all structural reinforcements, sash balance mechanisms, and mechanical connections for service outlets and controls (as indicated) and shall be of airfoil type not more than 4 in. (0.1 m) wide. Access should be provided for the inspection maintenance of the sliding sash operating mechanism and also for the installation of mechanical services.

3. The materials for the hood superstructure (unless otherwise specified) should be 1/4-in.-thick (6 mm), nonflammable, acid-resistant material for the hood interiors and factory painted (baked enamel) laboratory steel for the exterior. The color is selected by the owner or architect from the manufacturer's standard colors (unless otherwise specified).
4. If the hood is of the bypass type, the bypass should be located above the hood face opening and just forward of the sash when raised. All air exhausted must pass through the work chamber. The bypass must provide an effective line-of-sight barrier between the area outside the hood and the hood interior and must also provide an effective barrier capable of controlling transfer of flying debris during an explosion within the hood. It must assure essentially a constant volume of air at all sash positions. The bypass should control the increase in face velocity as the sash is lowered to at least twice the design velocity, but not more than three times the design velocity.
5. All hoods should have a vertical sliding glass sash of 7/32-in.-thick (6 mm) combination safety sheet with metal frame to operate on stainless steel cables over the ballbearing pulleys with metal counterbalancing weights. *(Note*: Spring sash balances are not acceptable.) When in the closed position the sash should rest on top of the bottom airfoil, and when fully raised the height of the open face should be at least 32 in. (0.8 m) from the top of the work surface. The sash must operate freely. A recessed finger grip(s) or drawer pulls (two per sash) should be installed for raising and lowering the sash.
6. The bottom airfoil should be fabricated from type 316 stainless steel.
7. All hoods should have a removable baffle with two slots, one upper and one lower, adjustable, with hand-operated plastic adjusting knobs for the adjustment of the airflow. A protective stainless steel screen with the equivalent free area of the total bottom slot opening should be provided for the bottom slot. This protective screen should not impede the use of the cup sink, if one is present.
8. The hood work surface should be of type 316 stainless steel and of the recessed (dished) type with a 3/8-in. (10 mm) raised lip along all four edges (to retain spilled liquids) and a uniform edge thickness of 1 1/4 in. (30 mm). The work surface should contain an integrally welded type 316 stainless steel 3- or 6-in. (0.1 or 0.2 m) cup sink located near one of the rear corners unless otherwise specified, so that it is not obstructed by the protective screen at the bottom slot and can receive the unobstructed discharge stream from the cold water outlet.

   If the storage cabinet below is to be vented into the hood plenum, the raised surface of the worktop, above the recessed area, should contain one or two holes to receive the 1 1/2-in. (40 mm)-I.D. vent pipe(s) from the acid storage cabinet(s) supporting the hood. The vent pipe can be constructed of lead, PVC, or another appropriate material compatible with the materials used in the hood. Vent pipe holes should be located between the rear baffle and back panel of the hood, in the raised portion of the worktop. The raised surface should be provided all around the recessed pan area, which should be 2–4 in. (0.05–0.1 m) wide across the front edge. The vent pipe should extend at least 2 in. (0.05 m) up behind the rear baffle.
9. At the top and front of each hood, a pocket enclosure should be installed to receive the vertical sliding sash when in the up position. Each pocket enclosure may contain two removable access panels, one each on the front and rear faces, for access to the electrical junction box and lighting fixture (relamping and cleaning). A removable end panel must be provided on each side of the hood, extending from the sash enclosure to the rear of the hood, for access to service fittings and service lines. The panels must be removable from the exterior of the hood, and reinstallable from the exterior, without interference with or removal of any drop ceiling, furring from the top of the hood to the ceiling, or any adjoining end curbs of worktops.
10. All fume hoods should be equipped with 1/4-in.-thick (6 mm), nonflammable, acid-resistant flush, removable access panels(s) on the side(s) of hood

interior of sufficient size required for the installation of the various mechanical services.

11. The hoods should be exhausted so as to maintain an average velocity of 80–100 fpm (0.4–0.5 m/s) through the full open face (sash fully raised). The velocity must also be uniform across the hood face and not vary more than 10 fpm (0.05 m/s) from the average.
12. When two-speed exhaust fan systems are used, a microswitch or similar device to control the exhaust air fan motor should be actuated by hood sash only. The microswitch should be so located that when the exhaust is turned to low speed the design volume of air is still exhausted from the room while maintaining an average face velocity of 100 fpm (0.5 m/s) through the reduced face area. When variable-air-volume hoods are used, an average face velocity of 100 fpm (0.5 m/s) must be maintained as the face area changes. A minimum total exhaust volume must be established for each hood. From this, one can obtain the sash height below, which the total exhaust volume will not change. A bypass will then need to be activated at this point (see Section 32.6).
13. Unless otherwise noted on a drawing or a job specification, piping from the hood service outlets, except for the drain and vent lines, should be installed between the double-wall side walls and extend up and be connected to the respective services above the hood.
14. All hoods should have a fluorescent lighting fixture operated by an exterior switch mounted on the exterior face of one of the vertical foils. The fixture should have two 40-W fluorescent rapid-start lamps. The fixture should be hinged on one side and be accessible for relamping, cleaning, or other maintenance work from the exterior of the work chamber. The fixture should be mounted at the top of the hood, set on a fixed and gasketed 1/4-in.-thick (6 mm) safety glass shield.
15. All hoods should have one or more 15-A duplex grounded receptacle(s) mounted on the exterior face(s) of the vertical foil(s). The opening and/or housing for the receptacle should have a built-in through-flow ground fault circuit interrupter (GFCI).

    Note: The wiring within the hood shall be so installed that when a through-flow GFCI is installed it also gives GFCI protection to the lighting switch and lighting fixture. When a hood has more than one duplex receptacle, only one through-flow GFCI is required, which is to give protection to any other receptacle in the hood.
16. The lighting fixture with its operating switch and the electrical receptacle(s) for each hood should be on the same circuit. The wiring for these electrical items should connect into a single 4-in. (0.1 m) square junction box so located above the hood structure that it is always easily accessible no matter in what position the hood is placed.

32.2.2.2 Hood Support Cabinets.

1. The base cabinet for hood support should be constructed and finished in a manner similar to the hood.
2. Acid storage cabinets should be provided as a hood support cabinet. The interior of the cabinet should be completely lined with 1/4-in.-thick (6 mm) nonflammable, acid-resistant material including the interior sides of cabinet doors.
3. Each base cabinet should be vented if used for storage of toxic materials. Each individual door should have an air-intake louver located at the center and bottom of the door. Each base unit should be exhausted by means of a 1 1/2-in.-I.D. (40 mm) pipe vent that extends from the center and top of the rear wall (unless otherwise noted) of the storage compartment itself and up through the 2-in.-I.D. (50 mm) hole in the raised portion of the work surface (refer to Section 32.2.2.1, item 9) and into the hood (behind the rear baffle plate) and terminating a minimum of 2 in. (50 mm) above the work surface.
4. A 12-in.-deep (0.3 m), full-width, noncombustible, adjustable shelf should be provided in each base unit. The shelf must be of sufficient strength or thickness so that excessive deflection does not occur when it is fully loaded. A 2-in. deep (50 mm) liquid-tight pan should cover the entire bottom cabinet.

32.2.2.3 Shelves Inside Hoods. There has been a recent trend among laboratory hood users to install storage shelves inside the hood. This is not encouraged, but if it is allowed by the facility managers it should be done carefully. The shelves should be positioned so as not to affect airflow within the hood. The best location is at the rear of the hood interior, in a position not to block the exhaust slots or perforated plenum panels. The slots should not be blocked by any storage. Shelves on the side of the hood may adversely affect airflow and should be avoided. Ideally, a performance test (Section

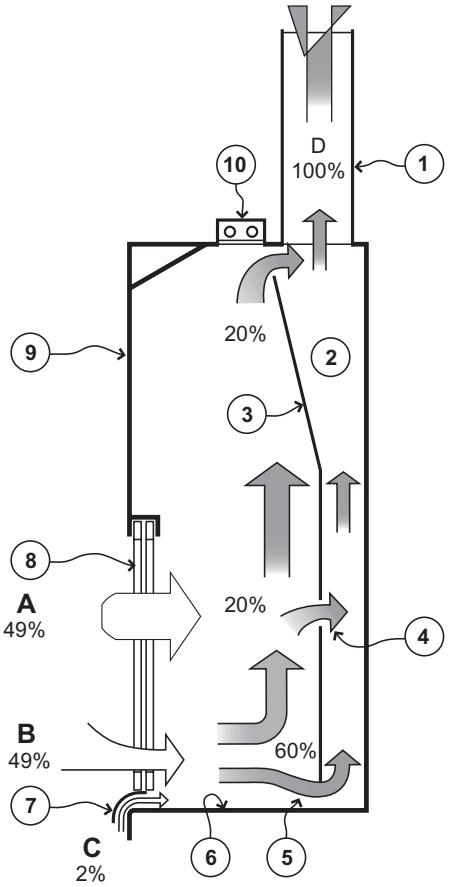
32.12) should be conducted to determine the effect of the shelf on hood containment.

32.2.3 Horizontal Sliding Sash Option

Although most chemical fume hoods are provided with a vertical sliding sash, it is possible to use a horizontal sliding sash instead. The principal advantage of a horizontal sliding sash is that only half of the hood face can be left open at any time while giving full access to all parts of the hood interior. With a vertical sliding sash, it is necessary to open the sash to its full height to gain access to the upper parts of the hood for equipment setups and monitoring of tall apparatus. A hood with a horizontal sliding sash is illustrated in Figure 32-2. With a horizontal sliding sash, the full height of the opening is always available whenever the sash is open, facilitating ready hood access. Combination vertical and horizontal sliding sashes are also available. Additional details of the horizontal sliding sash modifications for the chemical fume hood are contained in Chapter 35; use of a horizontal sliding sash or combination sash is an important method for reducing the need for laboratory exhaust air volume.

32.3 AUXILIARY AIR CHEMICAL FUME HOODS

Auxiliary air chemical fume hoods differ from bypass chemical fume hoods in only one important respect: A major portion of the air exhausted from the hood is provided from a supply air diffuser canopy attached to the hood just above the hood face. An auxiliary air chemical fume hood is shown in Figure 32-3. The purpose of this modification of a conventional bypass chemical fume hood (Section 32.2) is to reduce the demand for fully conditioned makeup air for hood service (see Chapter 35, Energy Conservation). This is accomplished during cold weather by heating the auxiliary air to a lower temperature than the room HVAC supply air—during hot weather by not cooling or dehumidifying the auxiliary supply air. The rationale is that the hood user ordinarily spends little time working in front of the hood, and in any event, will not be seriously discomforted by unconditioned air flowing from above into the open hood face. In hot climates, especially, the savings that can be realized by not cooling and dehumidifying all the hood exhaust air can be substantial. However, this type of chemical fume hood requires an auxiliary air supply system for each hood that is generally separate from the room HVAC supply air system, thereby



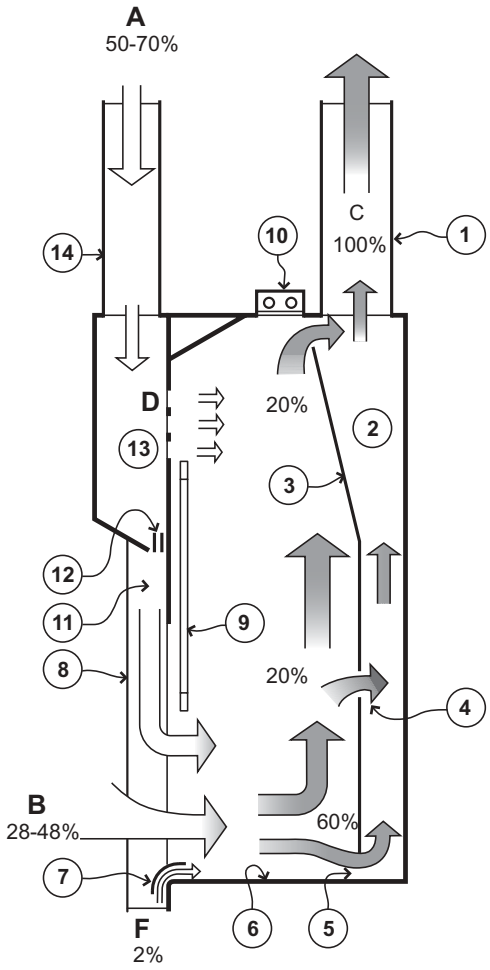
KEY

1	Exhaust Duct
2	Exhaust Plenum
3	Rear Baffle
4	Fixed Center Slot
5	Adjustable Bottom Slot
6	Work Surface
7	Airfoil Sill
8	Horizontal Sliding Sash
9	Lights
□	Clean Air
■	Contaminated Air

AIR FORMULAS

A + B + C = D

FIGURE 32-2. Bypass chemical fume hood with horizontal sliding sash: Section. (Approximate percentages shown for descriptive purposes only.)



KEY

1	Exhaust Duct	10	Lights
2	Exhaust Plenum	11	Supply Air Slot, Velocity 250-300 FPM.
3	Rear Baffle	12	Air Turning Vanes in Plenum
4	Fixed Center Slot	13	Supply Air Plenum
5	Adjustable Bottom Slot	14	Outside Supply Air Duct
6	Work Surface	□	Clean Air
7	Airfoil Sill	■	Contaminated Air
8	Side Baffle 6 Minimum		
9	Vertical Sliding Sash, Closes Top Air Supply when Open.		

AIR FORMULAS

A + B + F = C	
D + E = A	
D + F = C	(Sash Closed)
B + E + F = C	(Sash Open)
A = E	(Sash Open)

FIGURE 32-3. Auxiliary air chemical fume hood: Section. (Approximate percentages shown for descriptive purposes only.)

increasing the number and complexity of the HVAC services to the laboratory. In addition, in humid climates condensation on the cooler surface of the hood may impact the research being performed.

With the advent of variable air volume systems, the use of auxiliary air hoods has greatly diminished and is very rarely used and not recommended.

32.4 PERCHLORIC ACID FUME HOODS

Perchloric acid hoods are special because perchloric acid volatilizes when heated and can condense on and react with organic materials used in the hood or exhaust duct construction. Perchlorates are thus formed that may be explosive. Perchloric acid is a powerful oxidizer and a high-boiling-point chemical that undergoes spontaneous and explosive decomposition. The same is true of many perchlorate salts. In conventional hood exhaust ducts, volatilized perchloric acid cools, condenses, and deposits in horizontal duct runs, creating, in time, a severe explosion hazard. To avoid deposition and accumulation of perchloric acid in hood exhaust ducts, perchloric acid hood systems have been developed. They feature (1) dedicated duct systems that have few, if any, horizontal runs, and (2) no dead areas that can capture and accumulate condensed perchloric acid; furthermore, they are constructed of materials such as 316 stainless steel with welded seams or neoprene gaskets at joints that do not degrade under perchloric acid attack. In addition, they should be located as close to the outside of the building as possible and have stainless steel fans.

Additional special characteristics of perchloric acid hood systems are (1) the interior of the hood is constructed of materials that are not degraded by perchloric acid, and (2) all of the exhaust ducts are continually water-washed into a sewer or sump to remove condensed perchloric acid and prevent accumulation of the acid or its salts. The water wash should be adjusted for pH before disposal to the sewer or collected for treatment or disposal as hazardous waste. Perchloric acid hoods must meet the same performance requirements as those outlined in Sections 32.2 and 32.3 for bypass chemical fume hoods.

32.5 HOODS FOR WORK WITH RADIOACTIVE MATERIALS

Some radioactive materials, such as the long-lived emitters (for example, plutonium), have exceptionally low permissible exposure limits; consequently, hoods designated as radioactive hoods are usually operated at somewhat higher face velocities than are chemical fume hoods. Some users of radioisotopes recommend 150 FPM (0.75 m/s) average face velocity for hoods; this face velocity is too high because it promotes excessive air turbulence at the edges of the working opening. Instead, a maximum average face velocity of 125 FPM (0.63 m/s) is recommended with 100 FPM (0.5 m/s) acceptable. The work procedures followed should be designed to avoid the hood leakage discussed in Section 32.2.3. These include working farther into the hood and keeping the back hood slots unblocked. The hoods that are purchased for service with radioactive materials should include all the features outlined in Section 32.2. In addition, radioactive hoods should be equipped with 326, 18-gauge stainless steel ducts. All the interior hood surfaces should be constructed of a smooth, cleanable, nonporous material such as stainless steel.

Provisions should be made for HEPA filters and/or activated charcoal adsorbers to be installed at the hood air outlet when required by NRC regulations (NRC, 2012), and the fan should be selected to handle the increased static pressure produced by the air filtration system. Finally, provisions should be made to install a continuous effluent air radioactivity monitoring system when this is required by NRC regulations.

In some cases, it may be possible to install a "minihood" or enclosure inside of a conventional fume hood that has an integral air cleaner and blower that discharges air into the fume hood. This hood can be used for small amounts of liquids or solids that are radiolabeled. A health physicist should be consulted before such a system is used.

32.6 VARIABLE AIR-VOLUME HOODS

This type of hood and its associated systems have become a popular category of contaminant control system and are discussed in detail in Chapter 33. The general concept involves varying the quantity of air exhausted and supplied to a space based on the activity and needs of the space at any given time.

The selection of this type of hood must be made carefully, weighing its advantages and disadvantages. The significant advantage is that it can reduce the total quantity of supply and exhaust air to a space when it is not needed, thereby reducing total operating costs. The major disadvantages are that it requires more sophisticated controls and requires a different type of maintenance that traditional maintenance operators are not used to providing. Conditions for selection and safe use are discussed in Chapter 33.

32.7 HIGH-PERFORMANCE HOODS

Recently, many manufacturers have begun to produce what is referred to as "high-performance hoods or low-flow hoods." The concept behind this is the desire to provide a high level of containment at the lowest possible system airflow.

Hood designs have been improved to allow for more streamline airflow patterns into and through the hood and to minimize the effects of the internal hood vortex created by turbulent flow within the hood. Airfoils and rear hood baffles have been altered as well as delivery of "make-up" air under bottom and/or side airfoils.

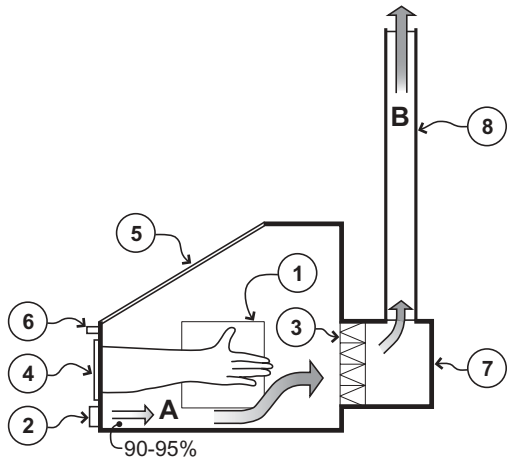
The more widespread acceptance and use of hood performance tests have allowed for innovation in new hood design. In particular, it is important that it has a dynamic challenge. An example of such a test can be found in the NIH requirements (NIH, 2012). Regardless of how the hood looks, ultimately it must meet rigorous performance tests described in Section 32.12.

32.8 GLOVEBOXES

When the toxicity, radioactivity level, or oxygen reactivity of the substances under study is too great to permit safe operation in a chemical fume hood, resort must be made to a totally enclosed, controlled-atmosphere glovebox. The special feature of a glovebox, as the name suggests, is the total isolation of the interior of the box from the surrounding environment and the consequent need to manipulate items inside the box by means of arm-length gloves sealed into a sidewall of the box. To prevent loss of materials from the inside of the glovebox to the laboratory, the box is maintained under substantial negative pressure [0.25–0.50 in. w.g. (60–125 Pa)] relative to the laboratory atmospheric pressure by means of an exhaust fan connected to the box interior. The atmosphere inside the box may be maintained sterile and dust-free by use of a constant air in-leakage through a HEPA filter. As shown in Figure 32-4, a diagram and photograph of a typical glovebox, the interior may be further isolated from the laboratory environment by the use of air locks for passing items into and out of the box.

Stainless steel and safety glass are the preferred materials of construction for the interior of the box, to facilitate cleaning and decontamination. The interior should be finished so as to be smooth and free of sharp edges that could damage the gloves. All controls should be located outside the box for safety and ease of manipulation, as shown in Figure 32-4B. When highly toxic or infectious materials are being used in the glovebox, the exhaust air should be cleaned in two or more stages. A

A



KEY

1	Air Lock Pass-Through
2	Constant Air In-Leakage Through HEPA Filter
3	Roughing Filter
4	Glove Ports
5	Glass Window (Sealed)
6	Controls
7	Exhaust Blower
8	Exhaust Duct to Final Air Cleaning Filter
□	Clean Air
■	Contaminated Air

AIR FORMULAS

A + Leakage = B

B

FIGURE 32-4. A. Glovebox: Section. (Approximate percentages shown for descriptive purposes only.) **B.** Glovebox in a laboratory setting.

prefilter should be used to remove the major load of coarse particulate matter, followed by a HEPA filter with a minimum efficiency of 99.97% for 0.3-μm test aerosol particles. When highly toxic volatile chemicals are used inside the box, an activated charcoal adsorber stage may be added to the air-cleaning train. When no toxic aerosols are present, the HEPA filter may be omitted, but it is advisable to retain the prefilter to protect the activated charcoal from dirt. The specific size of the air-cleaning components will depend on the size of the glovebox and the chemicals used. The fan must be selected to overcome the flow resistance of these added elements. ANSI Standard Z9.5 "Laboratory Ventilation" (ANSI/AIHA 2012) recommends that the typical glovebox size should not exceed 50 ft^3 (1.4 m^3) for single-sided access or 100 ft^3 (2.8 m^3) for double-sided access. More detailed construction and performance specifications have been prepared by the American Glovebox Society (AGS, 2007).

32.9 BIOLOGICAL SAFETY CABINETS

Three classes of biological safety cabinets are recognized (NSF, 2011):

1. *Class I:* A ventilated cabinet for personnel and environmental protection, with an unrecirculated inward airflow away from the operator. The cabinet exhaust air is treated (filtered) to protect the environment before it is discharged to the outside atmosphere. This cabinet resembles a chemical fume hood with a filtered exhaust and is suitable for work with low- and moderate-risk biological agents where no product protection is required.
2. *Class II:* A ventilated cabinet for personnel, product, and environmental protection having (1) an open front with inward airflow for personnel protection, (2) downward HEPA-filtered, airflow for product protection, and (3) HEPA-filtered exhaust air for environmental protection. Class II cabinets are used for low- and moderate-risk biological agents.

   Class II biological safety cabinets are widely used and are available in four recognized types:

Type A. Cabinets (1) maintain a minimum calculated average inflow velocity of 75 fpm through the work area access opening, (2) have HEPA-filtered downflow air from a common plenum (i.e., a plenum from which a portion of the air is exhausted from the cabinet and the remainder supplied to the work area), (3) may exhaust HEPA-filtered air back into the laboratory, and (4) may have positive-pressure contaminated ducts and plenums. Type A cabinets are suitable for work with low- to moderate-risk biological agents in the absence of volatile toxic chemicals and volatile radionuclides.

Type B1. Cabinets (1) maintain a minimum (calculated or measured) average inflow velocity of 100 fpm through the work-area access opening, (2) have HEPA-filtered downflow air composed largely of uncontaminated recirculated inflow air, (3) exhaust most of the contaminated downflow air through a dedicated duct exhausted to the outdoor atmosphere after passing through a HEPA filter, and (4) have all biologically contaminated ducts and plenums under negative pressure or surrounded by negative-pressure ducts and plenums. Type B1 cabinets are suitable for work with low- to moderate-risk biological agents. They may also be used with biological agents treated with minute quantities of toxic chemicals and trace amounts of radionuclides required as an adjunct to microbiological studies if work is done in the direct-exhausted portion of the cabinet or if the chemicals or radionuclides will not interfere with the work when recirculated in the downflow air.

Type B2. Cabinets (sometimes referred to as "total exhaust") (1) maintain a minimum (calculated or measured) average inflow velocity of 100 fpm through the work area access opening, (2) have HEPA-filtered downflow air drawn from the laboratory or the outside air (i.e., downflow air is not recirculated from the cabinet exhaust air), (3) exhaust all inflow and downflow air to the outdoor atmosphere after filtration through a HEPA filter without recirculation in the cabinet or return to the laboratory room air, and (4) have all contaminated ducts and plenums under negative pressure or surrounded by directly exhausted (nonrecirculated through the work area) negative-pressure ducts and plenums. Type B2 cabinets are suitable for work with low- to moderate-risk biological agents. They may also be used with biological agents treated with toxic chemicals and radionuclides required as an adjunct to microbiological studies.

Type B3. Cabinets (1) maintain a minimum (calculated or measured) average inflow velocity of 100 fpm through the work-area access opening, (2) have HEPA-filtered downflow air that is a portion of the mixed downflow and inflow air from a

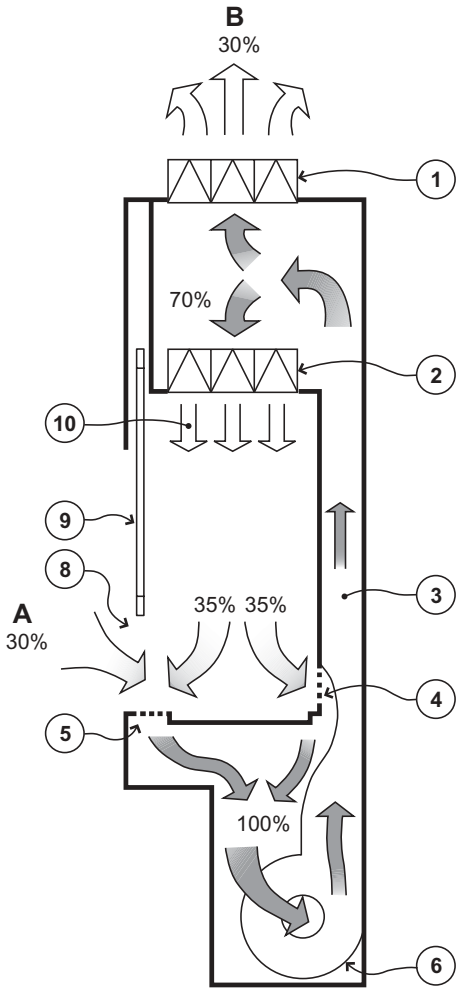
common exhaust plenum, (3) discharge all exhaust air to the outdoor atmosphere after HEPA filtration, and (4) have all biologically contaminated ducts and plenums under negative pressure or surrounded by negative-pressure ducts and plenums. Type B3 cabinets are suitable for work with low- to moderate-risk biological agents treated with minute quantities of toxic chemicals and trace quantities of radionuclides that will not interfere with the work if recirculated in the downflow air.

The above descriptions were taken from NSF International Standard No. 49 (NSF, 2009). Standard No. 49 includes basic requirements for construction and certification testing of all Class II biological safety cabinets. The appearance of the words "laminar flow" in the title of the standard—NSF International No. 49 for Class II (Laminar Flow) Biohazard Cabinetry—makes it necessary to caution against confusing Class II biological safety cabinets with laminar flow workbenches because, although the latter devices provide work protection, they fail to provide personnel or environmental protection. Therefore, they should never be used with toxic, infectious, or otherwise hazardous materials. Figures 32-5 and 32-6 identify the important parts and show the airflow patterns for Type A and Type B1 cabinets, the two most widely used types.

3. *Class III:* A totally enclosed, ventilated cabinet of gas-tight construction. Operations in the cabinet are conducted through attached rubber gloves. The cabinet is maintained under negative air pressure of at least 0.5 in. w.g. (125 Pa). Supply air is drawn into the cabinet through HEPA filters. The exhaust air is treated by double HEPA filtration or by HEPA filtration and incineration. Class III cabinets are suitable for high-risk biological agents and are accompanied by much auxiliary safety equipment. There are only a handful of such facilities worldwide. They must be designed, installed, and certified by experienced biological safety professionals.

The heart of every cabinet is the HEPA filter, a pleated paper filter contained inside a rectangular wooden frame. The filter is clamped tightly to a specially prepared flange built into the cabinet frame, and a compressible gasket on the face of the wooden filter frame makes the required airtight seal. Threaded clamps are usually used, but some manufacturers use spring-loaded clamps.

Most cabinets use direct-drive fans with forward-curved impellers driven by permanent split-capacitor motors and controlled by a Triac



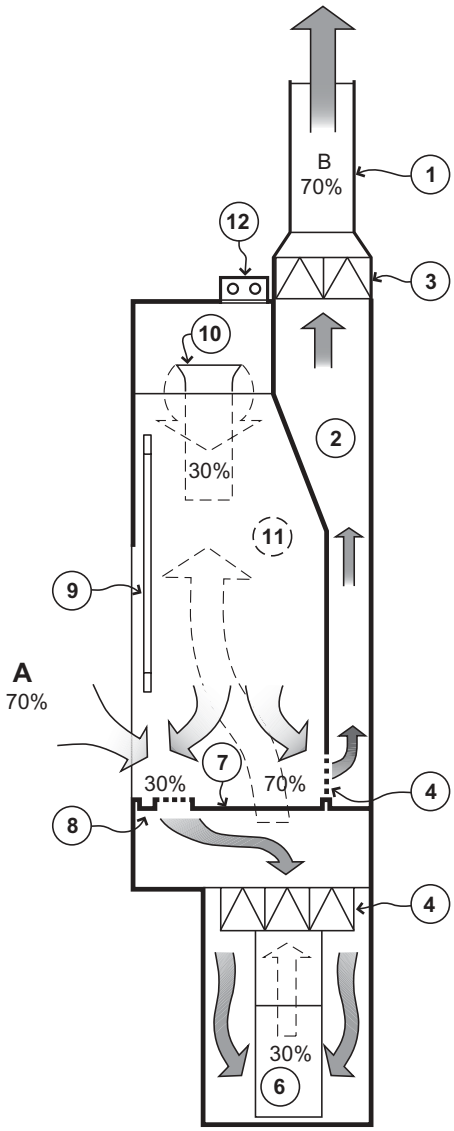
KEY

1	Exhaust Air HEPA Filter
2	Supply Air HEPA Filiter
3	Exhaust Plenum
4	Rear Exhaust Grille
5	Front Exhaust Grille
6	Fan (1 Per Unit)
7	Work Surface
8	Fan Opening
9	Vertical Sliding Sash
10	Filtered Recycled Air
11	Lights
□	Clean Air
■	Contaminated Air

AIR FORMULAS

A = B

FIGURE 32-5. Class II Type A biological safety cabinet: Section. (Approximate percentages shown for descriptive purposes only.)



KEY

1	Exhaust Duct
2	Exhaust Plenum
3	Exhaust Air HEPA Filter
4	Exhaust Plenum
5	Supply Air HEPA Filiter
6	Fan (Side View, 2 Per Unit)
7	Work Surface
8	Front Exhaust Grille
9	Vertical Sliding Sash
10	Filtered Recycled Ai
11	Side Wall Plenumsr
12	Lights
□	Clean Air
■	Contaminated Air

FIGURE 32-6. NCI-1 Type B biological safety cabinet: Section. (Approximate percentages shown for descriptive purposes only.)

speed controller. The Triac is a solid-state device that can be adjusted to vary the AC voltage at the output from essentially zero to full line voltage. The permanent split-capacitor motor is a brushless electric motor of fractional horsepower size. It requires an external capacitor that remains in the circuit during starting and while running. It is the largest AC motor that will run at variable speed, reducing rpm and horsepower as input voltage is reduced.

The forward-curved fan impeller has a performance characteristic that prevents it from overloading the motor as the filters increase in resistance because the torque required to turn this fan increases rapidly with increasing airflow, but only very little with increasing pressure. Therefore, as filter resistance rises, airflow tends to drop and the load on the motor to decrease, but this causes the motor to speed up and airflow remains close to its original value. Starting with new filters in a cabinet, airflow will not decline more than 10% even after filter pressure drop has increased 50%. But as filters increase above 50% of new resistance, the amount of pressure increase needed to produce a 10% drop in airflow decreases and more frequent manual adjustments are needed.

All cabinets contain electrical utility outlets. Some are useful only for powering small appliances, whereas others have full 15-A capacity. All units should have ground fault interrupters in the electrical utility outlet line. They measure leakage to ground and automatically cut off power when leakage exceeds 5 mA. The proper functioning of the ground fault interrupter must be verified for all units whenever cabinet certification tests are performed.

32.9.1 Biological Safety Cabinet Cleaning

Use of UV lamps in biological safety cabinets was discontinued in the 1983 revision of NSF Standard No. 49 because of their limited effectiveness for decontaminating cabinets. Correct procedure, when using a biological safety cabinet, calls for washing down the work area with a suitable disinfectant on completion of work. Without a good washdown, remaining soil is likely to shield organisms from the UV light, whereas with a good washdown, further disinfection of the cabinet surfaces is generally not needed, especially if the blower is left running continuously.

32.9.2 Biological Safety Cabinet Certification

Before sale, a model or type cabinet is submitted for certification to NSF International by the manufacturers.

Those that have passed the personnel, environmental, and product safety tests can be identified by a distinctive NSF medallion placed on the exterior of the cabinet. Field recertification by a competent technician is needed when a cabinet is first installed, at annual intervals thereafter, and whenever a cabinet is moved to a new location or is serviced internally. It is standard safety practice to sterilize the entire internal structure of a working cabinet with formaldehyde or hydrogen peroxide gas each time it is necessary to service interior parts. NSF Standard No. 49 contains detailed instructions for performing the field certification tests and for formaldehyde sterilization. The latest version of NSF Standard No. 49 should always be consulted for significant changes that may affect selection or design.

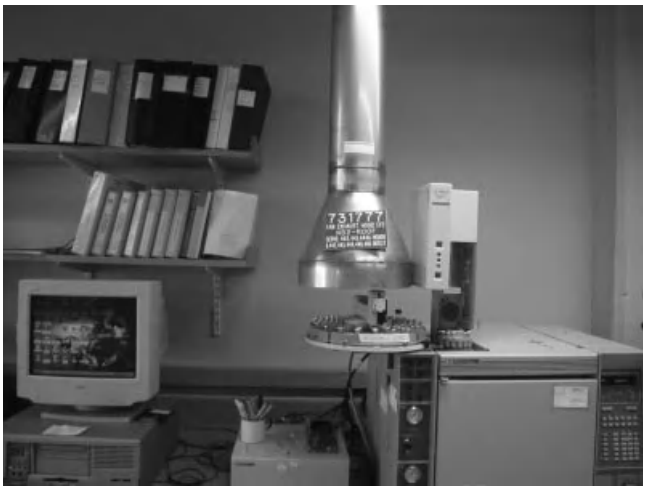


FIGURE 32-7. View of a capture hood in a physics laboratory.

32.10 CAPTURE (EXTERIOR) HOODS

The most efficient and cost-effective form of contaminant control is local exhaust ventilation (LEV). This involves capture of the air-entrained contaminant at its source of generation. The laboratory chemical fume hood (Section 32.2) is a specialized form of hood (sometimes called a containment hood or enclosure hood) that totally encloses the emission source. Often, total enclosure of the source is not possible or is not necessary. A capture hood (sometimes called an exterior hood) controls the release of toxic materials into the laboratory by capturing or entraining them at or close to the source of generation, usually a workstation or laboratory operation. In some cases, considerably less air volume is required than for the standard chemical fume hood.

To work effectively, the air inlet of a capture hood must be placed near the point of contaminant release. The distance away will depend on the size and shape of the hood, the volume of air, and the velocity of air at the intake slot or face, but should usually be not more than 12 in. (0.3 m) from the generation source. Design face or slot velocities are typically in the range of 500–2000 fpm (2.5–10 m/s). Many design guidelines for this class of exhaust hoods are contained in Chapter 3 of the *Industrial Ventilation: A Manual of Recommended Practice for Design, 27th Edition* (American Conference of Governmental Industrial Hygienists [ACGIH], 2010) and in Burton's *Semiconductor Exhaust Ventilation Guidebook* (Burton, 1995). Two types of capture hoods that find frequent application in the laboratory are "canopy" hoods and "slot" hoods. Canopy hoods are used primarily for the capture of gases, vapors, and aerosols released from permanent laboratory equipment. Examples of this type of equipment include ovens, gas chromatographs, autoclaves, and atomic absorption spectrophotometers. They are usually found in analytical and biological laboratories and some pilot plant operations. This type of hood is generally used when the process to be controlled is at an elevated temperature or the emissions are directed upward. Many equipment manufacturers recommend specific capture hood configurations that are suitable for their units. An example can be seen in Figure 32-7

Slot hoods are used for control of laboratory bench operations that cannot be performed inside a containment hood (chemical fume hood) or under a canopy hood. Laboratories that may find use for slot exhaust ventilation include clinical (histology, pathology), anatomy, teaching, and general chemistry laboratories. Typical operations include slide preparation, microscopy, biological specimen preparations, mixing, and weighing. An example is shown in Figure 32-8.

Another laboratory operation that needs special consideration is the weighing of highly toxic materials. Because of the nature of the materials used, it is prudent to do this in a ventilated enclosure. A chemical fume hood is not the best location because its relatively high airflow may disrupt the weighing process and it is not an efficient use of ventilated space. A ventilated weighing station has been developed as part of the National Toxicology Program (Hoyle, 1987) and is shown in Figure 32-9A and B.

32.11 DUCTLESS HOODS

Ductless hoods are an attractive substitute for exhaust laboratory hoods because of their lower initial cost, ease of relocation, and less use of energy; however, they are

FIGURE 32-8. View of a slot hood in a pathology laboratory.

inappropriate for some applications and if incorrectly selected or used, serious harm or injury may occur. These are more commonly used in facilities where there are a limited number of chemicals used and the specific hazards can be assessed.

Ductless hoods:

- Are stand-alone, bench top enclosures that are not connected to an exhaust system that discharges the laboratory hood exhaust outdoors but instead it exhausts directly into the room
- Incorporate an exhaust fan and filters as an integral part of the laboratory hood
- Discharge the exhaust directly into the room
- Draw air in through the front opening or face of the hood much like a standard laboratory fume hood, but is then passed through a self-contained charcoal or other solid adsorption media and/or HEPA filter and discharged through the fan back into the room.

Ductless hoods are available in a variety of sizes and shapes with a large range of volume airflow through the hood. Ductless hoods may also be referred to as a ductless fume hood, ductless filtering fume enclosure, portable hood, carbon-filtered enclosure, or enclosure for toxins using recirculating air filtration (ETRAF). Figures 32-10 and 32-11 are examples of typical hoods.

FIGURE 32-9. View of ventilated weighing stations. (Courtesy of Flow Sciences Inc., Wilmington, NC.)

Biological safety cabinets may also be called ductless hoods because of their manner of operation when not connected to an external exhaust system. Although they are not commonly referred to in this manner, any biological safety cabinet that is not connected to an external exhaust system can be considered a ductless hood.

32.11.1 Application

Ductless hoods should only be used with chemicals that the manufacturer has approved for use.

They are effective for handling laboratory quantities (<1 liter) of many but not all of the common organic solvents, acids, and bases. Manufacturers should supply a list of approved chemicals for use in their hood.

FIGURE 32-10. Ductless fume hood. (Courtesy of Erlab Inc., Rowley, MA.)

FIGURE 32-11. View of a ductless fume hood in a teaching laboratory. (Courtesy of Erlab Inc., Rowley, MA.)

There can be a wide variance in the performance of units between manufacturers or even between different models within the same manufacturer. The more reliable units are those that are tested to accepted performance standards as described below and are provided technical support by manufacturers to units in use. Manufacturers should also be closely involved in the selection of their units based on the proposed application and must be willing to demonstrate that their unit will perform adequately for its intended use.

The users must be aware of the limitations of these units and strictly adhere to the proper use, monitoring, and maintenance requirements. There must be an ability to identify when changes in chemicals are made to evaluate the appropriateness of use in a ductless hood.

32.11.2 Health and Safety Considerations

A. Advantages. The advantages of ductless hoods relative to standard chemical fume hoods are

1. Installation costs are generally lower because an external exhaust system is not required. The savings vary widely based on the complexity of the facility, but it can be in the tens of thousands of dollars range.
2. Energy savings (operating cost) can be significant because by recirculating the air back to the room there is a minimal amount of new (outside) air that is brought into the room and therefore less heating or cooling. The cost of exhausting air to the outdoors and replacing it with conditioned air is estimated to be $2 to $8 per CFM operating 24 hours, 7 days per week. For a standard 1000 CFM constant volume hood the operating savings would be in the $2,000–$8,000 per year range.
3. Because the units are relatively mobile, it is easier and more economical to move them allowing far more flexibility as work changes.

However, the potential savings must be evaluated on a case by case basis. A minimum volume of exhaust air from a lab still must be maintained and a chemical hood exhausted to the outdoors may be needed anyway. In addition, the heat level added by the ductless hood must be considered.

B. Disadvantages. The disadvantages of ductless hoods relative to standard chemical fume hoods are

1. The need to know every chemical that will be used or generated in it at any given time during the life of the hood.
2. They are not effective for all chemicals that could be used and proper assessments need to be conducted for each chemical potentially used or generated.
3. They require vigilant maintenance, in particular the frequency of changing the filtration device. This will vary depending on the specific materials and volume of materials generated. It can vary from months to years. Procedures for identifying when filter changes are needed and procedures for changing filters are therefore needed.

4. The chemical sensory device used to determine filter breakthrough (and thus the need to change the filter) needs periodic calibration and replacement.

There are two major health and safety issues with ductless hoods.

1. Containment: Does the hood contain the vapors, fumes, or dusts generated within the hood and not allow escape into the room? Several manufacturers as noted above have demonstrated the ability to provide acceptable containment. Very little data exists for performance as installed due to the difficulty in performing some of the standard tracer gas tests used for fume hoods in the laboratory. However, some field-testing has been performed following the guidelines published in the *ISPE Good Practice Guide: Assessing the Particulate Containment Performance of Pharmaceutical Equipment, Second Edition,* also known as the SMEPAC guide (ISPE, 2012). This is a challenge test using powders as a surrogate. Although these tests do demonstrate hood containment ability, they do not demonstrate the effectiveness of the hood filtration system.
2. Filtration: Are the hazardous materials generated within the enclosure adequately filtered or removed from the air stream before the air is discharged back into the room? Unfortunately, as of January 2013, there is not a consensus standard test recommended at this time. There are some tests being evaluated currently.

Not all hazardous materials used in laboratories can be demonstrated to be adequately filtered or retained by the hood's filtration system. This can be a major disadvantage. Activated charcoal is the most common adsorbent media used. Its limitations include

1. It is not effective for particulates or aerosols.
2. It will not react or bind with all substances including sodium, nitrates, aldehydes (e.g., formaldehyde and glutaraldehyde), some alcohols (e.g., methanol), inorganic acids, and amines.
3. Moisture and high humidity will decrease efficiency.
4. Adsorption generally decreases as PH and temperature increase.
5. The inability to adequately warn the user when the capacity of the filter is exceeded and breakthrough has occurred.

32.11.3 Selection and Operation

If ductless hoods are to be considered for use, the following process should be followed.

1. Obtain an inventory of all chemicals to be used inside the hood currently and potential uses in the future.
2. Perform a written hazard assessment to ensure proper air quality, effective occupant protection, and satisfactory system performance.
3. Identify potential manufacturers and types of ductless hoods.
4. Provide the inventory of chemicals to potential manufacturers and ask for verification that their product is effective for all materials to be used. The reputable manufacturers are willing to perform this assessment with you. The Scientific Equipment and Furniture Association (SEFA) requires its members who offer ductless hoods to review all applications proposed and determine its product's compatibility or incompatibility (SEFA, 2010).
5. Obtain information on retention capacity, e.g., pounds of material removed per pound of filter material. The manufacturer should provide this data.
6. Obtain the results of the manufacturer's containment and air-cleaning performance tests.

Ductless hoods considered for use must meet all the criteria specified in ANSI Z9.5 section 4.0 (ANSI/AIHA 2012) as follows:

1. The hood must meet the containment requirements identified in ANSI Z9.5-2012 for laboratory chemical fume hoods. A performance test such as ASHRAE 110-1995 (ASHRAE, 1995) should be conducted and results submitted for evaluation. An acceptance criterion of 0.10 ppm tracer gas at a generation rate of 4 liters per minute (lpm) is recommended for normal use. Where highly toxic materials will be used, a more conservative criterion such as 0.05 ppm at a release rate of 8 LPM could be used.
2. Another standard test used in the pharmaceutical industry is in the SMEPAC test noted above. The acceptance should be based on the occupational exposure limit (OEL) for the materials to be used in the hood. Hoods have been demonstrated to contain to below an OEL of 10 $\mu g/m^3$.
3. The filtration material used in the hood must be effective for all the materials to be used within the

hood. The manufacturer should verify this with performance testing such as AFNOR NF X 15-211 (AFNOR, 2009) for gases and vapors. SEFA recommends a challenge test for gases and vapors (SEFA, 2010). For particles, a challenge test such as that used in National Sanitation Foundation Standard No. 49 (NSF, 2011) for biological safety cabinets should be used.

4. There must be a mechanism to identify when the filtration device is no longer effective. This should be both a visual and audio alarm. For an adsorbent media like charcoal, there should be a method to identify breakthrough. Some manufacturers provide a back-up filter with a recommendation for periodic sampling between the main and back-up filter to determine when breakthrough occurs; some have a continuous monitoring system, while others recommend a routine replacement of the filter based on use. The most prudent practice would be to use a hood with a main filter with an interstitial space for air sampling for breakthrough and a smaller back-up filter. The back-up filter allows for a time delay in detecting breakthrough from the main filter. When multiple chemicals are used, there is no need and it is impractical to sample all to determine breakthrough. The selection of the proper chemical or chemicals to use as a surrogate will depend on the types and structures of the chemicals used and their affinity and capacity for charcoal or whatever media is used.
5. There must be signage on the hood indicating which specific chemicals are approved for use, test results of hood performance, and the hood maintenance schedule.
6. There should be a continuous air volume flow monitoring device. It should be visible to the user and should have both an audio and a visual alarm when the flow drops below 90% of design flow.

Note that some manufacturers are now providing the ability to transmit hood operating parameters directly to building management systems so that the hood operations can be monitored centrally. This feature allows information about flow rates, time of use, and maintenance needs to be accessed as needed.

32.11.4 Conclusions and Recommendations

Ductless hoods can have an application in the research laboratory, but it is critical to understand their limitations and proper operating and maintenance procedures.

All ductless hoods are not alike. The better ones are those that are routinely performance tested by the manufacturer and supported by the manufacturer before and after the unit is purchased and installed in the field. Good manufacturers can provide lists of specific chemicals and classes of chemical for which their product will perform well, as well as those not recommended for use within these hoods.

Ductless hoods should not be considered for use where unknown chemicals are used or chemical reactions conducted may create unknown compounds or chemicals not effectively removed by the filtration system. It is also inadvisable to use these when the research (and chemicals used) may be a rapidly changing focus.

Use with suspect carcinogens or acutely toxic materials should be avoided.

These are most applicable when there are a small number of chemicals used in the hood, and all have been demonstrated to be adequately removed by the filtration material.

All users must be trained in the operation and use of these hoods and a detailed maintenance schedule must be followed.

32.12 PERFORMANCE TESTS

From the initial selection of a hood to its continuing use in the laboratory, the owner will need a method to evaluate its performance. The procedure involves selecting the conditions under which the hood will be tested, choosing an appropriate challenge test, and developing acceptance criteria that will adequately determine whether the hood meets the user's protection needs. A variety of performance tests are currently used. We discuss several here, indicating their appropriateness for specific applications and their advantages and disadvantages. Users must select a test that will accurately determine whether a specific hood will provide the needed protection.

Factors to consider when choosing a performance test include (1) reason for testing; (2) type and quantity of chemicals or biological agents to be used in the hood; (3) types of operations and equipment to be used in the hood; (4) number and type of users; (5) diversification of hood use, both in the short term (months) and long term (years); (6) location of hood within the facility; (7) type of hood (constant volume or variable air volume); and (8) ease of performance of test. Hood performance tests are normally conducted (1) when selecting a type of hood to be purchased, and (2) when evaluating hoods in place. In-place tests may be conducted after installation, but before use and at intervals during routine use. The first category involves testing in a controlled, laboratory-type setting, whereas the second involves an

evaluation in the laboratory under practical use conditions. Both are discussed here.

Performance tests involve measurement of the hood flow characteristics (face velocity and air quantity) and the efficiency of the hood in containing an artificial challenge gas or aerosol generated within the hood.

32.12.1 Tests for Selection of a Hood

Before purchasing hoods, a user must determine under what conditions the hoods may be used, what type of hood to select (constant volume versus variable air volume), and what protection factor is needed. For example, what is the maximum allowable loss of containment (leakage) that is acceptable? (Refer to Chapter 2, Section 2.3.4.4 for assistance in defining hood use and types).

Considerable research on performance tests has been conducted, and several test protocols have been proposed for adoption as a standard. See ANSI standarad Z9.5-2012 section 4.2 for more details on ductless hood testing (ANSI, 2012)They involve a variety of challenge chemicals, methods of dispersing the challenge, and criteria for acceptance. Challenge chemicals include uranine dye (Chamberlin, 1978), freon (ASHRAE, 1985), and sulfur hexafluoride (ASHRAE, 1995; British Standards Institute [BSI], 2010; Chamberlin, 1982; NIH, 2012). These tests have been used under various conditions by a number of organizations. The reader is encouraged to review the above references in detail before making a selection. In addition, the current literature should be searched because this area is still receiving considerable research attention as alternatives to the use of SF6 are being evaluated.

The latest ANSI Z9.5 standard on laboratory ventilation recommends the use of ASHRAE Standard 110-1995, "Method of Testing Performance of Laboratory Chemical Hoods" (ASHRAE, 1995). Many purchasers of hoods now require some modification of this standard test such as the NIH (NIH, 2012).

32.12.2 Field Performance Tests for Fume Hoods after Installation

After hoods have been installed but before their use, they should be tested to verify anticipated performance characteristics. Generally, this involves measurement of volumetric flow rate and face velocity and comparison with design criteria (see Chapter 2, Section 2.3). Face velocity measurements should be made at 9–12 points equally distributed across the opening of the hood (ACGIH, 2010; ASHRAE, 1995; BSI, 1994; SEFA, 2010). In addition, observation of airflow patterns should be made by generating a source of smoke across the face opening. It has also been common practice to conduct these tests at regular intervals throughout the year on operational hoods.

For many years, health and safety professionals have recognized that this procedure may not be an accurate field assessment of hood containment performance. Other field-testing techniques have used variations of the ASHRAE test referred to in Section 32.12 (Fuller, 1979; Mikell, 1981). Although these tests can provide much information after hoods have been installed and before they are used, they are difficult to conduct on a regular basis because they are time-consuming and can intrude on operations performed in the hood. A new method that has been developed to provide an easy, quick, and unobtrusive assessment of fume hood performance involves the release of a tracer gas through a diffuser inside the hood under normal operating conditions (DiBerardinis, 1991; Ivany, 1986). Measurements of the tracer gas are made outside the hood to determine hood leakage. Leakage can then be related to permissible chemical exposure standards. This test can be used as an after-installation/before-use acceptance procedure and as a regular-interval performance test.

Whichever performance test is selected, it is important to include the requirements in the design documents, including criteria for acceptance.

32.12.3 Acceptance Criteria

The owner or designer must also specify the acceptance criteria for the hoods to be selected before they are purchased. Recommended maximum acceptable leakage rates are provided in the ANSI Z9.5-2012 standard (ANSI/AIHA, 2012) and the NIH design guidelines (NIH, 2010). A discussion of acceptable leakage rates is also provided in the ASHRAE 110-1995 standard (ASHRAE, 1995). The level of risk posed by the activity in the hood should determine the degree of protection desired.

33

EXHAUST AIR DUCTS AND ACCESSORIES

33.1 INTRODUCTION

Fume hood and capture hood ducts differ from HVAC ducts in that the materials that pass through them are often highly corrosive, flammable, and toxic. Consideration should be given to the fact that such ducts may have to be serviced or replaced during the life of the average laboratory building. Therefore, safety to personnel making repairs or replacement should not be overlooked. The *2011 ASHRAE Handbook, HVAC Applications*, Chapter 13 and *2000 ASHRAE Handbook, HVAC Systems and Equipment, Chapter 16* provide helpful guidelines.

There is no universal consensus on the best material to use for exhaust duct construction. The following is a review of a number of codes and standards:

- ANSI/AIHA Z9.5 (ANSI/AIHA, 2012) calls for that exhaust ductwork to be fire and corrosion resistant for the intended use.
- NFPA-45 Standard on "Fire Protection for Laboratories Using Chemicals" (NFPA, 2011) calls for laboratory hoods and local exhaust systems to be constructed of noncombustible materials.
- NFPA-90A Standard for the "Installation of Air Conditioning and Ventilation Systems" (NFPA, 2012) states that ducts need to be constructed of steel, aluminum, or other *listed* noncombustible materials. In addition, duct materials meeting the requirements of UL181, Classes 0 and 1, are acceptable—Class 0 materials having a surface-burning characteristic of zero. Class 1 materials have a flame-spread rating not over 25 and a smoke-developed rating not over 50.
- NFPA-91 and local building codes should be consulted for fire-resistance, flame-spread and smoke-generating ratings.
- NFPA-91 Standard for "Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Noncombustible Particulate Solids" (NFPA, 2010) calls for exhaust ducts to be constructed of noncombustible material. Plastic duct is allowed when the interior is protected with an automatic fire-sprinkler system.

Considerable care must be exercised to evaluate the types of materials that are likely to be used and how they will be used in laboratories prior to making a selection of duct materials. Similar considerations are a guide to the features to be provided in the design of the building for ease of servicing and replacing ducts. It should be kept in mind, as well, that laboratory usage may change over time; therefore, a conservative approach should taken when selecting chemical fume hood duct materials to avoid inadvertent future failures.

Many chemicals encountered in laboratories are flammable. For this reason, many fire departments oppose the use of rigid PVC ductwork because of the possibility of forming toxic *chlorine based* products *of combustion* in a fire. Transite *is no longer used as a duct material because of its asbestos content*. Table 33-1 is a

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

TABLE 33-1. Chemical Resistant Properties and Flame Ratings

Material	Acids[1]		Alkalies[1]		Organic Solvents[1]	Flammability[2]
	Weak	Strong	Weak	Strong		
Aluminum[3]	N	N	N	N	N	G
Asphalt-coated steel[4]	Y	Y	Y	Y	N	G
Epoxy-coated steel	Y	Y	Y	Y	Y	G
Galvanized steel[5]	N	N	N	N	Y	G
Epoxy glass fiber reinforced[6]	Y	Y	Y	N	Y	SL
Polyester glass fiber reinforced[7]	Y	Y	Y	N	Y	SL
Polethylene fluorocarbon[8]	Y	Y	Y	Y	Y	SE
Polyvinyl chloride[9]	Y	Y	Y	Y	N	SE
Polypropylene[10]	Y	N	Y	N	N	SE
316 Stainless steel[11]	Y	Y	Y	Y	Y	G
304 Stainless steel[11]	Y	N	Y	N	Y	G

[1] N—attacked severely; Y—no attack or insignificant.
[2] G—good fire resistant; SE—self-extinguishing; SL—slow burning.
[3] Aluminum is not generally used due to its subjectivity to attacks by acids and alkalies.
[4] Asphalt-coated steel is resistant to acids, subject to solvent and oil attacks.
[5] Galvanized steel is subject to acid and alkaline attacks under wet conditions.
[6] Epoxy glass fiber reinforced is resistant to weak acids and weak alkalies and is slow burning.
[7] Polyester glass fiber reinforced can be used for all acids and weak alkalies but is attacked severely by strong alkalies and is slow burning.
[8] Polyethylene fluorocarbon is an excellent material for all chemicals.
[9] Polyvinyl chloride is an excellent material for most chemicals and is self-extinguishing but is attacked by some organic solvents.
[10] Polypropylene is resistant to most chemicals and is self-extinguishing but is subject to attack by strong acids, alkalies, gases, anhydrides, and ketones.
[11] Stainless steel 316 and 304 are subject to acid and chloride attacks varying with the chromium and nickel content.

tabulation of commonly used duct material, and Table 33-2 gives the limitations of use for different duct materials. We recommend that exhaust ducts serving hoods, which exhaust radioactive materials, volatile solvents, and strong oxidizing agents (perchloric acid) be fabricated of Type 316 stainless steel. In general, high-alloy stainless steels (e.g., 316), and fiberglass-reinforced polyester (FRP) have proven to be the most satisfactory duct material for corrosion, impact, and vibration resistance, as well as for ease of fabrication and installation. Galvanized steel has proven to be a lower-cost alternative, with an excellent expected life for ordinary hood and general laboratory exhausts. Rigid PVC has excellent corrosion resistance, but is brittle; therefore, it has inferior cracking resistance to impact and vibration. Polyester resins can be formulated with fire-retardant additives that make them self-extinguishing. This type of fire-retardant polyester should be specified for all FRP ducts.

A typical duct specification is likely to mandate that all fume hood and local exhaust ducts be constructed of round piping with the interior of all ducts smooth and free of obstructions. In addition, the use of flexible ducts for spot exhaust points should be kept to minimum lengths within the laboratory, and equipped with tightly fitting, easily removable end caps for use when the exhaust is not being used. Flexible ducts should be non-collapsible and constructed entirely of metal or of a wire coil covered with multiple plies of UL Class 0 or 1flame-proofed, impervious fabric. Applicable leakage rates per SMACNA standards are briefly shown in Table 33-3. Full details are shown in Table 37-5.

33.2 EXHAUST DUCT CONSIDERATIONS

High-velocity air movement in ducts is desirable to ensure that solids do not deposit in the joints, seams, or corners of the duct system. A minimum suggested design velocity is 1500 FPM. This is adequate for gases and vapors, but not for particulates. Higher conveying velocities (1500–3000 FPM) are usual. See Table 33.4 for details. In general as recommended by ANSI/AIHA Z9.5 (ANSI/AIHA, 2012), the exhaust air velocities should be sufficiently high to retard condensation of liquids or adherence of solids within the exhaust system.

A minimum of turns, bends, and other obstructions to airflow is also desirable. Where perchloric acid is to be used, the duct configuration should be free of bends and horizontal runs, have inorganic sealing materials, and permit a thorough wash down of all interior duct surfaces.

Metal duct with a coating provides an inexpensive alternative for use in exhausting corrosive materials. However, any pinhole defect in the coating or

TABLE 33-2. Commonly Used Duct Materials and the Limitations of Their Use

Material	Limitations of Use
Glazed ceramic pipe	Rarely used today because of installation and sealing difficulties
Epoxy-coated stainless steel	Extensive experience not yet available, but appears promising as a versatile material
Stainless steel	May be attacked by some chemicals, especially hydrochloric acid. Care should be used in selecting type. Stainless No. 316 is one of the more resistant alloys.
Monel metal	May be attacked by some chemicals, such as halide salts and acids
Synthetic or cementitious "stones"	Absorb moisture, attacked by strong alkaline chemicals
Reinforced plastic, principally glass fiber-reinforced polyester (FRP)	Various resins have different chemical and fire resistance. Care should be taken to select chemically resistant resins for final interior layer.
Aluminum	Limited resistance to many chemicals. Care should be used to install only in systems that do not experience corrosive chemical exposure.
Galvanized steel	Limited resistance to corrosion by a wide variety of materials used in research and tesing laboratories. Not recommended.
Black steel	Useful only with dry and noncorrosive dusts

TABLE 33-3. Applicable Leakage Rates

Duct Class	0.5, 1, 2 in. w. g. (0.12, 0.25, 0.50 kPa)	3 in. w. g. (0.75 kPa)	4, 6, 10 in. w. g. (1.0, 1.5, 2.5 kPa)
Seal Class	C	B	A
	Leakage Class		
Rectangular Metal Duct	24	12	6
Round Metal Duct	12	6	3

TABLE 33-4. Exhaust Duct Velocities

Contaminant	Examples	Desired Velocited FPM (m/s)
Vapors, gases, smoke	All vapors, gases, smoke Acids and alkali	1,400–2,000 (7.1–10.2)
Fumes	Zinc and aluminum oxide fumes	1,400–2,000 (7.1–10.2)
Very fine light dust	Cotton lint, wood flour, litho powder, Pharmaceutical	2,000–2,500 (10.2–12.7)
Dry dust and powders	Cotton dust, lioght shavings, Pharmaceutical	2,500–3,500 (12.7–17.8)
Average industrial dust	Sawdust, grinding dust, carpentry or woodworlikg shops.	3,500–4,000 (17.8–20.3)
Heavy dusts	Metal turnings, lead dust, machine Shop	4,000–4,500 (20.3–22.9)
Heavy or moist dusts	Buffing lint (sticky), lead dust with small chips	4,500+ (22.9+)

Adapted from SMACNA *HVAC System Applications* (SMACNA, 2010)

scratching during installation can expose metal underneath, causing damage and duct leaks.

33.3 EXHAUST SYSTEM CLASSIFICATION

ANSI/AIHA Z9.5 (ANSI/AIHA, 2012) provides an excellent discussion on exhaust system classifications. Many building codes have taken an overly restrictive view of the International Mechanical Code (IMC, 2009) Section 510, "Hazardous Exhaust System," and have included laboratory exhaust systems in that category. The definition of a hazardous exhaust system covers an industrial ventilation system where high concentrations of flammable materials within the explosive limit are conveyed through the ductwork. Laboratory exhaust systems do not meet this definition.

33.4 DUCT ACCESSORIES

33.4.1 Trimming Dampers and Splitters

Trimming dampers should not be used for fume hood or contaminant control exhaust systems (IMC, 2009).

When such dampers are used, they should be equipped with indicating and locking quadrants and the damper blade should be riveted to the supporting rods. Dampers should be made of the same material as the ducts in which they are installed, but should be two gauges heavier. Cast or malleable brackets, riveted to the sides of the duct, should be sufficiently long to extend the full width of the branch ducts to which they are attached. Opposed blade dampers should have each blade sealed with foam rubber or felt to form an effective seal between blades with the damper in the fully closed position.

These trimming dampers, which are in fixed position, are different than the flow controllers of automatic dampers described in Chapter 29, which continually operate to monitor or balance airflow.

33.4.2 Fire Dampers

Ten-gauge galvanized steel sleeve-type horizontal and vertical fire dampers should be installed in all ducts that penetrate firewalls or floors. The assembly should consist of 18-gauge galvanized, formed-steel blades with interlocking joints to form a continuous steel curtain when closed. The assembly should have a maximum depth of 4 in. and be suitable for horizontal or vertical airflow as required. Fire and smoke control dampers should meet or exceed NFPA 91 (NFPA, 2010). Fire dampers installed in ducts with either dimension under 12 in. should be constructed and designed so that the damper blade in the open position will be completely outside the airstream.

Unless required by a local code, the use of fire dampers in hood exhaust ducts or hazardous (toxic) exhaust systems is not recommended by the International Mechanical Code or by NFPA-91.

33.4.3 Sheet-Metal Access Doors

Hinged-type sheet metal access doors are needed in the ductwork at each automatic damper and control device and at each fire damper to give access to the fusible link. Access doors should be of the same material as the ductwork on which they are installed and should be constructed to be sealed airtight.

33.4.4 Flexible Connections

The inlets and outlets of exhaust fans should be connected to ductwork with UL Class 0 or 1 flexible, airtight connectors for noise and vibration suppression. Those in outdoor locations should be constructed of suitable materials.

33.4.5 Sealing Duct Penetrations

Wherever ducts pass through walls, floors, or partitions, the spaces around them should be sealed for smoke transmission control with metal, mineral wool, or American Society for Testing and Materials (ASTM)/UL-certified filler materials and be of equal fire rating as the construction it penetrates.

34

VARIABLE-AIR-VOLUME SYSTEMS

34.1 INTRODUCTION

Variable-air-volume (VAV) ventilation control concepts are now a well-accepted design concept for installation in all types of laboratory HVAC systems. The more complex the system becomes and the greater the variety of functional demands made on it, the more desirable the special features of VAV is. In addition to almost unlimited flexibility of function, worthwhile energy savings over the useful life of the system more than fully compensate for a higher installation cost. The less-desirable aspects of VAV controls are the much greater complexity of the HVAC system, especially the sensors and controllers, and the difficulties associated with establishing and maintaining correct functionality over many years. Unlike people, mechanical systems do not get better as they grow older. A cautionary note is that all VAV systems are not the same. Some perform better than others in specific circumstances. In addition, their successful performance depends heavily on an understanding of how they work and what constitutes effective maintenance and providing consistent maintenance.

A very significant increase in system complexity occurs when laboratories and laboratory service areas must be maintained constantly at preselected pressure gradients relative to surrounding indoor spaces as well as to the out-of-doors. Maintenance of preselected differential room pressure gradients at all times when using VAV systems means that the controllers for each space must regulate both supply and exhaust air simultaneously over the entire demand range. This means, for example, that when one 6-ft chemical fume hood exhausting 1000 CFM is reduced by a VAV system in a high-toxicity laboratory, which must be maintained at a negative pressure relative to surrounding laboratories, offices, and public spaces to prevent spread of contamination, the laboratory air supply must simultaneously and automatically decrease by 1000 CFM. Or, if the hood is kept on, but the sash is lowered to a work opening of 1 ft, the supply and exhaust air volumes must both decrease simultaneously by 600 CFM. Modern well-designed VAV systems have successfully provided this level of control.

Yet additional levels of complexity are introduced into VAV control systems when (1) building code requirements set a minimum number of hourly air changes that must be met regardless of whether any of the local exhaust systems are in service; and (2) preset heating, cooling, and humidity needs must be satisfied. To function well, some systems of this nature demand high-tech computer programs that incorporate continuous feedback and rapid modular adjustment capacity. Again, modern well-designed VAV systems have successfully provided this level of control.

VAV systems can be described as either general comfort ventilation or contaminant control ventilation. VAV systems for general ventilation have been in use for several decades; therefore, more data are available on their performance and operation. The main focus of

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this chapter is the use of VAV systems for contaminant control. They may consist of (1) a single-exhaust fan with hood sash control or variable-speed motor to provide 100 fpm over the full range of sash opening, (2) two or more hoods in a laboratory with individual exhaust fans with controls, or (3) multiple hoods on a single-exhaust variable-speed fan with many VAV boxes delivering variable supply air to the laboratory as hoods go on and off and providing the required pressure relationship with other laboratories, corridors, and offices.

34.2 VAV HOODS

A VAV hood is a misnomer, even though this terminology is frequently used. Hoods are not VAV. They are connected to a VAV system. VAV hoods can be any of the chemical fume hoods described in Chapter 32, Sections 32.2 through 32.6, except that they will not generally have a bypass. The main concept is to provide a constant face velocity (usually 100 FPM) across the hood face opening by varying the volume as the hood opening is changed. When the flow is decreased, the operating costs are reduced.

To determine when a VAV system is applicable to a given situation, one must fully understand the advantages and disadvantages of these systems.

34.2.1 VAV System Advantages

Some of the advantages of the VAV chemical fume hood exhaust systems are as follows:

1. They reduce energy utilization by varying the air volume with respect to demand and by facilitating the installation of centralized heating and cooling energy recovery.
2. They reduce the number of exhaust fans. By combining hoods in a central system, one can reduce the need to one or two large central fans.
3. One or more central fans can be installed as a backup to provide continuous ventilation if the other fans fail. In this manner, some ventilation is guaranteed to all fume hoods at all times. If one installs a single fan to a fume hood, there will be no ventilation in that fume hood when the fan fails.
4. As the number of fume hood stacks is minimized, those remaining can, with less expense, be increased in height to reduce the possibility of reentry of exhaust contaminants into the building. Also, the effective stack height is increased as the mass of the exhaust increases. Architectural treatment can be provided to make them less conspicuous and to integrate them with the building design.
5. If a bypass damper is provided at the inlet side of exhaust fans on the roof, the air exhausted can be diluted, thereby minimizing the chemical concentration of the air exhausted.
6. As more fume hoods are connected, the concentration of a particular chemical will be diluted.
7. Because the total number of hoods in use at any time is estimated to be no more than 30–35% (Lentz, 1989; Moyer, 1983, 1987; Phoenix, 2000), the central mechanical system can be reduced in size for cost savings.
8. Reducing the number of individual stacks increases usable floor space and reduces the need for shafts.
9. In a small laboratory with a large number of fume hoods, but not all of which are used at all times, a VAV system may allow reduction of makeup air supplied in the laboratory. (See Chapter 2, Section 2.3.5 on diversity.)
10. Because the exhaust fan is usually located some distance from the laboratory, there is less noise.
11. Systems can be made more flexible for future hood installations.

34.2.2 VAV System Disadvantages

The disadvantages of a VAV system are as follows:

1. Mixing incompatible chemicals in the exhaust stream may result in an unsafe situation. This is highly unlikely given the relatively low concentrations of materials in most hood exhaust streams, but nonetheless should be considered. It should be noted that unusually hazardous or toxic exhaust streams might require a separate exhaust system because of special requirements for filtration, duct materials, and/or fire or explosion protection (e.g., radioactivity, perchloric acid).
2. When the control equipment used is a hot-wire anemometer element in the exhaust stream, it may be hazardous with certain chemicals being exhausted. Additionally, the element may become corroded and nonfunctional.
3. Operation of VAV systems requires active researcher participation to achieve potential airflow and energy reductions by closing hood sashes when they are not loading or working in a hood. If the sashes are not modulated, the airflow and heating/cooling savings will not be realized.

It is difficult to condemn or recommend any one approach. The present generation of automated controls

can make a manifold system of multiple exhaust hoods connected to one fan system work. Such was not the case some time ago when reliable controls were not available.

34.3 GOOD DESIGN PRACTICES FOR VAV SYSTEMS

1. The hood should have no air cleaning (HEPA or charcoal) or stack sampling devices in the exhaust system. (For example, stack sampling is done with high-level radiation hoods and biological cabinets have HEPA filtration). Varying the volume may interfere with the operation of this equipment or the monitoring technique.
2. The hood should have no high-velocity, low-volume spot exhaust systems on the same exhaust fan. This type of equipment is generally designed for a fixed volume and may not function well when the volume of flow is decreased.
3. The laboratory will remain under negative pressure with respect to the corridor or adjoining rooms even at the minimum exhaust rate, if negative pressure was part of the original laboratory design. When the exhaust quantity is reduced, the supply air quantity must be reduced by the same volume.
4. The minimum exhaust flow rate through the hood will be 10–25 CFM/ft^2 of hood work surface (ANSI Z9.5, section 6; ANSI, 2012).
5. There are a few extenuating circumstances based on hood or laboratory use that preclude the use of a VAV system. Examples of these circumstances might be (a) odorous emissions, and (b) excessive heat generation from process equipment or high-release compounds that require full exhaust rate dilution. All of these conditions might produce unacceptable conditions if the exhaust volume is reduced.
6. VAV permits the laboratory air volume to be reduced. We have seen instances in which a variable-volume system has been installed to meet minimum laboratory airflow requirements and the system is operated at full flow at all times. This is a waste of energy as well as the initial cost of the equipment.
7. Airflow monitoring and alarm devices must be installed at the hood to provide operating information to the hood user.
8. An override capability may be provided to allow the user to have maximum exhaust regardless of sash position.
9. User training is important. The hood user should know that the hood is a VAV hood and understand how it operates.
10. Control response time and stability should be reviewed to provide consistent repeatable performance. A response time less than 3 s after the completion of the sash movement is considered acceptable for most operations. Faster response times may improve hood containment after the sash movement, but may not be necessary (ANSI Z 9.5, section 6; ANSI, 2012; Exberg, 2000).

34.4 VARIABLE-VOLUME EXHAUST SYSTEM OPERATIONAL CONCEPT

The concept here is to maintain a constant face velocity at the fume hood sash at varying sash openings while varying the total volume of exhaust flow. A modulating damper or controller in the exhaust duct that is connected to the fume hood does this. The control systems used are classified into three types: (1) velocity measurement in the ductwork, (2) velocity measurement of the hood in the annular space between the outside and inside casing, and (3) direct sash position measurement.

The measurement of velocity pressure is difficult in the exhaust ductwork. The air velocity typically is very low, with correspondingly low-velocity pressure. In addition, the devices may become corroded when the exhaust stream contains material that will attack the sensor. Care is advised in the selection of in-duct sensors.

Air velocity measurements in the annular space have greatly improved recently; several commercial devices are now available to maintain constant fume hood face velocity. They are sensitive to changes in airflow patterns in the room as well as in the hood.

Varying the sash position works as follows: It could be connected by a cable to a potentiometer or other control system that transmits a signal to the volume control that opens or closes the damper as required, thus increasing or decreasing the total volume flow in proportion to the face opening. There are some devices that are excellent and some that are not. Care should be exercised in selecting the method of controls. In all cases, the signal controls a damper in the exhaust ductwork to ensure that the correct air quantity is being discharged from that one fume hood. The control systems can be either pneumatic or electronic. Electronic control systems have improved and are continually being upgraded to provide better control capabilities. Hence, we recommend an electronic control system.

The damper in the exhaust air or terminal box must be selected carefully. All moving parts in the damper will come into contact with the contaminated exhaust air. The damper should be either a stainless steel damper with Teflon bearings or a coated damper. The damper can be either a simple barreled plate damper or a more elaborate terminal box. Refer to Chapter 29, Section 29.5.1, which discusses terminal boxes. A terminal box is recommended because it has better control devices and has been in use long enough to demonstrate that it provides consistent results. However, it takes more space, so in cases where space is an issue a damper must be used.

34.5 VAV SYSTEM CONTROLS AND COMPONENTS

Control systems, in their simplest manifestation, consist of two pans, a sensor, and a control device. A sensor is a device that responds to changes in physical condition (such as temperature or pressure) and transmits a signal to a control device, an item of hardware that responds to changes in the sensor signal by restoring the measured environmental conditions (in this case quantity of airflow) to correspond with the sensor's set point.

34.5.1 Terminal Box

Many different methods and controls are available for VAV systems, and their selection will depend on the complexity of the systems. Terminal boxes are a necessary part of a VAV system. Refer to *HVAC Systems and Equipment* (ASHRAE, 2012) for a description of the principle and a discussion of the types of terminal boxes.

Briefly, the term *terminal box* commonly refers to a factory-made assembly for air distribution purposes. This terminal box, without altering the composition of the treated air from the distribution system, manually or automatically, fulfills one or more of the following functions: (1) controls the velocity, pressure, or temperature of the air; (2) controls the rate of airflow; (3) mixes airstreams of different temperatures or humidities; and (4) mixes, within the assembly, air at high velocity and/or high pressure with air from the treated space.

The types of terminal boxes can be classified as follows:

Volume Response

- *Constant Flow:* A constant flow of air is always provided.
- *Variable Flow:* The volume of air is varied as needed.

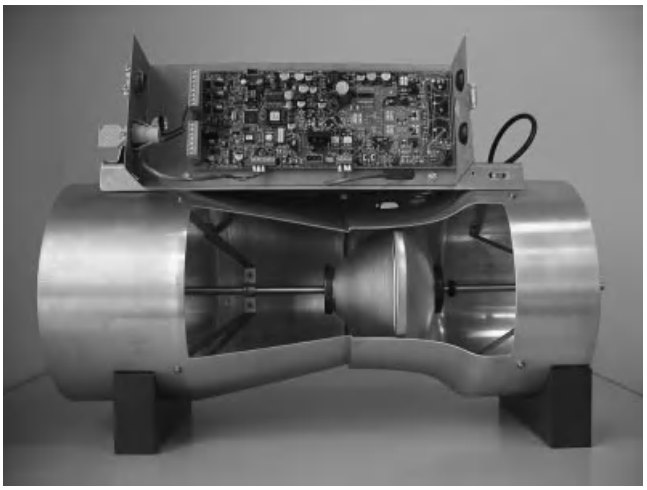


FIGURE 34-1. View of spring cone variable air volume terminal box. (Courtesy Phoenix Controls, Acton, MA.)

System Pressure Response

- *Pressure Dependent:* Airflow through the terminal box varies in response to system pressure.
- *Pressure Independent:* Airflow does not vary.

Method of Control

- *Self or Internal or Mechanical Volume Control:* No outside source of power is needed. Terminal box volume control is activated by the static pressure in the primary duct system.
- *External Volume Control:* An electric or pneumatic actuator is the power source. It consists of (a) velocity pressure or differential pressure sensors, (b) pneumatic or electric motors, and (c) linkages.

Commonly used boxes in laboratories are

Actuator Spring and Cone Type: This is usually a pressure-independent VAV terminal box with electric or pneumatic actuator control (see Figure 34-1).

Spring and Cone Type: Same as above, without an actuator, but with integral springs.

Butterfly Damper: This is a pressure-dependent, external power box and it requires an additional sensing system to function.

Box Type: The box is usually insulated. The inlet is usually round, and the outlet is rectangular. Care must be taken in the installation of box-type terminal boxes. When they are installed in return-air ductwork, it is a common mistake to pipe in the rectangular side (see Figure 34.2).

FIGURE 34-2. Box-type terminal box. (Courtesy Nailor Industries, Inc., Houston, TX.)

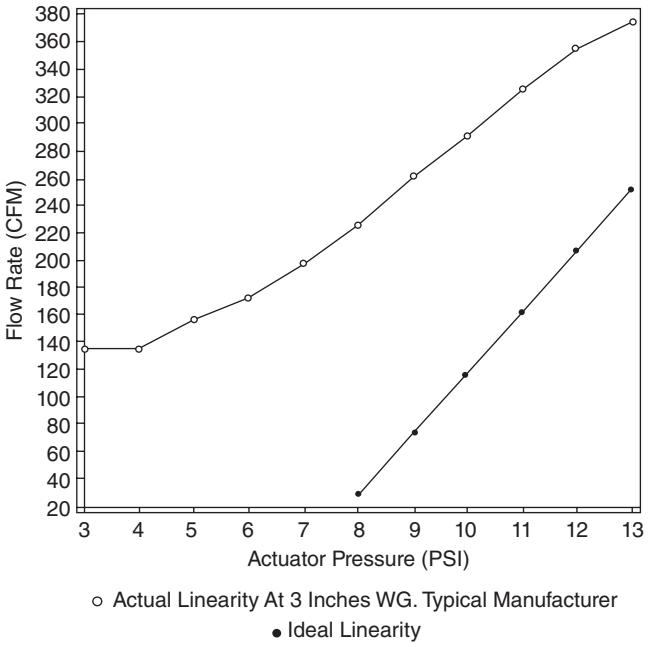


FIGURE 34-3. Linearity graph showing ideal versus actual for typical terminal box.

34.5.1.1 Terminal Box Issues. Krajnovich (1986) initially described the major issues that must be considered when selecting terminal boxes. These are

1. Linearity refers to the relationship between the actuator pressure (controlled by the sensor) and the flow rate. Without linearity, control becomes difficult. Figure 34.3 shows the ideal versus typical linearity achieved in field use.
2. Hysteresis is a measure of the difference in terminal box performance when increasing the input versus decreasing the input. Figure 34-4 illustrates an example of hysteresis. A small value of hysteresis is imperative for consistent operation. A large hysteresis value yields two vastly different output values for identical input values.
3. VAV terminal boxes must provide the necessary maximum airflow as well as maintain health and safety standards at the minimum airflow requirements of the exhaust system. In addition, temperature, humidity, and pressure balance must be maintained. It is important in selecting a terminal box that design linearity, hysteresis, and pressure independence characteristics are met for consistent trouble-free operation. Boxes should be corrosion resistant and factory calibrated. They should also be designed to be insensitive to inlet and exit conditions.
4. In addition, adequate consideration must be given to response time and stability for a VAV hood control system. Initial work by Ahmad (1990) provides an excellent discussion of the response time. Similarly, Avery (1992) describes the reasons for the instability of VAV systems. These issues have been subsequently confirmed independently by work done by Phoenix Controls (1999, 2010) and others.

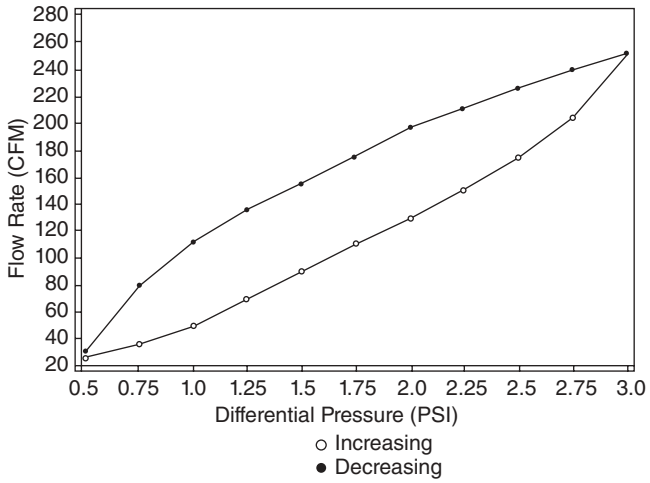


FIGURE 34-4. Graph showing hysteresis for terminal box.

The manufacturers of VAV terminal boxes have been addressing these issues. The current generation of the equipment is much more reliable and consistent. The user must carefully evaluate every aspect of the equipment specified for the project to ensure that all requirements are met.

34.6 VAV SYSTEM FAN CONTROLS AND COMPONENTS

In a VAV system, the volume modulation can only occur when the supply or exhaust fan is controlled by one or a combination of methods. It is important that both supply and exhaust fans are controlled to ensure that the fans continue to operate at the stable region of each fan curve. The control system consists of two parts: a sensing system and fan control hardware.

34.6.1 Sensing System

The sensing system usually measures duct static pressure at a location. The location (based on duct layout) is typically between 75% and 100% of the distance between the first and last air terminals (Figure 34.5). This control point static pressure is also called *reference static*. Care must be taken in selecting the reference static sensor location. Multiple static sensors (Figure 34.6) are required when more than one duct runs from the supply fan. The sensor with the lowest static requirement will control the fan to meet the set point. Selection of either a single-point sensor or a multiple-point sensor depends on the duct distribution layout. The sensing element (pneumatic, electric, or electronic) transmits a signal to the controller, which actuates the fan control hardware.

34.6.2 Fan Control Hardware

Many devices are available for controlling the fan for volume modulation. Some are more complex, more expensive, and more efficient than others. The selection of the particular control system is based on the end result required. The following options are described in *ASHRAE Handbook–HVAC Systems and Equipment*, Chapter 20 (ASHRAE, 2012).

- Fan inlet or discharge dampers
- Fan scroll or inlet box dampers
- Fan inlet vanes
- Fan runaround or scroll bypass
- Controllable pitch blades
- Variable speed

34.6.3 Fan Inlet or Discharge Dampers

Either parallel or opposed blade dampers are provided in the fan inlet or discharge duct. This option is fairly inexpensive, but not very energy efficient; the noise levels could be objectionable. The basic principle is to cause the fan to ride back on its curve, which results in reduced fan horsepower and energy consumption. The design engineer must be aware of the potential instabilities of certain fan types (e.g., forward-curved blades) so that when the volume of air generated by the fan is varied, it still operates within the stable region. In general, fan inlet or discharge dampers are easy to install and are low-first-cost items.

34.6.4 Fan Scroll or Inlet Box Control

Inlet box dampers may be used to control the airflow volume through the system. Either parallel- or opposed-blade types may be used. The parallel-blade type is installed with the blades parallel to the fan shaft so that in a partially closed position, a forced inlet vortex will be generated. The effect on the fan characteristics will be similar to that of inlet fan vane control, although it is less noisy. The opposed-blade type is used to control airflow volume by changing the system pressure through damper manipulation.

34.6.5 Inlet Vane Control

Variable vanes mounted in the fan inlet can be used to modulate airflow. They are arranged to generate a forced inlet vortex that rotates in the same direction as the fan impeller (prerotation).

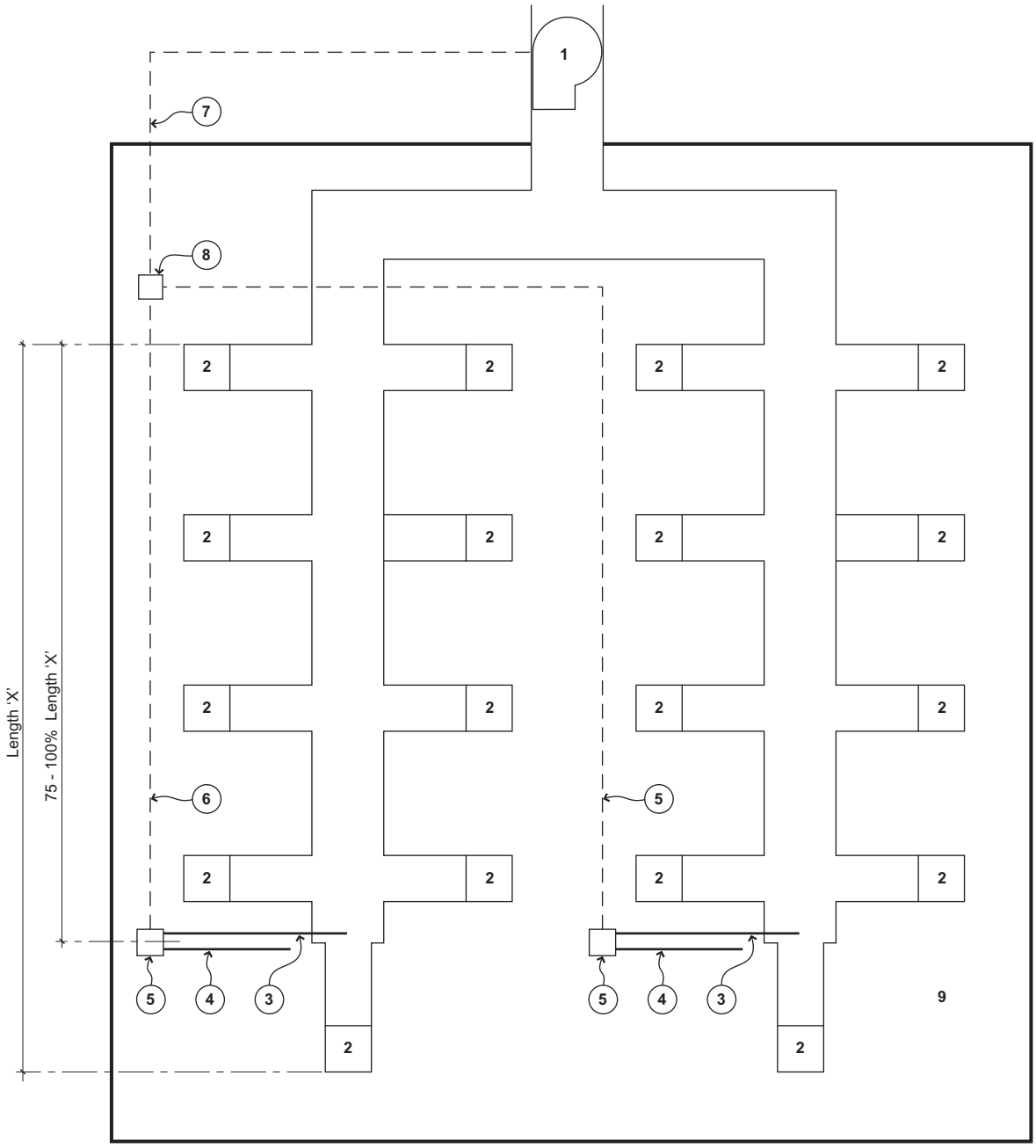
Inlet vanes may be of two different basic types: Integral (built in) or cylindrical (add on). This is a very efficient method of fan control. The application, however, is limited to centrifugal-type fans. The system can be retrofitted to existing centrifugal fans. Noise control and energy operating efficiency are within the acceptable range.

34.6.6 Fan Runaround or Scroll Bypass

A bypass duct arrangement with dampers is provided across the fan. The fan handles a constant flow, but the system flow is varied. This approach is usually not recommended. Even though the system flow can be varied, there is limited energy savings.

34.6.7 Controllable Pitch

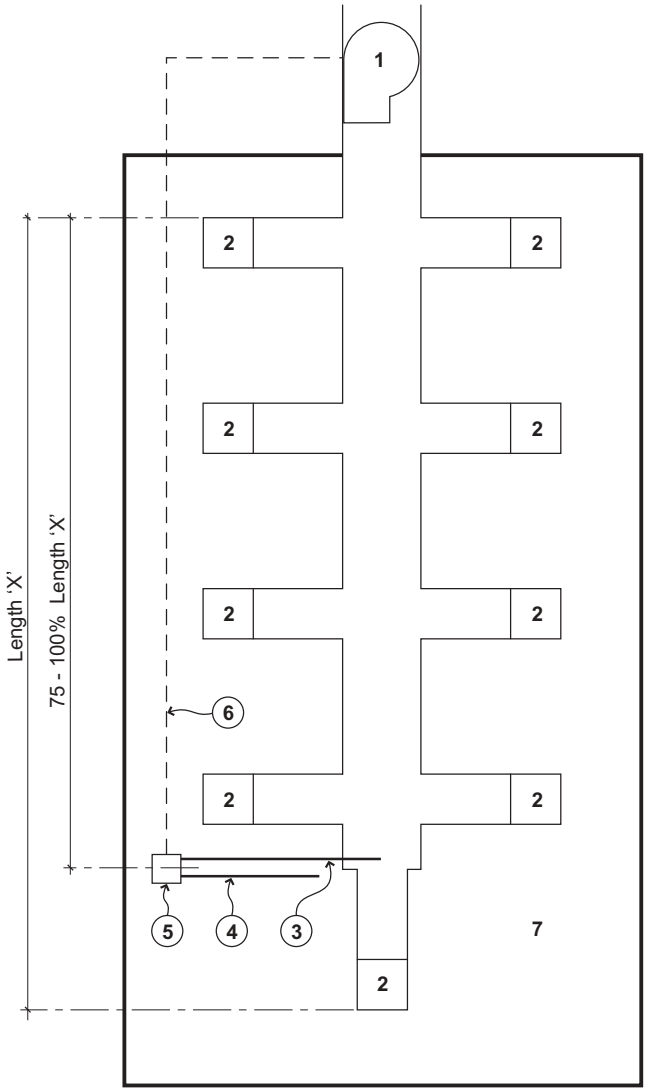
This is usually applied in vane axial fans. The pitch of the blades is varied by an actuator connected to a gear assembly that is capable of rotating the fan blades within a prescribed limit. This is a fairly efficient system. However, it is limited to vane axial fan systems. Care should be taken to ensure that the fan only operates in its stable region; otherwise, destruction of equipment is very possible. This option usually cannot be retrofitted.



KEY

1 Supply Fan
2 Air Terminals
3 Duct Static Monitor
4 Reference Static Monitor
5 Control
6 Control/Fan Link
7 Laboratory

FIGURE 34-5. Duct static control diagram with single sensor.



KEY

1 Supply Fan
2 Air Terminals
3 Duct Static Monitor
4 Reference Static Monitor
5 Control
6 Control/Selector Link
7 Selector/Fan Link
8 Selector
9 Laboratory

FIGURE 34-6. Duct static control diagram with multiple sensors.

34.6.8 Variable Speed

By varying the motor rpm, the speed of the fan is changed. This approach has also matured. There are many options for achieving true variable speed. Initially discussed by Branda (1984), the options include

1. Adjustable voltage inverter (AVI)
2. Pulse width modulator (PWM)
3. Adjustable current sensor inverter (ACZ)
4. Wound rotor slip recovery system
5. Eddy current drive
6. DC motors

There are various advantages and disadvantages to each option. A variable-speed drive is the most efficient manner in which to control the fan speed and thereby to increase or decrease fan capacity. However, it requires (1) availability of manufacturer support for the spare parts, and (2) trained technicians for start-up and maintenance. Before a specific application, the engineer should thoroughly review the various systems available and then make a choice. The variable-speed drive is electrically a nonlinear load. Damaging electric harmonic currents may result. Chapter 1, Section 1.5.5 should be consulted. New Institute of Electrical and Electronics Engineers (IEEE) and National Electrical Manufacturers Association (NEMA) standards should also be consulted.

34.6.9 Selecting the Fan Control Method

The selection of an appropriate fan control method is very complex. The following points should be considered: (1) first cost, (2) retrofit or new application, (3) efficiency of operation, (4) type of fan, (5) availability of spare parts and trained technicians, and (6) noise levels. The matrix shown in Table 34.1 has been provided to aid the user in selecting the fan controller. The electrical power consumption and relative efficiency of several fan control options are shown in Figure 34.7. The content of Figure 34.7 is summarized in Table 34.2 adapted from Goode (2000).

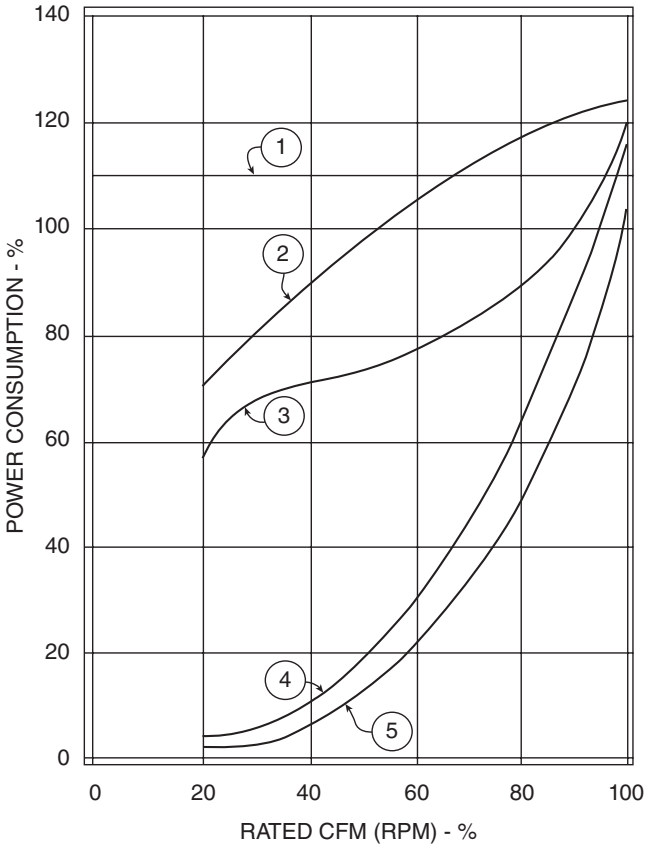
34.6.10 Occupancy Sensors

An occupancy sensor in front of a hood can easily sense the presence of a researcher. This signal can be used to operate a VAV hood in a 100% operation mode or "occupied" mode. The exhaust quantity goes to maximum designed for the hood. Similarly, when a

TABLE 34-1. Comparison of Fan Features, Performance Factors, Cost, and Maintenance

Fan Control	First Cost	New	Retrofit	Efficiency	Centrifugal Fan	Axial Fan	Service and Spare Parts	Noise
Fan inlet or discharge damper	1	5	1	4	1	NA	1	5
Fan inlet vanes	3	1	2	3	NA	NA	2	2
Fan runaround or scroll bypass	2	2	NA	5	1	NA	3	3
Controllable pitch	3	4	5	2	NA	1	4	2
Variable speed	1	1	1	1	2	2	5	1

Note: 1 = most recommended; 5 = least recommended; NA = not applicable.



KEY
1 Constant Volume
2 Outlet Damper
3 Variable Inlet Vane
4 Variable Speed Drive
5 Centrifugal Fan Curve

FIGURE 34-7. Power consumption efficiency for various fan control Methods.

researcher is not present in front of a hood it can be assumed that the hood is not in use and the exhaust quantity can be reduced. To reduce the exhaust to a minimum value, researchers should be trained to pull the sash down when they are not using the hood.

TABLE 34-2. Relative Energy Savings for Several Fan Control Options

Variable speed controller	Highest
Controllable pitch vane axial fans	↓
Inlet vane control for centrifugal fans	↓
Inlet or discharge damper control	↓
Constand volume run around	Lowest

34.6.11 Chemical Sensors in the Laboratory

Chemical sensors capable of sensing chemicals in low quantities are installed in the laboratory. When the concentration of those chemicals is within acceptable limits the air change rate per hour (ACH) in the laboratory can be reduced. Conversely, higher concentrations will increase the ACH in the laboratory. Care must be taken that this does not give a false sense of security. A thorough evaluation of all the chemicals to be used must be made in order to evaluate the ability of the sensors to provide adequate warning of a release of the chemicals of interest, that is, those that can cause adverse effects. Also, the location of the sensors is important in order to detect increased concentrations in time to provide a warning. The challenge is to be able to detect when the lab worker is breathing elevated levels of a chemical.

34.7 VAV SYSTEM DUCT CONFIGURATIONS

Goode (2000) provides an excellent discussion of this subject. It is summarized as follows. VAV systems normally use a centralized duct system to connect all of the exhaust hoods, grilles, and localized exhaust points (also known as elephant trunks and snorkels) to a central exhaust fan. However, limitations on equipment size and the desire for redundancy may dictate the selection of multiple fans connected to a common header to provide the required supply or exhaust airflow capacity.

As mentioned in Section 34.2.1, a diversity factor can be applied to the sizing of the equipment and the main riser ducts. However, diversity can be difficult to achieve

in laboratories because it depends on the discipline of the research staff to lower hood sashes when the hoods are not in use. If the sashes are not lowered, the exhaust and supply air volumes cannot be reduced, and there would then be no gain from diversity.

Goode (2000) recommends that the main riser ducts can be sized for a velocity as high as 3000 fpm and the main horizontal branch ducts with a maximum velocity of 2000 fpm. These are typical velocity guidelines that can vary depending on the acoustic sensitivity of the occupants and the construction materials used for the shaft walls and ceilings.

NFPA-45, "Fire Protection for Laboratories Using Chemicals" (NFPA, 2011) prohibits the combination of exhaust ducts from different "laboratory units" until the ducts reach a mechanical room, a shaft, or the outdoors. Therefore, depending on the number of laboratory units on a floor, manifolding of laboratory exhaust ducts may be restricted until they enter the exhaust shaft. NFPA-45 also defines the maximum size of a laboratory unit as a function of the quantity and class of combustible materials stored in the laboratories.

When a laboratory building has varying exhaust flow rates (as a function of use or occupancy), maintenance of a constant discharge velocity of the exhaust airstream from the stacks presents an additional challenge. A high and constant discharge velocity is needed to carry exhaust gases away from the laboratory building and to prevent reentrainment into the air intakes. A constant discharge velocity from the exhaust fans can be achieved either by staging the operation of manifolded exhaust fans or by inducing varying amounts of outside air to mix with the exhaust airstream.

34.7.1 Traditional Duct Distribution System

A traditional duct distribution system consists of the largest duct carrying the largest airflow. Although this approach is very efficient to install and is low in initial cost, it limits flexibility for making future changes in the system. For example, when there is a need to add additional fume hoods in a space this addition may not be possible with a traditional duct distribution system without extensive duct modifications. Ring duct distribution systems, described below, are more flexible.

34.7.2 Ring Duct System

Goode (2000) states that a correctly sized and designed VAV supply and exhaust system should give the building owner the capability to install additional exhaust terminals and to renovate laboratory spaces. The concept of the ring duct facilitates this capability by providing a looped header duct that can be tapped to create a new zone for addition of an equipment room or a laboratory module. Each zone will have its own terminal air boxes that are set for a specific airflow and maintain that airflow regardless of air pressure variations in the duct work (they are pressure independent).

The looped header ducts (supply and exhaust) are usually looped around a central building core. The core contains stairs, elevators, and vertical electrical and mechanical distribution systems. If floor-to-floor height is restricted, the supply duct loop might be located at the core and the exhaust loop might be located at the building perimeter to avoid crossing of the ducts. Each zone connected to the loop has the benefit of receiving or delivering air from the left, from the right, or from both sides of the duct loop. This helps to offset asymmetrical loading. When there is an unusually heavy concentration of laboratory exhaust loads at one end of the laboratory building, the duct loops can satisfy this load from two directions. A conventional duct system (no loop) might run short of capacity.

35

ENERGY CONSERVATION

35.1 INTRODUCTION

The conservation of resources and sustainability should be a fundamental requirement of building design and operation. The book attempts to address these issues in several locations. Chapters 1–4 describe basic conservation concepts in a building, laboratory, or renovation project. Unique sustainability concepts are discussed in Chapter 38. As many of the conservation opportunities are HVAC-related systems Chapter 29, HVAC Systems, and Chapter 34,Variable-Air-Volume Systems should also be reviewed.

The basic premise of energy conservation in laboratories or for that matter any building can be summarized as follows:

- *Shutdown*: Good engineering practice should allow shutdown of laboratory systems when not in use.
- *Optimize*: Optimize systems operation. For example, instead of a constant flow system, use a variable flow system as required.
- *Reduce*: Reduce operation when not required.
- *Recover*: Recover waste energy for useful purposes.

These basic principles are emphasized here as we review various conservation options. Laboratory buildings are energy intensive. Careful control of heating, cooling, lighting, and exhaust systems operation in laboratory buildings results in an environment that is compatible and reduces operating costs.

In this chapter, methods for achieving maximum energy conservation in laboratory buildings are discussed. This chapter should be reviewed during the planning stages of a new laboratory building, during renovation planning for an older building, or if looking for opportunities for energy conservation. The selection of one or another of the methods that are presented here will depend on a number of factors. For renovation projects, these will include age and size of renovation project, available capital and desired payback period, work schedules, and projected building use. For new projects, the geographic location of the building, and the spatial organization of laboratories and building are also important. All considerations for energy saving must be weighed against the need to ensure health and safety of the laboratory personnel and laboratory building equal to or better that the existing conditions. In new construction projects, there is no existing benchmark. Therefore, the professional judgment of the design team must be used.

The discussion of the major areas for potential energy utility conservation is divided into five categories: (1) exhaust ventilation for in-laboratory contamination control by the use of chemical fume hoods/biological safety cabinets, local exhaust points and general laboratory ventilation; (2) lighting; (3) thermal insulation; (4) humidity control, and (5) water use. But first, we will explore recent trends in building energy conservation.

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

35.2 RECENT TRENDS

ASHRAE Standard 90.1 (ASHRAE, 2011) provides a rigorous baseline of energy consumption goals in buildings. These goals are characterized by the energy use index (EUI; BTU/ft^2/year) and are normalized by the weather in the region. Most state energy codes mandate that the building energy use index either meets or exceed that standard.

Net-zero energy buildings have become a goal. Many building designs must beat the ASHRAE 90.1 standard by a certain percentage (refer to Chapter 38, Sustainable Laboratory Design).

Regardless of its contribution towards Global Warming, it is understood by most scientists that manmade CO_2 emissions to the atmosphere should be reduced. Many industries and institutions have adopted goals for carbon emission reduction. Energy conservation has a linear correlation with carbon emission reduction.

In 2007, the American Institute of Architects in collaboration with the U.S. Green Building Council (USGBC) and ASHRAE adopted "The 2030 Challenge" (http://www.architecture2030.org/2030_challenge/index.html). The program challenges the global architecture and building community to adopt the following targets:

- All new buildings, developments, and major renovations shall be designed to meet a fossil fuel, greenhouse gas- (GHG-) emitting, energy-consumption performance standard of 50% of the regional (or country) average for that building type.
- At a minimum, an equal amount of existing building area shall be renovated annually to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 50% of the regional (or country) average for that building type.
- The fossil fuel reduction standard for all new buildings and major renovations shall be increased to60% in 2010, 70% in 2015, 80% in 2020, 90% in 2025, and be carbon-neutral in 2030 (using no fossil fuel GHG-emitting energy to operate).

These targets may be accomplished by implementing innovative sustainable design strategies, generating onsite renewable power, and/or purchasing (20% maximum) renewable or certified renewable energy credit. Because these goals have yet to be achieved with this book's publication, the resolution might be more appropriately named "The 2050 Challenge."

The EPA undertook an initiative to conserve energy in laboratory construction and operation called "Laboratory of the 21st Century". Since its inception in 1999, several workshops have been sponsored and considerable information is available on methods of energy conservation in laboratories on their website (www.epa.gov/labs21century/). In addition, Lawrence Berkeley National Laboratory (LBNL; Berkeley Lab at the University of California, Berkeley) has developed a program to assist laboratory designers to design energy-efficient laboratories (LBNL, 2012).

Although not specifically designed for laboratories, the original Leadership in Energy and Environmental Design program developed by the USGBC (2011) is being modified to develop general guidance on design, construction, and operational methods for sustainability, or "green" laboratories.

In many jurisdictions, local electrical utilities are mandated by the government to offer energy efficiency rebates. These rebates are paid from a fund managed by the utility where a certain percentage of each utility bill from every customer is deposited. The rationale is that conservation strategies reduce overall electrical demand, thereby reducing the need to construct new power plants. A kilowatt saved is always cheaper than a kilowatt generated by a new power plant. It is better to save a kilowatt rather than generate it from a more efficient source of power. In addition, there is now the option to have real-time monitoring of electrical use and demand in a facility. Power can be purchased in realtime and consumption reduced when the power cost is very high, althoughthis is easier said than done. Laboratories have limited flexibility to shut processes or equipment during the daytime when the power cost is the highest. Before embarking on such a strategy, a careful analysis is needed to ensure that laboratory safety systems will not be compromised.

35.2.1 Use of Computerized Control Systems and Modeling

The availability of excellent direct digital controls and inexpensive computers has formulated a change in how buildings are designed and operated. Many of the energy-conserving strategies discussed here are easily incorporated in new computer-controlled buildings.

At a minimum, these programs allow a rapid review of energy usage in the building. A daily, weekly, monthly, and yearly profile can provide enormous information on building operation and potential insight on conservation strategies (see Figures 35-1A–C for examples of energy usage profiles). The Figure 35-1A shows that there is baseline energy use and a variable energy use. For conservation purposes, both need to be reduced. Examination of nightly and weekend energy use may identify systems that could—or should be—shut off or remain operational. Corrective action can then be taken.

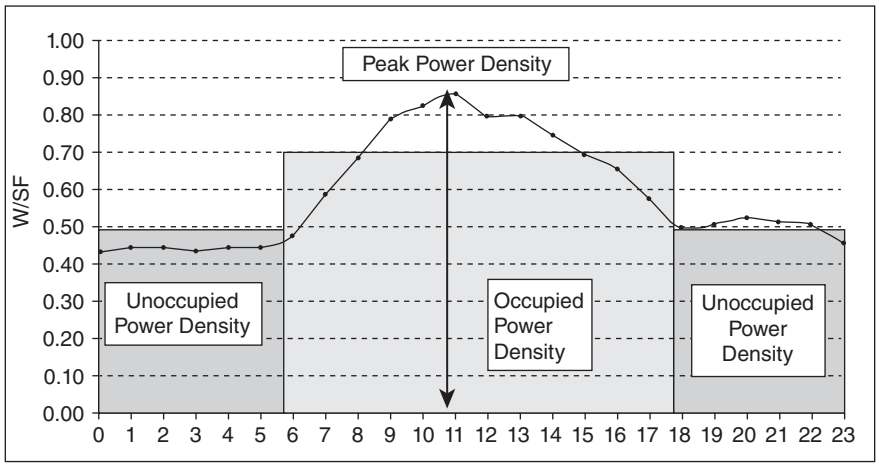


FIGURE 35-1A. Baseline energy usage. (Courtesy: New Buildings Institute [NBI])

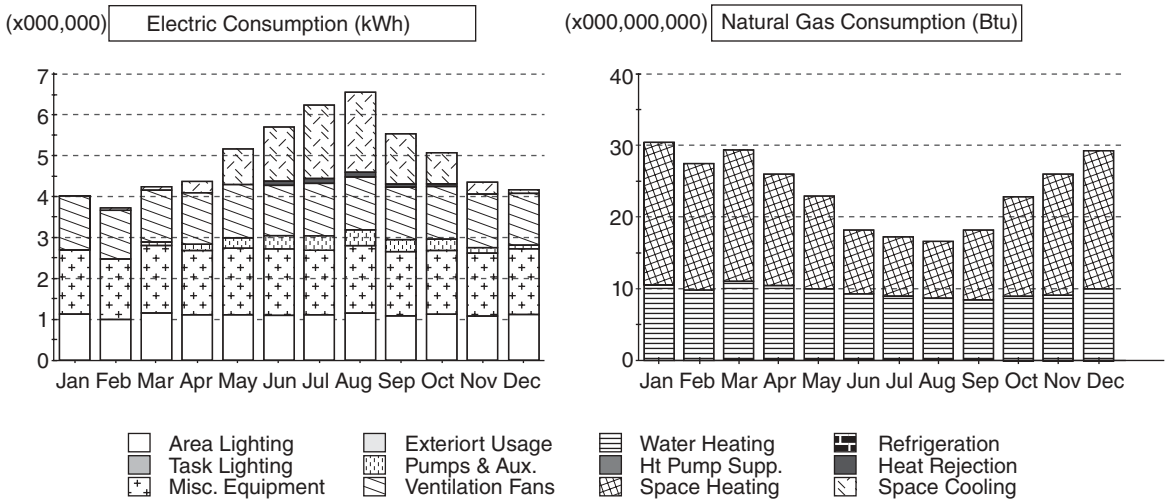


FIGURE 35-1B. Monthly energy use profile. (Courtesy: Cannon Design.)

Figure 35-1B shows the monthly energy use profile for a typical building in North America; Figure 35-1C shows typical end use energy distribution.

Computer programs are also available for simulation or modeling of building operations and provide an excellent tool for evaluating design strategies. There are many such programs available. Table 35-1 shows a flow chart of a typical energy simulation or modeling program. The flow chart describes an example of how it can be used.

A basic program uses weather data from a Weather Library prepared by NOAA (http://www.lib.noaa.gov/) coupled with a description of the building to calculate building heating and cooling loads. The program conducts a systems analysis, which analyzes energy use by systems and generates hourly equipment loads by system. The program then uses a description of the plant to conduct a plant analysis, which determines the fuel demand and consumption for the plant. Using economic data, the program conducts an economic analysis that results in life-cycle cost. The life-cycle cost of various design options can be calculated, compared, and an appropriate option selected.

Examples of design strategies evaluated by computer systems are

1. Analysis of day lighting and glare for different glass and window systems (see Section 35.4 for more detail)
2. Building massing studies to select an optimum configuration
3. Evaluation of HVAC systems to select the most optimum. This is particularly important when various heat recovery options are being evaluated.

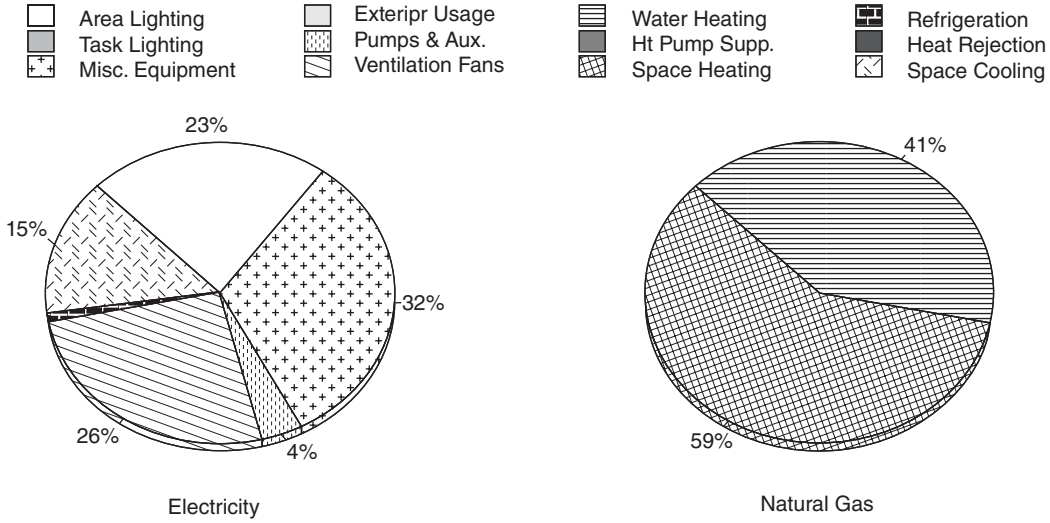
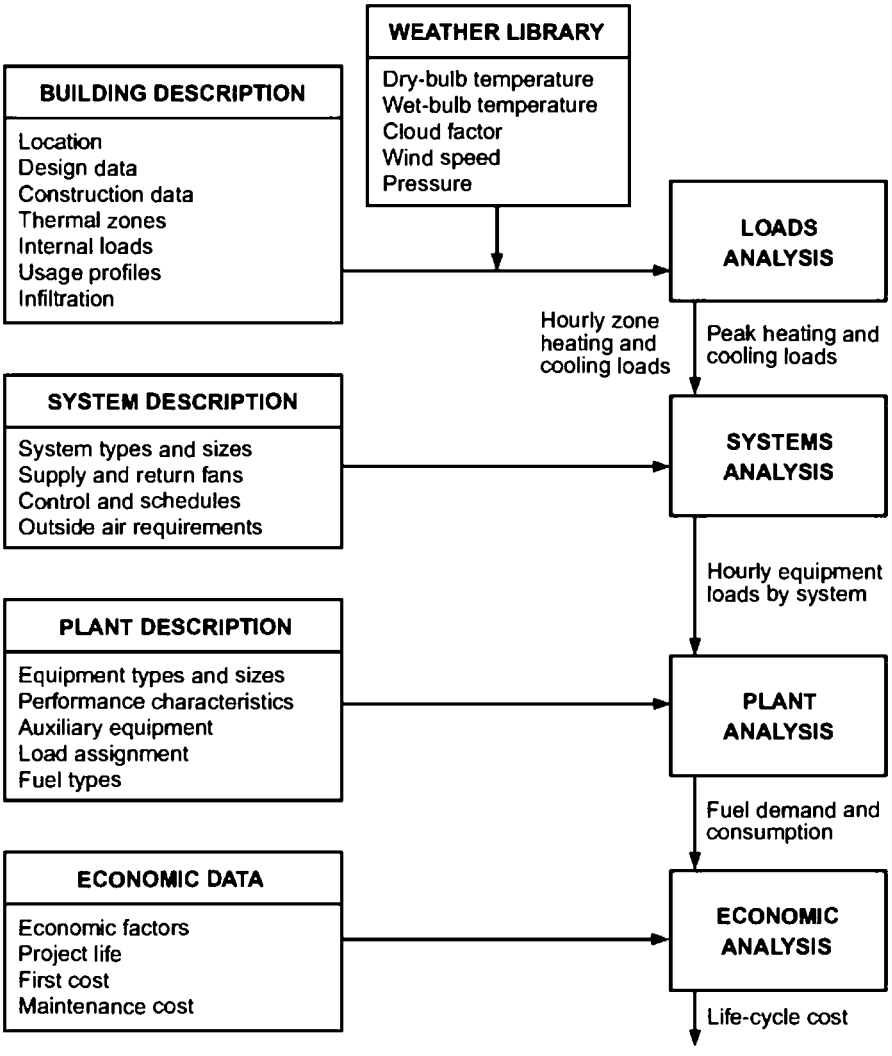


FIGURE 35-1C. Energy end-use profile. (Courtesy: Cannon Design.)

TABLE 35-1. Flow Chart for Building Energy Simulation Program (Ayres and Stamper 1995)



35.3 EXHAUST VENTILATION FOR CONTAMINATION CONTROL

A major operating expense for most laboratory buildings is associated with the operation of chemical fume hoods. It is estimated that laboratory buildings consume three to four times more energy than conventional office buildings. Therefore, major energy savings can be made by the selection of fume hoods that minimize loss of conditioned air. In addition, operational considerations, such as exhaust air quantity and period of operation, play an important part in determining the energy cost of essential laboratory services.

The laboratory chemical fume hood and other contamination control ventilation systems, along with fire suppression equipment, emergency eye wash, deluge shower plumbing, and emergency spill control supplies are the major pieces of safety equipment available to laboratory personnel who must, from time to time, work with hazardous chemicals biological and/or radioactive agents.

Publications by Lawrence Berkley National Laboratories (LBNL) and the EPA/DOE Labs provide significant details on methods to calculate exhaust air energy cost. The website for a fume hood calculator can be found at http://fumehoodcalculator.lbl.gov/. With the input of site-specific data the website will calculate the cost per CFM.

Depending upon the local utility costs, a laboratory fume hood could cost between $3,000 to $8,000 per year on a 24 h/day,7 day/week operation. In any large facility with multiple fume hoods, this cost can be substantial. Therefore, substantial energy savings can be realized by installing the most energy-efficient hoods, and equivalent savings can be realized by installing new hoods in older laboratory buildings (see Chapter 32, Laboratory Hoods and Other Exhaust Air Contaminant-Capture Facilities and Equipment, for a discussion on high performance and ductless hoods. See Chapter 2, Section 3.4 for a discussion on air change rates in laboratories.

35.3.1 Alternative Energy-Saving Methods

Looking at laboratory chemical fume hoods from an energy-conservation point of view, there are seven basic alternatives:

1. Reduce operating time
2. Limit the air quantity exhausted from each hood, including installation of VAV systems or reduce the size of hood
3. Design for diversity
4. Limit hood use
5. Eliminate inappropriate hood use
6. Reduce laboratory air exchange rates
7. Use heat-recovery systems

The advantages and disadvantages of each option from an economic and safety viewpoint are evaluated below.

35.3.1.1 Reduce Operating Time. Many laboratory chemical fume hoods are operated 24 hours a day, 7 days a week. The reasons for this include the fact that laboratory personnel may work in the laboratories at all times of the day and night as well as on weekends and holidays. In addition, volatile hazardous chemicals are stored inside hoods when they are not being used. In fact, a need to continue to vent these chemicals is cited as an important reason for operating hoods in a continuous mode. There are also times when reactions and preparations must be continued in the hood, uninterrupted, for 24 hours or longer.

The philosophy behind reduced hood operating time is that when there is no need for a hood to operate (that is, when no one is working actively in a hood or there is no long-term reaction or preparation taking place), there is no need for that hood to be exhausting the amount of air that it normally does. To reduce operating time when the hood is no longer needed, it is essential either to shut off the fume hood entirely or to lower the quantity of exhaust air. To accomplish this, it is necessary to establish routine working hours when hoods and exhaust points will be fully operational and to establish a procedure whereby legitimate needs during off-hours can be accommodated. It is also necessary to arrange for alternative safe storage for volatile toxic and other hazardous chemicals, including compressed gases for the period the hood is shut down. It is recommended that chemicals are not routinely stored in hoods used for research or forms of experimentation.

It is estimated that laboratory fume hoods can be shut off or their operation significantly reduced at least 50% of the time without serious interference with research and teaching activities. The advantage is that it can provide a large energy savings. There are also disadvantages that must be evaluated carefully, and the plan must be adapted to individual circumstances.

Restricting hood use may mean that it is not available when a user wants to use it. This can be overcome by providing local control—that is, by giving each user the option of turning the hood on whenever it is needed during off-periods. This is best handled by a central building service capability because individual control at the hood usually results in the hood never being turned off. The hood exhaust must also be tracked by the supply

air to maintain the desired directional air flow and pressure relationships in the laboratory.

Hood operation connected to light switches offers another means of control. The assumption is that when the lights are off, the hood is not in use. This assumption is mostly correct. However, there may be instances where an experiment is in process inside the fume hood for a long, continuous period. Researchers may elect to shut lights off when they are not physically present in the room, although the hood must continue to operate.

Motion sensor technology has been applied to laboratory hoods as a means of reducing air flow when no one is working at them (see Chapter 2, Section 2.3.4). Many of these options are now available on a standard basis and the designer has the freedom to integrate them in their energy efficient design and control strategy.

Modern electronic access control systems also provide an excellent hood control option. The access control system can easily keep track of laboratory occupancy. Per access control system, if the laboratory is unoccupied the fume hood can be shutdown.

The need for volatile chemical storage can be satisfied by providing alternative safe storage space for the hood user. This can be achieved in several ways: One way is to use flammable-liquid storage cabinets that meet NFPA, FM, and OSHA requirements. A second way is to provide a separate storage area for nonflammable hazardous liquids that can take the form of (1) a separate, exhausted air storage cabinet; (2) storage under a laboratory fume hood provided with a separate exhaust connection that operates continuously; or (3) storage in a specially designed, passive chemical storage box/cabinet, An initial capital expense will be required to provide these storage box/cabinets for each laboratory. In some cases, there may be impediments due to space limitations and/or competing HVAC requirements in exhausting numerous separate cabinets. Although the air volumes needed to exhaust closed cabinets will be modest (that is, a few cubic feet of air per minute), the Harvard storage box requires no ventilation because of its charcoal filter.

However, when a hood is shut off there may be reverse flow through the hood into the room if the building becomes negative to the atmosphere, particularly in warm weather when thermal updraft may not be present. In this case, the presence of toxic materials in the hood could result in a hazardous situation.

A troublesome problem associated with reduced hood operating time is maintaining adequate air balance within the laboratory and the building. Many buildings have one supply system for the entire building or for each large group of laboratories. The difficulty in maintaining correct pressure relationships when hoods and exhaust points are shut down (that is, maintaining laboratories negative with respect to corridors and maintaining hazardous areas more negative than nonhazardous areas) may be difficult to overcome in certain types of buildings and in laboratory wings of multifunctional buildings. This matter must be evaluated closely for renovations. In most cases, a modulating air supply system that responds to changes in exhaust air demand will be needed. It is possible to resort to a two-step supply air system on the assumption that not more than a few hoods will be operational during off-hours; therefore, the normal building requirement for outside air will provide sufficient supply air for the few exhaust facilities in operation.

The safety problems associated with reduced hood operating time are encompassed in the points discussed above, the primary one being provision of alternative storage for hazardous materials.

There is also some potential to reduce the operating time of some biological safety practices, particularly those that recirculate air back into the laboratory. One reason these cabinets are kept running 24 hours a day is the perception that this is needed to keep the work environment within the hood sterile. Depending on the kind of work being conducted, this may not be necessary. It may only require the cabinet to be turned on an hour or so before experimental procedures are to start. This must be decided on a case by case basis and the cabinet manufacturer and researchers should be consulted for advice. However, there is an opportunity for energy savings here and as we gain more experience with doing this the researchers comfort level may increase.

35.3.1.2 Limit the Air Quantity Exhausted from Hoods. The basis for limiting hood air quantity is that under past good practice conditions, the exhaust air requirement was based on the largest possible hood opening. The largest possible opening is usually the length of the work surface of the fume hood times the height of the fume hood opening when the sash is in the fully raised position. However, the maximum possible hood opening can be reduced in two ways:

1. Limit the height of the vertical sash opening. If, for example, under normal conditions, the laboratory fume hood sash can be raised 30 in., the exhaust air requirement must be designed for that full opening. If, however, it were arranged that the sash could only be raised 20 in., there would be a one-third savings in the amount of air to be exhausted. This method of reducing the hood face opening may present a problem to hood users because it restricts access to the upper part of the

hood. To overcome this restriction, it is possible to equip the hood with an alarm system so that when the sash must be raised above 20 in. for short periods to allow installation and construction of apparatus within the hood, an alarm, both audible and visual, will be activated to let the hood user know that the hood is not in a safe operating mode. When the sash needs to be above 20 in. for longer periods, the audible alarm may be turned off, but as soon as the sash is lowered to or below 20 in. or after a period of usually 30 minutes, the alarms will be reset and become available to respond whenever the hood sash is raised above 20 in. Twenty inches is an arbitrary height for the sash alarm; it can be varied depending on the needs of individuals. In some cases, less height may be needed, whereas in others, the full opening may be required at all times.

2. Limit the hood opening by the use of a horizontal sliding sash rather than vertical sliding sash. Usually, at least three panels of horizontal sliding sash are used. At any given time, for a chemical fume hood with four panels, only one-half of the full width of a hood is open and only the open area needs air flow. About 50% energy savings can be realized by this hood design. A frequently encountered problem with this type of hood sash is nonacceptance among hood users used to working with the more-conventional vertical rising sash. A distinct advantage of the horizontal sliding sash over restricting the height of vertical sash is that users can still get to every part of the hood, although they have to move the sash horizontally to do so. An added safety benefit of the horizontal sliding sash is that it provides a safety shield that users can work behind by placing their arms around it. From a safety point of view, certain designs produce disruptive air currents at the edges of the horizontal sliding sash, and this must be corrected. Unsafe conditions can be created by the ease with which the horizontal sliding sash can be removed from the hood. A method for monitoring and ensuring that the sash remains in place is needed. Some manufacturers provide a combined sash, a vertical sash with horizontal sliding safety glass panels within. This offers an additional feature for safe fume hood usage.

Significant energy conservation opportunities are possible with a variable-air-volume (VAV) system. A full discussion of options plus advantages and disadvantages is contained in Chapter 34.

A variable-volume exhaust system modulates a damper in the exhaust duct or uses a variable-volume fan to adjust exhaust quantity to demand. The systems are discussed in more detail in Chapter 2, Section 2.3.4.4.6 and Chapter 34. The variable-fan-speed system may be a single-hood variable-speed fan or a multiple-hood exhaust system with an infinitely variable-speed fan instantly responsive to changes in hood demand.

Use of a two-speed motor (though normally not used in the United States, but may be popular elsewhere) makes it possible for a hood to be switched to low speed when not in active use, thereby reducing the volume of air exhausted. As discussed in Chapter 34, it is also necessary that the makeup air be modulated simultaneously to ensure a negative pressure in the laboratory at all times.

Duty cycling of laboratory exhaust systems creates very unsafe conditions and should *not* be used for energy conservation purposes.

Additional methods to reduce air quantity exhausted from hoods are

1. Substitute local point exhaust systems for conventional hoods. Certain applications do not require a laboratory chemical fume hood. A local point source of exhaust air fits over such devices as gas chromatographs and may be located on laboratory benches where limited quantities of toxic chemicals will be used. The advantages of local exhaust points are that they exhaust far less air than a conventional hood, even when the face opening is restricted; and that the open end can be directed to capture contaminants at the source of generation. One of the disadvantages is that they are usually designed for specific applications. When different applications are called for, they are sometimes difficult to adapt successfully. In addition, they do not provide the protection that a fume hood does in terms of containment of spills or protection from small explosions or fires (see Chapter 32, Section 32.10for a more complete discussion of alternative local exhaust devices).
2. Use of multispeed fans to limit air quantity, though used in past, are no longer used as variable-speed motors are readily available. At high speed, a fan will provide enough exhaust air to give the design face velocity across the entire open face of the hood, but when the hood is not in use and the sash is lowered, the fan will go to a lower speed, only one-third to one-tenth full speed, and exhaust just enough air to prevent escape of vapors from the materials or equipment left in the work space. This air volume will be very much less than what is needed when the hood is in full use.

Various alarm systems have been designed and are commercially available to inform the hood operator of potential unsafe conditions. A similar concept is to install a device that locks the sash closed when the hood is not in a safe operating mode.

35.3.1.3 Design for Diversity. The concept of diversity is discussed in Chapter 2, Section 2.3.4.6. It has been successfully applied in several research and academic facilities (Rock, 1996a; Phoenix, 2012).

Studies (Lentz, 1989; Phoenix, 2012) have shown that the number of fume hoods in use at any given time in a research facility is significantly lower than the installed number, the exhaust air volume is therefore reduced. Consequently, there is an opportunity to reduce the total installed exhaust and supply air volumes to conserve chase and shaft space as well as air-tempering equipment. Care must be taken, however, not to block a future expansion of activities and people by undersizing equipment significantly. This is also not applicable when all hoods in a facility may be used at the same time, e.g., a teaching laboratory.

35.3.1.4 Limit the Volume of Conditioned Air Exhausted from Hoods (Auxiliary Air Hoods). Auxiliary air hoods are laboratory chemical fume hoods that supply a major part of the total exhaust air volume from a dedicated supply air duct located above the work opening of the hood, with the remainder coming from the general room supply air. Up to 70% of the air that the hood exhausts is provided at the face of the hood, and the remainder is provided by the building supply air system.

These hoods still exist in many buildings, but are not presently installed in new installations and are not recommended as energy-saving devices.

35.3.1.5 Limit Hood Use. Similar to the description in Section 35.2.1, in large laboratory buildings containing numerous fume hoods, it has been found that even in the normal occupied hours the number of fume hoods in operation at any one time is fairly small. Studies (Lentz, 1989; Moyer, 1987, Phoenix, 2012) indicate that only about 30–50% of available hoods are in use at any one time during the day. The criteria for assessing hood use were that someone was working at the hood, or an experiment was being conducted inside the fume hood.

The lower percentage of hood use suggests the following opportunities for conservation.

Whatever system is used for controlling exhaust air volume, there must be a minimum ventilation rate in occupied laboratories to provide comfort and safe conditions and a minimum airflow through the hood to kept any flammable vapors from reaching 25% of the lower explosive limit (see Chapter 2, Section 2.3.4). Therefore, no matter how low the exhaust air requirements from laboratories become, sufficient supply air must be provided (and removed) to maintain approved air exchange rates and still maintain the desired pressure relationship.

35.3.1.6 Eliminate Inappropriate Hood Use. In many laboratories, the fume hoods are rarely used for anything other than storage of chemicals or equipment.

This is a very energy-wasteful practice. Chemical storage cabinets are much less expensive in terms of both first cost and operating cost. Many items of equipment often found in hoods, such as gas chromatographs, could be provided with a bench-mounted local exhaust point at the gas outlet port instead of locating the entire unit in a hood. If a piece of equipment must be in a ventilated enclosure, then one designed for specific application should be constructed following the design guidelines in the *Industrial Ventilation: A Manual of Recommended Practice for Design, 27th Edition* (American Conference of Governmental Industrial Hygienists [ACGIH], 2010).

The research director as well as the contractor and entire design team should discuss real needs frankly and in detail. Often, immediate needs can be reduced when space is provided for the future installation of additional fume hoods.

If the design or operating air exchange rate is based upon a defined number rather than heating or cooling requirements and contaminant control exhaust needed, then it should be explored as a potential area for energy savings. See Chapter 2, Section 2.3.4.1 for additional discussions on this issue.

35.3.1.7 Heat-Recovery Systems. Heat-recovery systems use some type of heat exchanger to extract heat from the exhaust air stream in winter and use the recovered heat to partially warm the incoming air. The reverse cycle is applied in warm climates. The application of this type of system must be evaluated on a case-by-case basis because the climate in the area of contemplated use may not lend itself to a useful amount of energy savings with these kinds of systems. It should be kept in mind that, although a worthwhile savings may be calculated for days of extreme temperature excursion, such days are often too few each year to pay back the cost of the installation plus the energy cost associated with operating the heat-exchanger system. The additional pressure drop introduced by all these devices leads to increased horsepower requirements that must be considered in the economic analysis. In addition, maintenance and repair requirements when recovering heat

TABLE 35-2. Methods Available for Air-to-Air Recovery

	Run-Around Loops	Heat Wheels	Heat Pipe Systems	Plate Heat Exchangers	Air-to-Air Exchangers	Heat Pumps	Chemical Regenerators
Space	Minimum	Significant height required to accommodate heat wheel	Significant	Significant	Significant	Usually not an issue	Significant
ROI (Return on investment)	Very good	Good	Good	Poor	Good	Good	Poor
Energy usage	Additional energy used for recalculating pumps	Reclaims both sensible and latent energy	No additional energy used for operation	No additional energy used for operation	No additional energy used for operation	Requires compressor operation	Additional energy used for recalculating pumps
Needed proximity to supply and exhaust air	NO	Yes	Yes	Yes	Yes	No	No

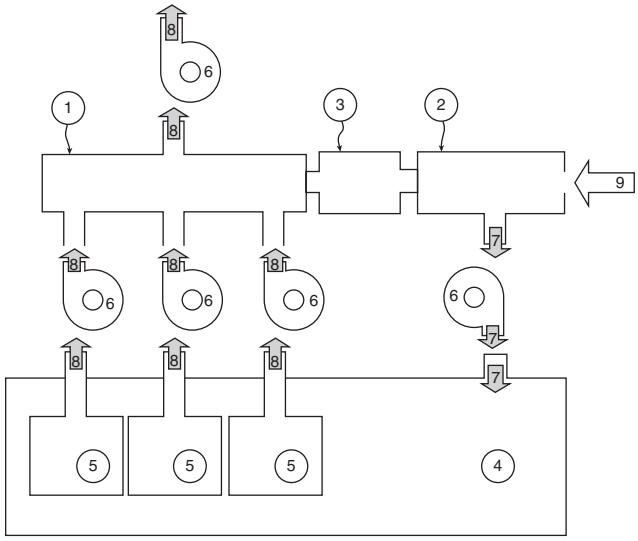
from laboratory exhaust air tend to be higher than normal.

Because laboratories are thought by some to be energy wasteful, some administrative codes, e.g., ASHRAE 90.1 (ASHRAE, 2010) mandate heat recovery from laboratory exhaust systems even though small temperature differences make heat recovery inefficient thermodynamically.

Methods available for air-to-air recovery are run-around loops, heat wheels, heat pipe systems, plate heat exchangers, heat pumps, chemical regenerators, and air-to-air exchangers (not acceptable in laboratories because of contamination and other problems). See Table 35-2 for an overview of these methods.

Most heat recovery system installations require the exhaust and supply air streams to be near each other to be cost effective. In many buildings, this proves to be challenging. For example, the exhaust is always at the roof level. It is desirable to locate the air intake as far away from the exhaust as possible to minimize reentry. Figure 35-2, originally adapted from Carnes (1984) and later reproduced extensively, shows how some options have been accomplished. The example shows dedicated exhaust fans from a fume hood discharging into an exhaust plenum. This could easily be adapted to a VAV exhaust fan system.

ASHRAE *Laboratory Design Guide* (McIntosh, Dorgan, & Dorgan, 2001) provides a good description of some of these systems, giving their advantages and disadvantages.



KEY

1 Exhaust Air Plenum
2 Make-up Air Plenum
3 Heat Recovery System
4 Buiding
5 Fume Hood
6 Fan
7 Make-up Air
8 Exhaust Air
9 Fresh Air Intake
□ Clean Air
■ Contaminated Air

FIGURE 35-2. Diagram of a typical multiple fume hood recovery system.

35.3.1.7.1 Run-Around Loops. Standard fin-tubed water coils installed in the supply and exhaust airstreams are connected via piping. A pump circulates a water, glycol, or thermal fluid solution. The intermediate circulating solutions transfer energy between exhaust and supply airstreams. The coils must be constructed to suit the environment and operating conditions to which they are exposed. The effects of condensables and corrosives may require specialized materials or coatings. A three-way valve provides the control. The system is shown in Figure 35-3.

35.3.1.7.2 Heat Wheel. A heat wheel is a revolving cylinder filled with an air-permeable medium. The medium may be selected to recover sensible heat only or sensible and latent heat. The medium should be reviewed with the properties and contaminants of the airstreams involved. A typical unit is shown in Figures 35-3 and 35-4. Some air carryover from the supply side to the exhaust side is possible.

The wheel as the name implies is a large wheel impregnated with an absorbent media placed in outside air and exhaust airstreams. It rotates slowly. When the outside airstream is cooler than the exhaust stream, it allows the moisture from the exhaust stream to be absorbed in the media. As the media comes in contact with the outside air, it releases moisture in the colder outside air by providing humidification and heat transfer. Conversely, when the outside airstream temperature is higher and perhaps more humid than the exhaust airstream, it cools and dehumidifies the outside airstream.

To be most effective, heat wheels should be installed before a cooling coil in the air-handling system. This will allow maximum heat recovery potential. They also should be installed in a "blow through" mode, i.e., the supply fan pushes air through the heat wheel. This allows any air leakage around the heat wheel to be only from un contaminated supply air.

The ASHRAE Standard 62.1, "Ventilation for Acceptable Indoor Air Quality" (ASHRAE, 2011) clarifies which exhaust stream can be passed through the heat wheel. In general, hazardous fume hood exhaust is not recommended for use in heat recovery. The

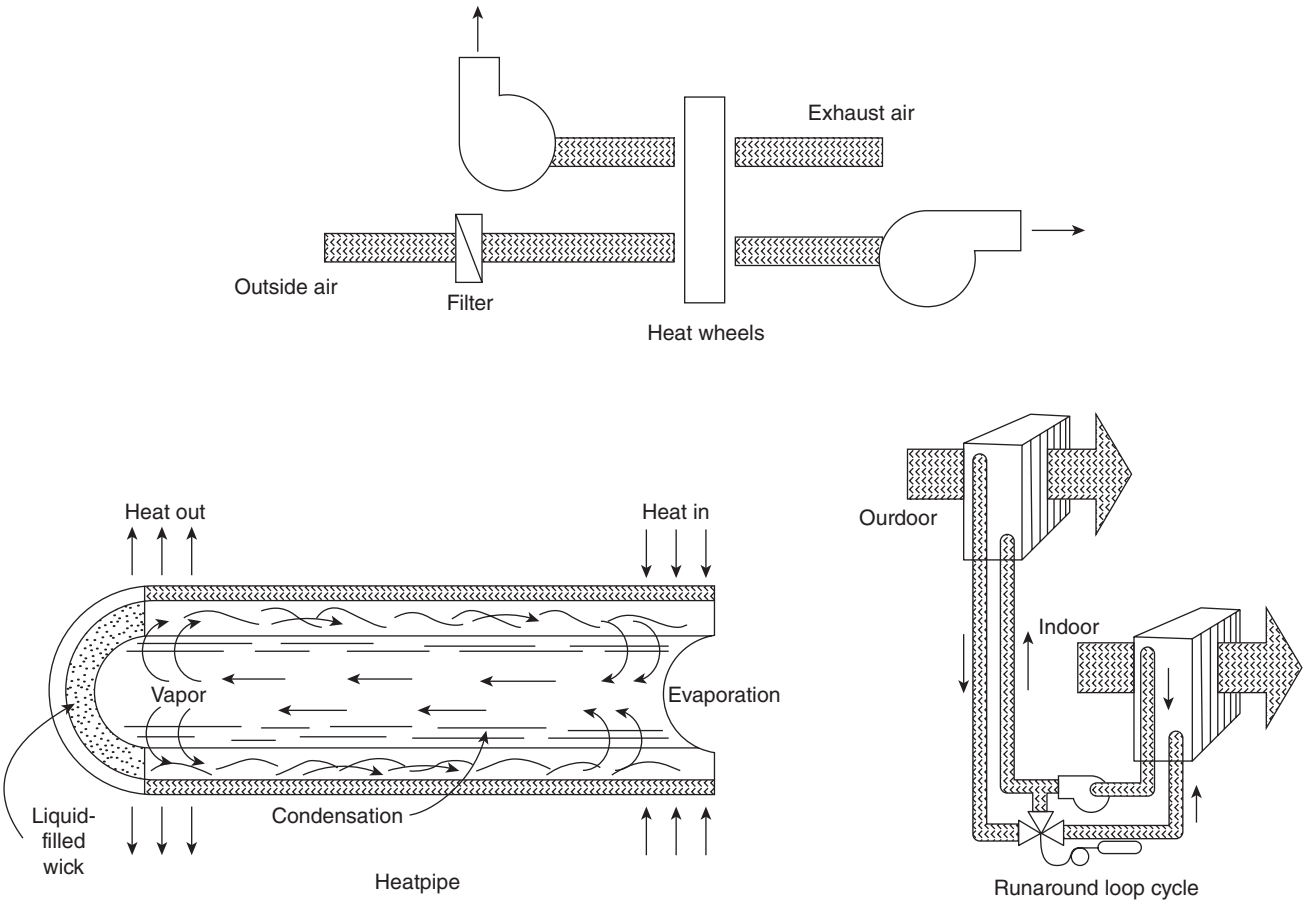


FIGURE 35-3. Heat recovery from exhaust airstream.

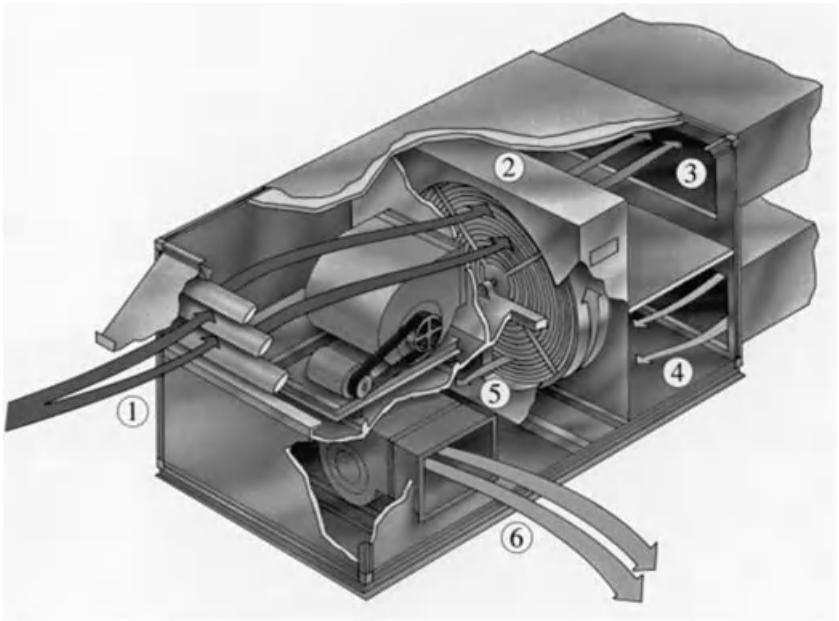


FIGURE 35-4. Typical heat wheel. (1) Fresh outdoor air (hot and humid) is passed through the wheel. (2,3) Outdoor air is cooled, dehumidified, then supplied to HVAC system. (4) Exhaust air is pulled from the space (cool and dry). (5,6) Exhaust air is heated and humidified, then sent outdoors. (Courtesy SEMCO.)

potentially contaminated exhaust air and supply air are only separated by the wheel and its seal; hence, air leakage is possible.

A heat wheel is a continuously rotating mechanical piece of equipment, which means components such as the electric motor, wheel deflection, bearings, belt, and drives require careful selection and maintenance. The seal design should ensure minimum leakage. The inspection and maintenance processes should assess for loose parts. A careful acceptance process must be undertaken to ensure problems are not present and each of these components are working properly.

Performance requirements and tests must be established before any system selection is made. Performance tests should include a tracer gas challenge to measure the amount of leakage. Allowable leakage should not exceed a value agreed upon by all client stakeholders and the manufacturer. It must be a value than can accurately be measured by the performance test chosen. Procedures for yearly maintenance and some routine testing should also be established. Performance tests with a tracer gas challenge should be conducted at a specified frequency. The recommended frequency will depend upon the type of wheel, the degree of hazard potential in the exhaust, and manufacturer recommendations. It could be as frequent as yearly.

35.3.1.7.3 Heat Pipe. The heat-pipe heat-exchanger device is also called a thermosiphon. The exchanger consists of a tube that is fabricated with a capillary wick, filled with a refrigerant, and sealed on both ends. Thermal energy applied to either end of the sealed pipe causes the refrigerant at that end to vaporize. The refrigerant vapor travels to the other end of the pipe. At this end, removal of thermal energy causes the vapor to condense into liquid, giving up the latent heat of condensation. By action of the capillary wick, the condensed liquid flows back to where it was originally vaporized, completing the cycle.

Each heat pipe operates in a closed-loop condensation-evaporation cycle. The heat pipe exchanger appears very similar to the standard HVAC coil, except that each tube is not connected by return bends and headers. Each individual tube of a heat pipe operates independently from the others. The exhaust airstream passes over one end of the heat pipe, and the makeup airstream passes over the other end. A sealed partition normally separates the two airstreams, minimizing cross-contamination. They do require significant floor space. The system is shown in Figure 35-3.

35.3.1.7.4 Plate Heat Exchangers. As the name implies, plate heat exchangers consist of plates that provide

stationary channels in which exhaust and makeup air (supply air) pass adjacent to each other. Heat transfer takes place through the plates. No secondary heat transfer media are used.

35.3.1.7.5 Heat Pumps. In a direct-expansion heat-pump refrigeration system, the evaporator and condenser sections can be reversed. This allows exhaust and supply airstreams to pass through either the condenser or the evaporator. In the winter, the exhaust airstream passes over the evaporator and releases its heat to the refrigerant. Heat is transferred into the supply air on the condenser side. In the summer, the reverse occurs.

35.3.1.7.6 Chemical Regenerators. Chemical spray headers are installed in both supply and exhaust air streams. The chemical is usually lithium bromide (LiBr). The chemical becomes the heat-transfer medium. This heat transfer medium transfers heat and/cooling from exhaust to supply airstreams (see Figure 35-5).

35.3.2 Special Considerations for Biomedical Laboratories

Before heat recovery systems can be implemented in biomedical laboratories, certain special requirements must be addressed:

1. In some cases, the exhaust air must be incinerated to eliminate the danger of biological contamination.
2. The exhaust air from animal areas must be carefully filtered to eliminate animal hairs, food particles, and so forth, before it enters a heat recovery device.

35.3.3 Selection of Air-to-Air Heat Recovery System

The selection process for any type of air-to-air heat exchanger requires a thorough analysis of the costs associated with (1) equipment purchase and installation, (2) equipment operating and maintenance costs, (3) steam and chilled water consumption, and (4) capital deferrals. If buildings are served from a central steam and chilled water generating plant, the present-worth cost of a future central utility plant expansion should be applied for the capital deferral values.

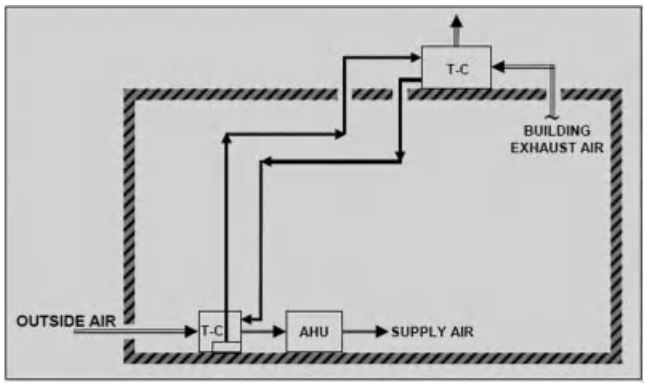


FIGURE 35-5. Example of a chemical regeneration system.

Only sensible heat-transfer devices are recommended. Stationary plate exchangers provide good separation between makeup and exhaust streams, but they are heavy and bulky and are difficult to build for large installations. In addition, they have only a 40–60% range of efficiency. Coil run-around systems have good potential when makeup and exhaust streams are physically remote. However, the range of effectiveness is also only 40–60%. A nonregenerative heat pipe in a coil configuration can be more effective, ranging from 60% to 70%, and the airstreams are isolated from each other by a center baffle or separator, preventing cross-contamination. Liquid LiBr systems are not used for laboratory air heat recovery because they are unlikely to avoid contamination of the incoming air. Energy modeling described in Section 35.2 provides a quantitative analysis of these options. Table 35-2 can provide a guide to analyze these options.

35.3.4 Conclusions

It can be seen that there are several alternatives that may be applied to realize energy savings when dealing with laboratory chemical fume hoods. There is no single answer as to which may be the best method. In many cases, a combination of methods may be required, particularly in new buildings. In retrofitting or renovation of older buildings, it may be difficult to apply some of the methods that have been reviewed; therefore, each situation must be evaluated as a unique problem. This factor must be evaluated carefully, including consideration of (1) providing additional storage space, (2) acceptance by laboratory personnel of restricted operating time, and (3) use of different types of laboratory fume hoods.

The issues that must be evaluated to make the best decision include the following:

1. Potential to adversely affect the health and safety of occupants
2. Cost of retrofit for each of the alternatives
3. Acceptance by hood users of a variety of restrictions that may be placed on hood use
4. Effect of each alternative on the functioning of the building HVAC systems, on the comfort of the occupants, and on the type of work that must be

conducted in the laboratory fume hoods within each building

5. Future building expansion or possible change in program should also be considered

Any program that seeks to alter the traditional use of laboratory chemical fume hoods must include a detailed education and training program for laboratory personnel that will include information on how a laboratory chemical fume hood operates, what restrictions, if any, are being placed on its use, and how the restrictions may affect their research activities.

35.4 LIGHTING

A reduction in the energy required for lighting can be accomplished in laboratories by using task lighting at desks, laboratory benches, and workstations. The use of energy-efficient fluorescent tubes and ballasts, along with multiple switching, within a laboratory building will also conserve electrical energy. Lighting should be maintained at the levels outlined in Chapter 1, Section 1.5. Lighting is an area where energy savings can be accomplished. The exact light level needed for various laboratory tasks is still controversial. Wherever possible, natural lighting should be used. It is therefore easy to overlight or underlight a specific area. Light levels on bench tops, in equipment rooms, and in storage areas should be reviewed.

Use of day lighting to eliminate electrical light usage in daytime or when ambient lighting is high is a very effective strategy. In Chapter 38, Sustainable Laboratory Design, we describe some specific strategies. Computer simulation of building operation can provide an evaluation of day lighting; a glare analysis for different fenestration systems and configuration provides an optimum solution.

Automatic light switching using occupancy or motion sensors can be very effective. Use of occupancy sensors in bathrooms is recommended to ensure an occupant is not left in the dark should the automatic system switch off the light. Another method is to shut lights off based upon building occupancy schedule. There are several novel ways for lighting control. The key here is to select a system that is reliable and simple to use, otherwise there are no savings. Override switches can provide local lighting when lights are normally off. Such switches are highly recommended as they allow the safe operation of a laboratory during a normal "unoccupied" period.

In recent years, there has been tremendous progress in efficient light source and lighting fixture design. An efficiently designed light fixture will transmit most of the light to the working surface and less loss.

Light sources have also progressed and more options are available to designers. Incandescent lights are very energy inefficient and their use should be discouraged. Compact fluorescent bulbs provide attractive cost-effective alternatives. T-8 and T-5 type lights with high-energy efficient ballasts are readily available. LED- (light-emitting diode-) based light fixtures can provide equivalent light intensity, but with very limited use of electricity.

A team effort with all building users and designers is recommended to ensure that an attractive, energy-efficient, easily maintained light fixture is selected. Careful attention to light fixture location should be paid; in general, light fixtures parallel to laboratory benches are more efficient.

35.5 THERMAL INSULATION

This energy-conservation measure is very effective for residences, but is not as useful for laboratory buildings because the heat transferred through the structure is a small fraction of the energy expended through ventilation, air-conditioning, and contamination control ventilation. Nevertheless, the energy savings achievable through the use of good building thermal insulation are worthwhile and should be realized. Solar heat loads through windows are particularly troublesome for laboratories. Thermal windows with low-E glass are desirable in almost all climates for south and west building exposures. Good-quality thermal windows will also prevent condensation occurring on the inside surface in winter. More details are contained in Section 35.6.

35.6 HUMIDITY CONTROL

Needs for humidity control should be considered carefully to avoid condensation during cold weather. It will require the control point to be lowered in some cases (Hermans, 2000) although it is desirable to maintain conditions as close as possible to 30–40% RH. Should extensive condensation occur, there is a potential for mold growth and damage to the building structure. The American Architectural Manufacturers Association (AAMA) has established condensation resistance factors (CRF) for newly manufactured windows that seek to limit RH in cold climates. Recommended levels of RH are based on a tight, well-insulated multipane window with a CRF of 54 (Hermans, 2000). The RH setpoint for the space should be reset to this schedule when windows with a CRF rating higher than 54 are used; set points can be raised. For winter temperatures above 20°F (–7°C), spaces should be maintained between 30 and 40% RH.

35.6.1 Winter Humidity Control

To maintain desired humidity in winter, moisture must be added to the air, and this is also energy-intensive. Air humidification methods are reviewed in Chapter 18. Recently, there has been much debate on the minimum relative humidly in the spaces. To meet a 30% standard in the winter, owners have documented that the expense is too great and difficult to maintain. Considerations are underway to reduce this minimum to 20% (ASHRAE, 2010).

35.6.2 Summer Humidity Control

Hermans (2000) recommends an upper limit of 60% RH. Maintenance of extremely close humidity tolerances or exceptionally low humidity in summer means intensive use of the air-conditioning system because the usual method for reducing humidity in the air is to subcool it to reduce the moisture content and then to reheat it to the required room temperature. Because this process is an enormous energy consumer, it should be avoided wherever possible.

35.7 EVAPORATIVE COOLING

Evaporative cooling is another energy-conserving process. For more details, see Chapter 50 in the ASHRAE *Handbook: HVAC Application* (ASHRAE, 2011). This method may be very appropriate in certain climates and should be considered.

35.8 WATER CONSERVATION

Laboratories and their support systems use a lot of clean, quality domestic water for drinking, sanitary (toilets, cage, and bottle washing) and other process needs. Conservation practices must be undertaken to conserve this resource. Some of the approaches are similar to those used for energy conservation, namely, identify where it is being used, reduce waste, and recycle wherever possible. Some specific strategies follow.

- *Reduce domestic water usage* by installing low-flow toilets, urinals, etc. Modern toilets and urinals use very little water compared with older units. In some cases, state plumbing codes mandate the use of these fixtures. In existing buildings, units may be retrofitted to reduce water consumption or may be replaced with newer water-efficient fixtures. If a retrofit of existing fixtures is selected, the toilet fixture design should be reviewed to ensure that it can flush solid matter even with the reduced water flow. If solid matter removal is not complete, the user will double or triple flush, negating any potential water saving.
- *Reduce processed water usage* by eliminating water-to-waste systems. Some laboratory equipment is city water cooled. Instead, these systems can be connected to either a chilled water system or to a closed water loop cooled by a dedicated heat rejection device. In older facilities, such water-to-waste systems are very common and present a great water-saving opportunity.
- *Reduce building systems water usage*. Many water-based HVAC systems use a lot of water. For example, cooling towers connected to a chilled water system have a large water basin with overflow prevention controls. When these controls malfunction, the tower sump basin will overflow. As these towers are located in less-frequented areas, many times such overflow conditions can go undetected for a long time, resulting in substantial waste. By careful monitoring of water usage in building systems such situations can be prevented.
- *Reuse wastewater where possible*. A common term for this type of water is "gray water." An example is the use of reject water from a "pure water" production system. The reject water can be reused for some purposes. Similarly, last-rinse water from cage or bottle washers can be collected and used as "first rinse" in the next cycle. In areas where water is scarce or very expensive, use of gray water for toilets, irrigation, makeup water for mechanical systems, or other nonpotable purposes is common practice. Waterless urinals have been used in many areas to reduce flush water usage.
- In some areas, sanitary waste from a laboratory is cleaned in a water-treatment station. The effluent can be used for irrigation and other processes. Depending upon the nature of the treatment process, the effluent may even be of drinkable quality.
- *Collect rainwater*. A common practice required by LEED certification. The rainwater is collected from roofs and ground surfaces. This rainwater can be used for almost any purpose. The quantity is dependent on the local weather conditions.

35.9 EFFICIENT OPERATING STRATEGIES

35.9.1 Utility Metering

In many facilities, utility use is not metered but should be. Even submetering of large utility-using functions

should be considered. Present metering technology provides an inexpensive method to monitor various utilities usage routinely around the clock. By monitoring usage during unoccupied periods previously undetected losses and other sources of waste can be identified.

35.9.2 Continuous or Ongoing Commissioning

Chapter 37 describes the building acceptance and commissioning process. These processes are utilized to ensure the building or the project meets its intended design goal. There is also another need to ensure the building or project continues to perform as designed. Computerized energy management systems (EMS) or building management system (BMS) provide that opportunity in a very cost-effective manner. Trend logs of various control points can be analyzed to detect any aberrant mode of operation. For example, in an air-handling unit simultaneous operation of preheat coil (which indicates low ambient temperature requiring heating) and cooling coil (which implies high ambient temperature requiring cooling) is most undesirable. There are many systems available whereby the output of EMS or BMS is analyzed regularly and corrective work orders can be generated for the building operating staff. Modern buildings have complicated safety strategies integrated with building system operation. If those systems are not operating correctly, some of the safety strategies just may not be available when needed.

PART V

ADMINISTRATIVE PROCEDURES

It is important for laboratory owners and responsible technical directors to understand the construction and design process to be sure that they have made their needs abundantly clear even though the preparation and evaluation of bidding documents will ordinarily be conducted or supervised by a knowledgeable and experienced professional architect or engineer for all but the most trivial of projects. When it comes to the matter of acceptance, it is essential that all the technical laboratory directors participate in a detailed examination of every aspect of the construction and furnishings that are about to become their personal work environment and that of the support staff; they leave this final task solely to a third party at their own risk.

Also included in this Part is the subject of sustainable design. Although many aspects of the subject are highly technical, the design decisions that must be made with regard to sustainability are administrative in nature and readily understood by administrators and laboratory directors. These individuals can directly affect the safety and comfort of the occupants and owners' costs for many years. It is very important that proposed project scope modifications in the value engineering process be examined carefully by all interested parties. In some instances, after initial cost estimates are received from contractors, drastic cutbacks will be recommended. Some may seriously damage the project's integrity if adopted. There is a tendency for ornamental architectural features such as coved ceilings, expensive case work, and an impressive facade to be retained in the project, while compromises tend to be made in the wear resistance of the interior structural elements, the adequacy of the ventilation and temperature control systems, safety and other essential building services. It is tempting for administrators and owners to allow such compromises because the architectural features are very visible, whereas the mechanical and electrical systems will be hidden above the ceiling or behind the walls. Such temptation should be resisted.

The project specifications should include good definitions for project commissioning as well as for documenting all operating and maintenance requirements. There are several excellent guidelines. ASHRAE Guidelines 0 to 3 provide an excellent resource material and can be very helpful in preparing this information.

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

36

PROJECT EXECUTION AND BIDDING PROCEDURES

36.1 GUIDING CONCEPTS

36.1.1 Introduction

The intent of this chapter is to provide a brief guideline to the steps to be taken from the inception of a project to its completion. The methodology described is by no means mandatory. It only provides a framework for the principles that can be applied in other methodologies for successful project execution.

36.1.2 Building Committee

For large projects, many owners form a high-level building team or committee responsible to a chief executive officer or a board of directors. This group is responsible for setting the goals and objectives for the project, approving budgets, space assignments, securing financing, etc. In smaller projects, such a group may not be needed, but it is necessary to have a person or persons who can describe a client's needs and requirements. It is critical that health and safety professionals have an opportunity to review any budget modifications (resulting from value engineering, defined later in Section 36.1.7), which may have an effect on the health and safety considerations of the occupants, and/or impact risk management.

36.1.3 Project Director

The project director is directly responsible to the administration and/or building committee for the success of the project. Any attempts to dilute the authority of the project director generally end up costing time and money. The designation of such a person commits the owner to a dedicated implementation of the project. The project director is selected by the owner. It could be an outside expert under contract or an in-house high-level person with authority like a facility director, senior faculty, or administrator. This is a responsibility not to be taken lightly. It can consume considerable time and effort.

36.1.4 Project Team

The project director should assemble the project team consisting of qualified architects, engineers, health and safety professionals, and construction experts to design and build the project.

36.1.5 Construction Manager

This role is different from a project director. This role (service) is provided by experts who have extensive construction management and estimating experience. In essence, the construction manager provides guidance to the owners' project director in evaluating various options and develops cost and construction schedule information. In some cases, the construction manager accepts a financial stake in the project by assuming the role of general contractor. This causes a conflict of interest and is not a recommended practice.

A project may not have a construction manager.

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36.1.6 Project Manager

The project manager (PM) from the client side is one who derives his or her authority from the project director and is responsible for routine day-to-day management of the project. Like the other stakeholders in the building team such as architects, engineers may also assign their own PM to manage their responsibilities.

36.1.7 Value Engineering

This is a term that came into popular use around the 1960s. However, the concept is as old as when projects bidding process became formalized. Essentially, when prices are obtained for any project after design a construction budget can be established (see section 36.4.4 for additional details). If this budget is higher than the owner's original budget (as is frequently the case), the owner only has a few options (we assume project cancellation is not a viable option) some of which are to get additional funds, reestimate the project with different contractors, or change the scope of the project.

The first two options are self-explanatory. The last option is known as *value engineering*. The concept is to keep the essential value in the project while engineering change to reduce costs. This may mean reduction in scope, or changes in system design, materials, or method of delivery.

Value engineering is initiated by the owner, mostly by the project director and the whole team participates. It is a critical time that requires full participation and input from environmental health and safety professionals to ensure that critical safety features are not cut from the project and that risks do not increase to an unacceptable level. The facility operation and maintenance group needs to review these proposed changes from a life-cycle cost point of view to ensure choices are not made with low first cost that then have high operating and maintenance costs.

Unfortunately, mechanical and electrical systems tend to present one large category brought to the chopping block. Architectural features tend to be retained instead. We suggest that thorough discussions and careful compromise are necessary. We have observed situations where extremely expensive case work, as well as personal office features and furnishings, are retained at the expense of vital health and safety items. The temptation is great, and usually health and safety items (that are behind walls and above ceilings and not readily apparent) are easier for users and owners to justify removing from the project.

36.1.8 Building Information Management (BIM) Systems

It may be worthwhile to review a bit of history. Before the 1980s, most building projects design drawings were drafted by hand. Then came CADD (computerized-aided drafting/design), which automated this task via graphical elements (lines, symbols, arcs) in a two-dimensional (2D) manner. Then three-dimensional (3D) CADD became available. These 3D drawings were able to provide a greater visualization of the system's complexity. The next evolution was to add in 3D symbols of building elements (objects) with nongraphic attributes. This added "intelligence" to these objects allows complex geometric as well as functional relationships to be represented. For example, walls are objects, which can be joined, lengthened, and have fire rating and insulation value. Doors and windows are represented as objects capable of representing their relationship with walls, etc.

With the availability of high-speed computational tools and cheap computer memory storage, the BIM approach is getting very popular. Each space can be modeled in three dimensions and include all necessary spatial and performance information. Different views of the model can describe different information. For example, in a research laboratory the design can include information on laboratory size, structure, floor finishes, casework, electrical, plumbing outlets, and supply and exhaust diffusers, etc. Conflict between systems can be easily resolved.

This BIM model can be expanded from a laboratory space to the entire building. The construction team can also use this information later for further construction efficiencies.

36.2 IMPLEMENTATION

The following construction options can be considered:

- Conventional
- Turnkey or design build
- Design Assist
- Integrated project delivery (IPD)
- Fast track

36.2.1 Conventional

Under this approach, the owners hire an architect who assembles a project team made up of the building users; they are the research community, engineers, and safety professionals. The following steps usually take place:

1. *Program.* This is a detailed description of the requirements of the research community. This component will indicate the kind of laboratory required, the type of systems needed, and the level of utilities in the building. Refer to Chapter 1, Section 1.2.1 for an extensive discussion of the programming process.
2. *Schematic and design development phases.* Schematic drawings indicate the overall concept of the project and ensure that the program fits into the confines of the building or space as designed and can be serviced with practical mechanical and electrical systems to provide a safe and workable environment. Design development is the phase in which the concept is fully articulated before all the construction details are defined. It is strongly advisable to estimate the project cost at completion of both phases to see whether the project estimated construction cost still falls within the projected budget. It could very well be that budget constraints or cost overruns might require program modification or curtailment. Additional funds may need to be acquired for the project. It is recommended that the design development sets be "signed off" with the users and owners to ensure that they fully understand and agree with the program.

   If the BIM process is being implemented, more details are required early; therefore, traditional schematic and design development scope is modified. To have a successful BIM process the design team needs to understand this reality and be able to work accordingly.
3. *Construction documents.* After the design development drawings are completed, construction drawings and specifications can be formulated. (Chapter 1, Section 1.2.1.4 explains the design development phase.) It is customary to issue these drawings for review by the project team on a regular basis to ensure that the intent of the design concepts, the needs of the investigators, and health and safety concerns are being met. It may be necessary for the user to engage an independent EHS consultant to ensure the adequacy of the design. This may be necessary as a staff EHS is not available or special expertise is needed. The customary review targets are 25%, 50%, 75%, and 90% of the drawings and then a final review before the bids are solicited.
4. *Prebid Conference.* After the documents have been submitted to contractors for bidding, it is customary that a prebid conference be held. At this conference, all pertinent requirements or questions the contractors have should be documented. The questions may range widely from site access to specific detail on the types of components shown on the drawings. It is highly advisable that this conference (or series of conferences) is documented and that the information be shared equally with all bidders. Otherwise, all kinds of misinformation or misunderstanding can occur. Bid clarification documents or addendums or deletions can be issued for clarification of the scope of the project.

36.2.2 Turnkey (Design Build)

Under this approach, a vendor who typically is a commercial developer or general contractor is held responsible for all design and construction of the project. Upon completion, the vendor "turns over the keys" to the users. There are several advantages to this approach. Most importantly, the one-source responsibility for the overall project means completion can be faster. The disadvantages are that the owners do not necessarily get the very best price for the endeavor, the eventual users and owners are less involved in the decision-making process, and sometimes the end product is not exactly what is desired. It is vital that the design/construction team reviews environmental health and safety issues with the owner's EHS to correct any deficiencies. If the vendor does not have significant and creditable experience in construction of laboratory buildings, the end product may be defective. A similar approach is called *design–build*, in which legal ownership of the project remains with the developer until completion and then it is turned over to the owner.

36.2.3 Integrated Project Delivery (IPD)

As buildings have become more complex, their delivery system has also become complex—with too many interrelated and often conflicting priorities and goals. Some studies have indicated that building industry overall efficiency has declined. This often results in cost and schedule overruns and corresponding delay in research building projects being completed on a timely basis. This can result in loss of valuable laboratory activity. The IPD process was developed to counter some of these trends. There still is not a consensus on the exact form IPD should take, but in essence IPD represents a return to the "master builder" concept where the entire building team including the owner, architect, general contractor, building engineers, fabricators, and subcontractors work collaboratively throughout the

construction process. This is clearly different from the design–build project delivery method where the contractor has the leading role. It is critical that an environmental health and safety professional is part of the integrated team.

36.2.4 Fast Track

This is a fairly common technique. Portions of design and construction of the project are done simultaneously. Construction commences before all construction documents are complete. For example, as soon as the building shape and size are decided, foundation work can be designed and commence while the superstructure is being designed. The superstructure can be constructed while the final mechanical and electrical systems are being designed, and installation occurs later. The laboratory apparatus can be selected last.

There are obvious advantages in reducing the time from overall concept to finish. It means that the building can be commissioned earlier and that productive research work can start accordingly. The problems are as follows:

1. Even with an experienced design team, serious errors can occur in haste, which become very expensive to rectify in the future.
2. No adjustments can be made to early design decisions without financial penalties.
3. Frequent and close coordination between design phases is critical.
4. The users are forced to make decisions very early and in a very quick manner. Some of them are not used to making these decisions and change their minds later. This could result in significant changes in construction with substantial cost additions. There is also a significant potential to compromise safety and health design features as a result of these changes. For example, an increase in scope needing specialized ventilation may be made, but the building layout may not provide adequate space for the additional mechanical systems needed. Some change is inevitable; however, attempts should be made to reduce changes as much as possible.

36.3 BID FORM

The importance of the bid form cannot be overemphasized. A good bid form summarizes the cost of the project in an easy to understand format. At the same time, it documents any component cost (or cost of alternates) in an easy format. Some contractors may take exception to certain segments of the construction documents. The bid form allows a place for them to do so. The owner regards a contractor completed bid form as a legal and binding document.

36.3.1 Bidding Documents

Bidding documents can be divided into three major sections: (1) contract forms, (2) general conditions, and (3) technical specifications. Contract forms and general conditions address the legal and administrative requirements of the project and vary according to the size of the project and its location. The Construction Specification Institute's (CSI, 2012) list of normal specification categories are an excellent method of preparing these documents.

Requirements for adhering to all applicable federal, state, and local health and safety regulations during construction should be included, and all unusual hazards, including those likely to be present as a result of construction activities, should be identified here. These unusual hazards may include the presence of asbestos-containing materials, mercury, PCBs, etc., during renovation or demolition (See Part I, Section 6 for additional details). The technical specifications may include many of the statements contained in this manual along with non-safety-related items. A careful review of all sections should be made by health and safety professionals to identify all health and safety issues to achieve correct and complete specifications.

To ensure that all of the safety and health considerations will be incorporated into the completed laboratory, building, or renovated area, it is of utmost importance that the relevant criteria delineated in this book be incorporated into the final technical specifications put out for bid. It is equally important that correct bidding procedures be established and closely followed to ensure efficient construction of the facilities as designed. To that end, a set of bidding documents must be prepared. They should be carefully reviewed by certified health and safety professional for appropriate additions or deletions.

36.3.1.1 Bill of Quantities (BOQ). In many countries and jurisdictions, a detailed "quantity" survey and bill of quantities is provided to the contractors for pricing purposes. The BOQ is usually prepared by the design team and includes a list of all construction materials.

36.3.2 Types of Bidding

Bidding procedures vary from location to location. In specific cases, bidding guidelines exist because of federal and state regulations. In many countries, contract terms

differ from those in the United States. In Great Britain and many other countries, bidding is called a *tender offering*. The procedures described in this chapter are those used in the United States; however, the general concept and principles are similar and could be applied anywhere. In general, the bidding process can be broken down into competitive and negotiated bidding.

36.3.2.1 Competitive Bidding. Competitive bidding is when more than one contractor or vendor is requested to provide pricing for the complete building/project package. In general, the contract limits itself to the construction and the mechanical and electrical systems. It does not include owner-furnished items like movable research equipment. Competitive bidding may be open or closed. In an open-bid process, the owner places a public announcement and any contractor who meets minimum requirements on bonding and financial status may bid on the project. In a closed-bid process, a limited number of general contractors and subcontractors who have been researched for their qualifications to do a particular project are invited to bid on that project. Most bids for publicly funded buildings are done on an open-bid basis, but many private organizations prefer to close their bidding process to ensure only well-qualified contractors.

Prequalification of contractors and subcontractors where possible ensures only qualified and experienced firms are bidding on the projects. One of the selection criterion could be their job safety record and any OSHA violations.

36.3.2.2 Negotiated Bidding. Under this approach, the owners negotiate with one vendor for the construction of the building and the mechanical/electrical systems. The owner-furnished items described above may or may not be included in the contract. It is recommended that laboratory equipment be specified and purchased by the research organization rather than by an outside construction vendor. Researchers know best what is needed and the quality level required for scientific equipment. It is not cost effective to have a third party brought into the middle of that negotiation. When selected, the equipment can be competitively priced from more than one vendor. Bidding offers a significant opportunity for project cost savings. Researchers should work with the administrators to look for competitive bidding opportunities for the purchase of laboratory equipment when possible instead of using a sole-source vendor.

36.3.3 Bid Opening

After the bids are received, bid opening is required. In certain cases, the submission of the bid and the opening may be highly structured. For example, certain federal and state regulations require the bid opening to be public, where not only the main general contractor, but also the various subcontractors are decided. All the requirements should be carefully noted, reviewed, and followed through to ensure fair bidding practice.

36.3.4 Project Cost Estimate

After the final bids are received, a final project cost should be projected. It is important to note that the project cost is entirely different from construction cost and includes other items such as the architects' and engineers' fees, legal and other consultants' fees, site preparation cost, utility service extensions and connections, document printing, moving expenses, etc. Once the project cost is estimated, it should be reviewed with the funds available. If there is a discrepancy in funds available, either additional funds must be raised or the project is required to go through redesign. This is a rather delicate period. Many times, the carefully designed health and safety features are compromised for cost containment. A very careful review of the project scope and needs is absolutely vital to ensure that once construction is complete, the intent and requirement of the laboratory objectives, as well as environmental health and safety goals are being met.

36.4 CONTRACT

After a contractor is selected and adequate funds are available, a contract is signed between the building contractor and the owners. This contract may take several forms. Several jurisdictions have contracts of their own. If none is available, the American Institute of Architects (AIA) offers several contracts that may be considered. Legal advice and review should be employed on this and all contracts.

One of the most important duties that requires attention before the contract is signed is a comprehensive review of all sections of the specifications and contract drawings with the contractor. This review of all the building systems will ascertain whether all parties understand what is expressed or implied in the documents. All too often, items are overlooked that result in additional costs to the project.

36.5 CHANGE ORDERS

Change orders are a fact of life in a construction project. No matter how well the project is designed, there will always be changes due to different site conditions,

changes in scope, or unavailable materials; sometimes, a better solution is proposed to solve a problem. It is absolutely vital that change orders be monitored on a very careful basis. Many times, change orders have been authorized without due regard to the effect on the overall cash flow, availability of funds, or safety and health considerations. Architectural and engineering redesign costs should be added to the contractor's estimate. Excessive change orders can result in the owner and builder running out of money in the middle of the project. The project manager may be authorized to approve change orders up to a certain dollar value. It is necessary, therefore, that the project director be given authority to say no to the requestor of changes when needed. This is not an easy matter because nobody likes to be in that role; however, the role is vital for overall success of the endeavor. At the same time, a balance is necessary. There are some decisions that become irreversible and become a limiting factor for the life of the building. Other items can be changed or implemented later on. It is much easier to postpone or defer the items in the second category. For example, the amount of vertical chase space in the building is somewhat irreversible. Once a decision is made, the number of chases is designed and provided. It becomes very expensive to provide additional chases for mechanical and electrical systems. On the other hand, a D.I. water system can be added. Additional exhaust systems can also be added, but only if an allowance for expansion was made in the design phase.

The AIA has some very good documentation available for help with this issue. The latest edition of the *Architects' Handbook of Professional Practices* (AIA, 2008) should be consulted.

Authority having jurisdiction (AHJ) reserves the right to conduct inspections and request change during construction as well as before occupancy. These authorities may be a building inspector, plumbing or electrical inspectors, the department of public health, the fire department, etc. Depending upon the project, the quality of design, or local conditions, these inspections can be routine to onerous. A well-designed and constructed project should have fewer problems during such inspections.

36.6 CONSTRUCTION INSPECTIONS

During the construction process, it is vital that the architects, engineers, and commissioning agent (CA; if engaged) provide routine inspection to ensure that the intent of the design is being met by the contractor. EHS professionals should be involved in this inspection process at some designated point(s). One the goals of their inspection would be to ensure that the contractors are not compromising the safety of the owner's personnel.

Usually, shop drawings of the equipment used or material to be supplied by the contractor are submitted to the owner and design team for review and approval. This is another stage at which the level of quality should be carefully maintained. The contractor or subcontractor, in the desire to increase profit, sometimes tends to shop the market and provide the lowest-priced material for many items in the construction project, not realizing the effect these changes may have on the final building. Some of the items may be clearly unsuitable for the intended use. A good design and construction specification will assist the design team at this level to delete or reject lesser products. Otherwise, it may be necessary for the owner to pay extra to get the desired quality.

It is recommended that construction site visit notes be kept in consecutive order to be deleted as the problem items are corrected. With today's computer applications, it is very easy to keep a running document of the problems noted, and the dates and methods by which they are resolved.

36.7 PUNCH LIST

This is the stage in the construction period when the design team is informed by the contractor that the project is substantially complete, and they are invited to inspect the construction for quality as well as completion and to issue a punch list itemizing the problem areas noticed. It is important that this punch list be comprehensive and thorough. This is almost the very last opportunity the design team and owners will have to request contractors to make major corrections. Refer to Chapter 37 for inspection guidelines.

36.8 ADDITIONAL TESTING AND ACCEPTANCE

Various mechanical and electrical systems in the building require additional testing as part of the acceptance process. They may include (1) short-circuit analysis and testing of the electrical switchboard, and (b) pressure testing of the piping system and the exhaust duct systems. It is important that the design team provide clear instructions in the design documents so that the contractor is able to implement such tests. The acceptance of the test should be in written form and should be approved by the design team.

36.9 BENEFICIAL OCCUPANCY

At this stage, the project is substantially complete, and the owner is able to move into the space and to connect utilities to various scientific equipment. It is usual to find some deviation from the original intent at this time. There may be a missed utility connection, or wrong voltage is provided. Provisions should be made, therefore, in the project schedule for this final fine-tuning. This shakedown period can extend over several months on complex research laboratory or production buildings, particularly those for the pharmaceutical and chemical industries.

Some issues are not identified or realized until after occupancy when laboratory users start to work with the equipment. It is essential that the project schedule and budget allow for such modifications. However, it should be noted that users are in a new environment, possibly very different than their old one; hence, there is a tendency to request lot of changes directly after the move in. It is recommended that some time be allowed for adjustment. If change is still required, it should then be made.

36.10 FINAL ACCEPTANCE AND COMMISSIONING

More details are provided in Chapter 37 about project acceptance and commissioning. Several state, local, and federal agencies may need to inspect the project during construction for final approval. Fire alarm systems or fire suppression systems may need to be approved by the local fire department. After all these required code-related acceptance tests are done, a request is made to the local building department for the occupancy permit. The requirements for this permit vary from locality to locality and may be called something different from place to place; however, it should be recognized at this stage that the building is safe and is habitable by the user without any undue health risk or life safety problems. For example, in a high-rise building the smoke evacuation system or the sprinkler system must be operational. This leads to an interesting situation: In a high-rise building, the various floors could be issued an occupancy permit independent of one another as long as certain building code required systems are completed. The requirements vary, and a local regulation should be checked to see how feasible it may be.

In large research buildings a “pull the plug” test is recommended. The electrical systems in a research building are very complicated and therefore must be commissioned to ensure correct operation. This “pull the plug” test confirms the proper transition of electrical systems from normal to emergency mode and ensures that all systems which should operate during an emergency are so connected. This may include testing of uninterruptible power systems in data closets, egress lighting locations, and other critical areas.

37

COMMISSIONING AND FINAL ACCEPTANCE CRITERIA

37.1 GUIDING CONCEPTS

37.1.1 Introduction

The intent of this chapter is to describe the construction acceptance and testing procedures in relation to a laboratory building's health and safety issues. It is assumed that all quality control testing on the soil, foundation, and structure, as well as other systems testing necessary for a structurally sound building has already been done as a part of the normal construction delivery process. This chapter discusses the "quality assurance" also called the *commissioning* process for building systems operation.

It is critical that the health and safety systems in the laboratory building or renovated space be carefully inspected periodically during construction, because it is easier and more economical to correct defects during this stage than to wait until the final acceptance inspection is made. Such items as accepted welding techniques, use of correct construction materials, application of proper pest control techniques, and precise location of safety equipment storage areas should be observed during construction.

For large projects, onsite engineer(s) independent from the contractor responsible directly to the building owner should be present continuously during the entire construction period to monitor compliance with the plans and specifications. It is recommended that this person be appointed in addition to the normal Clerk of the Works. Commissioning agents or a commissioning authority (CA), described in detail in Section 37.5, should be retained prior to the design stage and participate in the design process.

37.1.2 Regular Testing Before Occupancy

To ensure that emergency systems will perform satisfactorily when needed, it is essential that frequent testing be conducted even during the interval before the building is occupied. This is commonly carried out once a week and should include the emergency electrical systems, the fire alarm systems, and all other emergency alarm systems.

For certain systems (e.g., fire suppression), it is not possible for a useful inspection to take place during construction because for these systems, only a complete system-wide test after completion will be meaningful.

37.2 DESIGN, CONSTRUCTION, AND PREOCCUPANCY CHECKLISTS

The list presented below can serve as an aid in focusing on major safety and health items that must be addressed during various stages of laboratory construction. This is by no means intended as a complete list, but it will serve as an initial checklist to be added to depending on the special needs of the particular project.

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

37.2.1 The Construction Safety Design Review Checklist

This list can be prepared by one or more member(s) of the design or construction team with the help of a CA. Some of the items mentioned are generally used for meeting regulating authority requirements for beneficial occupancy of the building. Some are future expandability issues that have long-term effect. Some have an effect on efficient building operation.

Operational and Design Efficiency Checklist

- □ Avoid horizontal runs of ductwork in all exhaust systems susceptible to internal condensation. Perchloric acid hoods are a special hazard when condensate can collect inside the ducts. Do not combine exhaust ducts from perchloric acid hoods with other exhaust air systems. (Refer to Chapter 32, Laboratory Hoods and Other Exhaust Air Contaminant-Capture Facilities and Equipment; and Chapter 33, Exhaust Air Ducts and Accessories, for additional details.)
- □ Determine whether exhaust air from some chemical fume hoods will have to be cleaned before being emitted to the environment. When air cleaning is needed, the type, size, and location of the equipment and the utilities required (water, sewage, electricity, etc.) should be designated in the plan and checked for correct installation.
- □ Check that the location of air-supply intakes is away from the influence of exhaust stacks, parking lots, loading docks, and other sources of contaminated emissions, including those from adjacent buildings.
- □ Make certain that all fans, ducts, air cleaning devices, and the hoods they serve are labeled with coded tags for easy identification.
- □ Make certain that all specified flow indicators have been installed in the correct location in every local exhaust system.
- □ Make certain that the bottled compressed air backup system for equipment that would be damaged by a loss of compressed air is installed and connected to all designated delivery points.
- □ Check that supply air outlets are not directly installed in front of the fume hoods.
- □ Clean out all compressed gas lines with a nonflammable solvent followed by compressed nitrogen drying before hookup to compressed gas sources. Cleanliness testing is recommended by microscopic examination of white membrane filters through which 1 m^3 of compressed gas has been passed after passage through the longest branch of the piping systems.

  Check that copper piping was *not* designed for acetylene gas lines.
- □ Make certain that all piping systems have been clearly marked for easy identification in a readily visible area according to an acceptable standard coding system.
- □ Check identification for shutoff valves for all piped utilities, including water services.

  Check locations for waste containers that segregate combustibles chemicals, hazardous waste, broken glass, and trash.
- □ Check if space is allocated for receipt, storage, handling, and disposal of radioactive materials, and initiate paperwork to obtain the required license(s).
- □ Check locations for use and storage of cryogens (e.g., liquid nitrogen) when these products are needed.
- □ Check that there are chemical storage facilities for segregated storage of small amounts of oxidizing and combustible chemicals in laboratories and for major stores of chemicals and gases in segregated and specially constructed gas and chemical storage sheds.
- □ Review compressed gas storage installation for compliance with all legal, insurance company, and fire protection standards.
- □ Check and identify locations for ground fault interrupters wherever electrical shock hazards may exist.
- □ Make certain that all electrical outlets in laboratories are labeled and that corresponding labels are provided at each panel box before occupancy.
- □ Make certain that all solvent storage cabinets are UL- or FM-approved as solvent storage cabinets and are electrically grounded by inspection and test.
- □ Identify and record where explosion-proof or laboratory-safe refrigerators are required.
- □ Check outlets for potable water and special laboratory water.
- □ Verify that floor materials are resistant to slipping and resistant to spills of chemicals and materials that are likely to be used in large amounts.

  Ensure that a viable pest control system has been incorporated during construction.
- □ Check that all penetrations into the buildings and laboratories are sealed.

Future Expandability

- □ Provide adequate chase space for currently specified exhaust ductwork, compressed gas piping, and so on. Allow at least 25% additional space for future additions.

Health and Safety

- □ Plan for purchase and storage of necessary personal protective devices such as self-contained breathing apparatus and protective clothing.
- □ Select and identify locations for eye protection (i.e., safety glasses, goggles, face shields) and eyewash dispensers at the entrance to eye-hazard areas (e.g., in safety stations at laboratory entrances).
- □ Check locations for portable fire extinguishers and make sure the correct type of unit is at each location.
- □ Document the safety and health practices that contractors and their subcontractors are expected to comply with while working on the site.
- □ Check locations and installation of safety stations and first-aid facilities.
- □ Check installation of warning signs in conspicuous locations to identify dangerous areas.

  Check areas requiring emergency lighting capabilities. Restrooms and some laboratory areas are frequently overlooked even though they are included in the NFPA codes.
- □ Investigate fire-escape routes and document for postoccupancy training.
- □ Check locations for fire-alarm installation.
- □ Check height of storage shelves so that sprinkler systems are not compromised.
- □ Identify the systems that will require backup emergency services (e.g., electricity, cooling water, compressed gases) and make certain they function.
- □ Check rating and locations of emergency exit doors, and verify direction of door swing with respect to direction of egress.
- □ Check that all locations where hazardous chemicals are used are within 10-seconds travel from an emergency eyewash and shower.
- □ Complete a site safety handbook for when occupancy begins.

37.2.2 The Preoccupancy Safety Review Checklist

- □ Test eyewash fountains and safety showers.
- □ Test functioning and audibility of fire evacuation-alarm system.
- □ Verify direction of door swing with respect to emergency egress routes.
- □ Check all cup sinks for strainers.
- □ Check that all equipment items, such as sinks, compressors, cabinets, and shelves are firmly secured.
- □ Review all ventilation system balancing records and make certain that all systems are certified to be in conformance with all applicable plans and specifications.

With regard to the environmental health and safety areas in laboratory commissioning, guidelines detailing whether it is the project manager's or commissioning agent's acceptance responsibility are provided in Table 37.1.

37.3 HEATING, VENTILATING, AND AIR-CONDITIONING

Review Chapter 2, Section 2.3 for more details on HVAC issues. Chapter 43 of the *ASHRAE HVAC Application Handbook* provides excellent guidelines (ASHRAE, 2011). And ASHRAE Guideline 0, The Commissioning Process (ASHRAE, 2005).

37.3.1 Air Balancing

For ventilation systems to perform as designed, the supply and exhaust systems must be balanced after installation is completed. Balancing will necessitate fan tests that include measurements of static pressure, fan and motor rpm, air volume rate, temperature rise, current draw (to determine brake horsepower), etc. Adjustments of sheaves, dampers, and so on will also be necessary to distribute air in accordance with the HVAC drawing specifications. All balancing should be conducted in accordance with the standards of SMACNA, and a written report should be submitted for the design engineer's review and approval. A sample test sheet is shown in Table 37-2.

The contract mechanism for obtaining a balancing contractor is a special concern. One approach is to insist that the testing and balancing contractor work for the owner, and thereby have autonomy and the ability to report freely to the owner or his or her representative any problems noticed with regard to the work of the mechanical contractor. The other approach is to have the testing and balancing contractor work directly for the mechanical contractor on the assumption that this arrangement leads to closer coordination and greater effectiveness. Our recommendation is for the testing and balancing contractor to work directly for the owner and that a sum of money is designated for this service function right from the start. We do not recommend that any contractors be permitted to monitor their own work.

37.3.1.1 Air Balancing for VAV Systems. Variable-air-volume (VAV) systems can be very complex, with extensive controls that operate to exacting

TABLE 37-1. Acceptance Responsibility in Laboratory Commissioning in Relation to Health and Safety Concerns

Health and Safety Concerns in Laboratory Commissioning	Responsibility
Certificate of Occupancy posted	PM
Post necessary permits (e.g., flammable liquid, gas, solid permit)	PM
Operation and maintenance manuals	CA
Signage	PM
Flush and inspect emergency eyewashes and showers	CA
• Eyewash/safety showers tested	CA
• Equipment and maintenance schedule added to R&M database	PM
• Tempered water system tested	CA
• Equipment and maintenance schedule added to R&M database	PM
Emergency evacuation maps posted	PM
NFPA 704 diamonds posted at chemical storage rooms and 90-day hazardous waste storage rooms	PM
Hazardous material storage areas (bulk nitrogen, oxygen, carbon dioxide, etc.)	CA
Portable fire extinguishers mounted	CA
• Fire extinguishers tested	CA
• Equipment and maintenance schedule added to R&M database	PM
Fire doors (close flush)	CA
Exit signs	CA
Floor numbers posted in exit stairwells	PM
Fire alarm system	CA
Sprinkler system	CA
Lighting	CA
Emergency equipment	CA
HVAC	CA
Fume hoods	CA
Biological safety cabinets	CA
Autoclaves	CA
Local exhaust ventilation	PM
Monitoring systems	CA
Fire stopping	CA
Emergency generator	CA
• UPS	CA
Lab waste system	
• Discharge added to permit	PM
• O&M manual available	CA
• Meters calibrated	CA
• Piping is identifiable	CA
• Alarms communicated to operations center	CA
• System added to contracted operator	PM
• Equipment and maintenance schedule added to R&M database	PM
Water	
• Backflow devices tested	CA
• Equipment and maintenance schedule added to R&M database	
• Non-potable water piping is identifiable and signs posted in labs	PM
Water reuse (RO reject, etc.)	
• Use has documented approval by plumbing board	CA
• Volume / flow data available	CA
• Piping is identifiable	CA
• O&M manual available	CA
• Equipment and maintenance schedule added to R&M database	PM
• Clean water discharges communicated to AHJ of water supply permit contact	PM
Treated water (for animals)	
• O&M manual available	CA
• Piping is identifiable	CA
• Equipment and maintenance schedule added to R&M database	PM

(*Continued*)

TABLE 37-1. (*Continued*)

Health and Safety Concerns in Laboratory Commissioning	Responsibility
• Clean water discharges communicated to JHA of water supply permit contact	PM
Chilled water	
• Piping is identifiable	CA
Photo/film processing	
• Silver recovery system in place	PM
Foundation sumps	
• Discharge permitted or allowed	CA
• Equipment and maintenance schedule added to R&M database	PM
Generators or other fossil fuel-burning devices	
• Source added to permit	PM
• Fuel tank added to SPCC inventory	PM
• Hour log established	PM
• Equipment and maintenance schedule added to R&M database	PM
Solid waste and recycling	
• Hazardous waste accumulation room capacity calculated and posted – all room requirements set up (berming, ventilation)	CA
• Recycling system / equipment / signage in place	CA
• Sharps and biowaste collection system / equipment / signage in place	CA
• Mini MAAs on each floor – set up	CA
Miscellaneous	
• Tanks and drums for hazmat storage(detergent, fuel oils, hydraulic oils, water treatment) in chemtracker or SARA database	PM

Note: PM = Project manager; CA = commissioning agent; HVAC = heating, ventilating, and air-conditioning; AHJ = authority having jurisdiction; O&M = operations and maintenance; R&M = repair & maintenance; RO = reverse osmosis; SARA = Superfund Amendments and Reauthorization Act; SPCC = spill prevention and control countermeasure; UPS = uninterruptible power supply.

requirements. Therefore, a complete understanding of the operating characteristics of the system and the controls is mandatory. It is important that the balancer is a professional technician who can use instruments for air flow, hydronics, and electricity measurements and who can work with automatic controls that could be electric/electronic, or pneumatic. The system should be balanced at maximum air flow and then at minimum air flow. If the required outside-air quantity at the outside dampers is measured at both maximum and minimum air flow, this health and safety concern will be satisfied. The hood exhaust fans and general exhaust fans will require checking to ensure that the supply fan will track changing exhaust air requirements. Duct and terminal box static pressure controllers should be checked to determine that they perform as designed with the correct air flow at maximum and minimum positions.

37.3.1.2 Checking for Pressure Relationships. In certain types of laboratories in which pressure relationships are especially critical (e.g., biosafety laboratories), air tightness of the room enclosure is very important. All penetrations into the room (pipes, electrical conduits, ducts) must be well-sealed. A leakage test, using sulfur hexafluoride tracer gas, may be appropriate when total containment is required. One such test has been described by Billings and Greenley (1989).

37.3.2 Chemical Fume Hoods

VAV-system chemical fume hoods require careful testing and balancing to ensure that the correct air flow is achieved at maximum and minimum settings.

The face velocity of all chemical fume hoods should be checked to ensure that the air flow rate is in conformity with design requirements. Appropriate labeling is required on each hood to indicate correct operation before it is released for service. If the chemical fume hood is an auxiliary air type, it is necessary to test for correct operation of the makeup air system by smoke trails. Chemical fume hood field performance tests are discussed in Chapter 32, Section 32.12. If the chemical fume hood has an integral flammable liquid storage cabinet, selection of the correct fire rating should be verified. Correct installation and operation of all piped-in gases and electrical fixtures associated with the chemical fume hood should be verified. In hoods

TABLE 37-2. Air-Moving Equipment Test Sheet

Air-Moving Equipment Test Sheet

Date _____

Project _____ Project Number _____

System no.								
Location								
Manufacturer								
Model no.								
Serial no.								
Operating conditions	Specified	Actual	Specified	Actual	Specified	Actual	Specified	Actual
Total CFM								
Return CFM								
Outside Air (OSA) CFM								
Exhaust CFM								
Total static								
Suction static								
Discharge static								
External static								
Bmp								
Motor manufacturer								
Size (hp)								
Voltage								
Rpm motor								
Safety factor								
	Rated	Running	Rated	Running	Rated	Running	Rated	Running
Amperage								
Rpm fan								
Sheave position								

equipped with HEPA filters, the integrity of filters and filter mounting should be verified by in-place testing using the standardized techniques recommended for biological safety cabinets in National Sanitation Foundation Standard 49 (2009) or the techniques recommended for nuclear applications in ANSI/ASME N510 (ANSI, 2007). A sample report is included in Table 37-3. When two-speed, variable-speed, or parallel fan types of arrangements are used for exhausting a chemical fume hood, operation should be verified in each separate mode.

An example of some of the acceptance testing is shown in Table 37-4.

37.3.3 Ductwork Testing

All exhaust ductwork should be tested to ensure that excessive leakage does not occur. This is most important when exhaust fans are in series and sections of the exhaust ducts are under positive pressure and may leak contaminants into occupied areas. SMACNA gives approved criterion for testing the leak-tightness of exhaust ducts and plenums. The association's leakage rates and classification of duct sealing are listed in Table 37-5.

Most up-to-date of SMACNA standards should be used (See SMACNA, 2011).

TABLE 37-3. Acceptance Testing for Chemical Fume Hoods

BUILDING DEPARTMENT ROOM NUMBER DATE

HOOD NUMBER PERSON IN CHARGE LOCATION OF HOOD IN ROOM

USE OF HOOD:
RADIOACTIVE MATERIALS
PERCHLORIC ACID
GENERAL CHEMISTRY
HIGH-HAZARD CHEMISTRY
SPECIAL PURPOSE

HOW OPERATED

MANUFACTURER _____
TYPE OF HOOD _____
SASH: Vertical
Horizontal

RECOMMENDED SASH HEIGHT
VELOCITY FPM _____
HEIGHT _____
DATE _____
SMOKE TEST _____

HOOD MEASUREMENTS

BOTH SASHES OPEN

AV. VEL. ____

ADJACENT SASH OPEN

AV. VEL. _____ AV. VEL. _____

EXHAUST FOR CABINET:

	HIGH	LOW
LEFT	_____	_____
RIGHT	_____	_____
SMOKE TEST	_____	_____

AIRFOIL _____ AV. VEL. _____
_____ AV. VEL. _____
SMOKE TEST _____
COMMENTS:
DATE OF LAST SURVEY _____
HEIGHT OF SASH _____

MICROSWITCH _____
ALARM _____
MAGNEHELIC LOW_____ HIGH _____ *H_2O

TABLE 37-4. Testing Standards

Standard	Affected System/Equipment
NSF 49, (2009)	In-place HEPA filter testing for biological safety cabinets
ANSI/ASME 510, (2009)	In-place HEPA filter testing for biological safety cabinets
ASHRAE 110, (1995)	Fume hood testing
NIH	Fume hood testing
ANSI/AIHA Z9.5, (2012)	Laboratory ventilation
SEFA	Ductless fume hoods

37.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

37.4.1 Fire-Suppression Systems

Each fire-suppression system should be tested in accordance with (1) NFPA 25, Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems (NFPA, 2011), (2) the International Fire Code (ICC/IFC, 2012), and (3) or other local codes adopted by the AHJ (authority having jurisdiction).

TABLE 37-5. Duct Leakage Rates and Sealing Classes

Applicable Leakage Rates			
Duct Class	0.5, 1, 2 in w. g. (0.12, 0.25, 0.50 kPa)	3 in. w. g. (0.75 kPa)	4, 6, 10 in. w. g. (1.0, 1.5, 2.5 kPa)
Seal Class	C	B	A
Leakage Class			
Rectangular Metal Duct	24	12	6
Round Metal Duct	12	6	3

SMACNA Duct Sealing Classes		
Seal Class	Sealing Required	Static Pressure Construction Class
A	All transverse joints, longitudinal seams, and duct wall penetrations	4 in. w. g. and up (1.0 kPa and up)
B	All transverse joints and longitudinal seams	3 in. w. g. (0.75 kPa)
C	All transverse joints	2 in. w. g. (0.50 kPa)
In addition to the above, any variable air volume system duct of 0.5 or 1 in. w. g. construction class that is upstream of the VAV boxes shall also meet Seal Class C.		

Source: SMACNA 1985.

37.4.2 Fire and Smoke Alarms

The entire fire alarm system in the building should be checked for correct operation. Each device should be checked individually and as a part of the system by simulation of alarm conditions. Procedures for testing fire alarm systems are described in NFPA 72, the National Fire Alarm Code (NFPA, 2010).

37.4.3 Other Alarm Systems

The correct operation of all other alarm systems should be verified. Alarms are frequently used to signal unbalanced air flow, incorrect operation of mechanical equipment, and so on. Each device should be checked individually and as part of the entire system by simulation of alarm conditions to ensure correct operation even at remote station monitors.

37.4.4 Emergency Electrical System

The emergency electrical generator and associated electrical systems should be started and tested under appropriate load conditions and the engine should be operated for at least 3 h under 100% load to ensure that the system will operate as specified when called into service. All transfer switches and ancillary devices should be tested individually and again as part of the system. A "pull the plug" test where normal power is shut off and the emergency system is allowed to operate is an excellent method of confirming that all systems which should be available in an emergency condition are in fact operational.

37.4.5 Eyewash Facilities

The water flow rate of each tempered and nontempered eyewash station should be verified, and a record should be made that it meets the criteria set out in ANSI Standard Z358.1, Emergency Eyewash and Shower Equipment (ANSI, 2009). The angle and height of rise of the streams should be documented as well. Tempered eyewash stations should be checked to ensure water temperature is between 65–90°F (18–32°C).

37.4.6 Emergency Showers

The water flow rate of each emergency shower should be measured, and a record should be made that it meets the criteria set out in ANSI Standard Z358.1, Emergency Eyewash and Shower Equipment (ANSI, 2009). The minimum acceptable flow rate is 20 gal/min (1.2 L/s). The temperature of tempered showers should be between 65–90°F (18–32°C).

37.5 PROJECT COMMISSIONING

As buildings and projects get more and more technically complex, it also becomes increasingly important for the users or the laboratory owners to be certain that an installed system performs in accordance with the original design intent. The best way this goal can be met is by a very detailed assessment of the start-up of various systems. This process is called *commissioning*. Commissioning can be defined in several different ways and is performed for multiple reasons. The following definition

described in ASHRAE Guideline 0-2005 provides an excellent guide: "Ensuring that systems are designed, installed, functionally tested and capable of being operated and maintained to perform in conformity with the design intent."

The commissioning agent (also known as the commissioning authority [CA]) should be responsible for the project from the design through the warranty phase. The CA is never responsible for design or general construction scheduling, cost estimating, or construction management, but should be available to assist with problem-solving or addressing nonconformance issues or deficiencies if desired by the owner. The process can be described as follows:

- Confirmation that the below parameters are met.
  - Clear documentation of intent of design by owner and design team
  - Identification of certain utility metrics and expected performance
- Documentation of test results
- Preparation of owner and operator manuals
- Training of operator and maintenance personnel to ensure that the design parameters can be met consistently over a long period

The commissioning effort entails additional testing and other requirements by contractors. It is essential that the commissioning specification be prepared and incorporated into the project's specifications. To be effective, commissioning tasks should integrated into the project's overall schedule. The CA must be able to work together with various stakeholders in the construction process.

Commissioning can also be performed as a separate effort by the design or construction team. Many architects, engineers, contractors, and construction managers provide this service. Conflict of interest should be reviewed and avoided. The USGBC LEED program provides an additional point for Enhanced Commissioning to be provided by an independent CA.

Project commissioning can be an additional cost to the project. Many owners are against adding additional cost, saying that they have already provided for the service from the architect–engineer team. It should be understood that commissioning is different from traditional construction supervision services provided by architectural, engineering, and construction firms. It is essentially a quality-assurance process that provides detailed independent review, additional functional performance testing, and documentation that is not usually provided within the construction process. This additional cost is easily justified by systems working properly and providing a safe working environment in laboratory buildings. The number of systems malfunctions is reduced, and contractors' call-back to fix the problems during the warranty period is reduced. In fact, some owners have used their operating budget and not their construction budget to pay for the commissioning effort. In their experience, reduced call-backs and systems operational efficiency are well worth the additional quality-assurance cost.

37.5.1 Fundamental Commissioning

LEED programs sponsored by the USGBC and many other programs require fundamental commissioning as a "prerequisite." This requirement has made many owners accept and benefit from the commissioning process. The scope for this effort is fairly narrow. It requires commissioning only those systems that have an impact on utility conservation and is mostly limited to HVAC, lighting, water conservation, and control systems.

37.5.2 The Commissioning Process

The commissioning process is depicted in Figure 37-1. To be most effective, the commissioning should start from the planning stage, continue to the design to the construction stage, to acceptance, and then to the warranty stage. The tasks to be performed are described below.

- Prepare commissioning requirements in specification format for inclusion in the project manual

  This specification should provide in detail the responsibilities of all contractors during the commissioning effort. It should include sample functional performance tests as examples so that the rigor and effort needed by contractors is clear.
- Development of a commissioning plan

  The CA should develop a commissioning plan that includes an overview of the commissioning process, a list of systems included in the commissioning scope of work, identification of the commissioning team, description of management and communication process, overview of commissioning process activities, list of work products, and list of key commissioning milestones.
- Verify installation and performance of system

  The CA should conduct site visits and verify the functional performance and completion of system installation, and issue checklists as needed.
- Verify requirements for training are complete

  The CA should assist in identifying and planning for training needs.

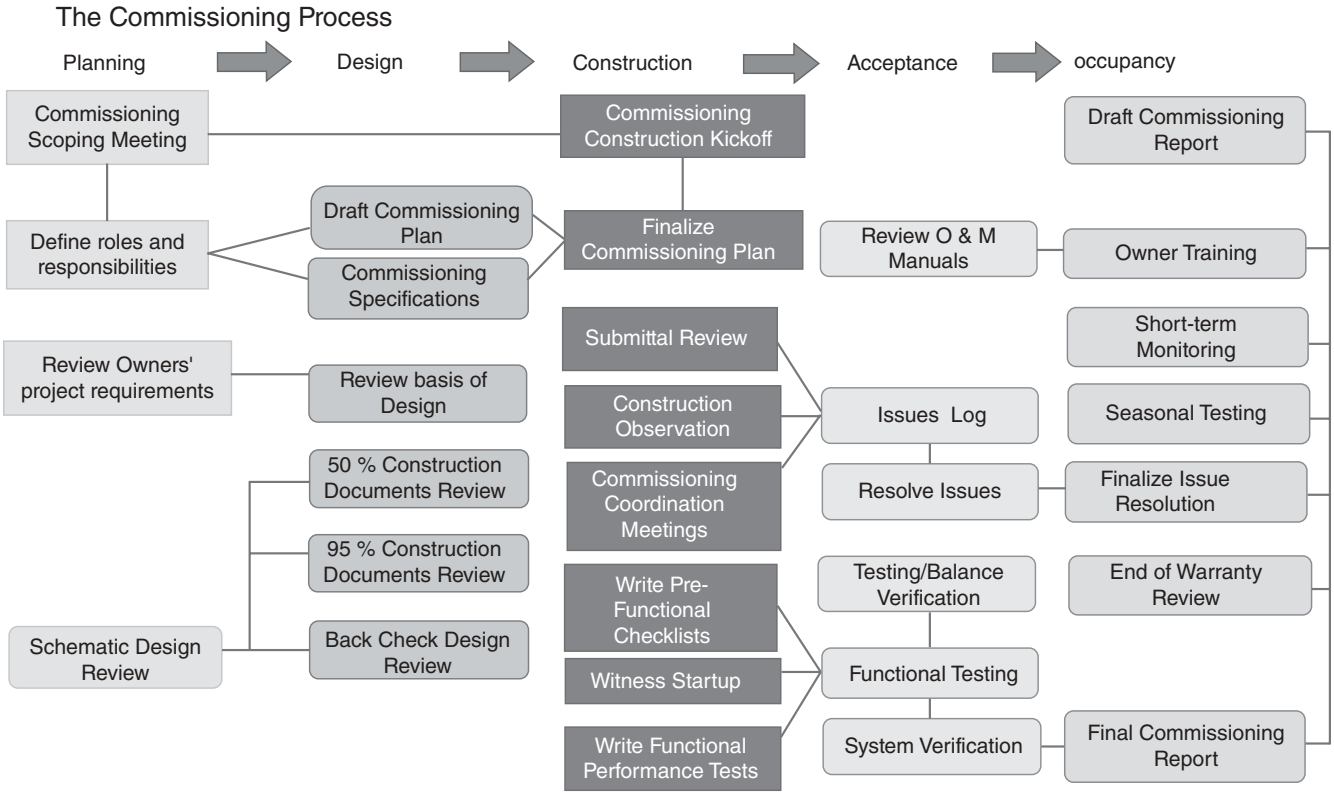

FIGURE 37-1. Commissioning process flow diagram. (Courtesy Cannon Design.)

- Prepare and submit a commissioning report that includes the verification of installation, results for functional performance testing, an assessment of the commissioning process, and identification of outstanding issues

37.5.3 Enhanced Commissioning

Enhanced commissioning usually provides an additional point in the USGBC LEED or other such programs. As the name suggests, the commissioning scope is enhanced. The major additional components of this effort are

- Owner's project requirements(OPRs) workshop

  A workshop is conducted with various stakeholders including the owner and the architects and engineers. This group may also include operating and maintenance personnel, EHS personnel, and user groups to ensure the OPRs are documented. The results from the workshop allow the CA to prepare the OPRs. This should be an ongoing document and should be updated as the project progresses to reflect any owner decisions.
- Review of project design documents for compliance with the OPRs
- Review of energy-related submittals for compliance with design intent
- Review of equipment submittals for selected energy-consuming systems for conformance with the OPRs and BOD.
- Develop manual for recommissioning

  The CA, working with the designer and contractor, should develop a system manual that can be used for recommissioning and for the training of maintenance personnel and occupants.
- Prepare and submit a commissioning report documenting compliance with the OPRs This is similar to the report generated in the fundamental commissioning, with an added emphasis on OPR compliance. There should be a review of tenant-space operations prior to the end of the warranty.
- The CA should conduct a review of the systems and occupant space approximately 8–10 months after occupancy. This review will identify any ongoing issues so the issues may be resolved before the end of the warranty.

37.5.4 Systems to Be Commissioned

A complete list of systems to be commissioned is based upon the project design and owner's preference; however, the following systems are assumed to be in the project:

Alarm systems
Building envelope
Central building-automation system
Data & communication
Daylight dimming controls
Domestic & process water systems
Electrical (normal & emergency)
Equipment sound controls and testing
Heating, ventilating, and air-conditioning systems
Irrigation
Paging systems
Plumbing
Refrigeration systems
Safety systems (fire alarm, egress pressurization, fire protection)
Scheduled or occupancy sensor lighting controls
Security systems

37.5.5 Building Envelope Commissioning

The building envelope basically consists of wall, roof, and window systems. These are fixed elements and if not designed and installed properly can result in air and water leakage throughout the life of the building. Energy loss and resultant temperature control problems also result. Improper vapor barrier installation can result in condensation and possible mold growth. Because of these potential problems, more and more owners are accepting the additional quality-assurance scope of envelope commissioning. A robust and detailed design review is essential. Many times, model envelope sections are constructed and tested against wind and water spray to demonstrate effectiveness. It is essential that the CA be either present during these tests or is able to review in detail the test process.

37.5.6 Warranty Review

In the United States, it is customary for contractors to provide a full-service warranty for 1 year. Contractors are obligated to correct any deficiency in the building or in their work at no charge to the owners. It is also common for many owners not to take advantage of this feature as warranty periods and scope is often ill defined and confusing. The CA can assist in this matter, ensuring that the warranty scope and duration is well understood. The CA should review commissioned systems operation prior to the end of the warranty or approximately 8–10 months after occupancy. This review will identify any ongoing issues to get them resolved before the end of the warranty.

38

SUSTAINABLE LABORATORY DESIGN

38.1 INTRODUCTION

The primary goal of sustainable laboratory design is to build a healthy and safe workplace for workers in science and industry while protecting the environment. This chapter focuses upon specific health, safety, and environmental issues as they relate to sustainable construction materials and systems used in laboratories. The chapter addresses the current nationally accepted sustainable design certification programs by the Green Globe and U.S. Green Building Council organizations. Chapter 31, Air Cleaning, and Chapter 35, Energy Conservation, address issues of indoor air quality, and the reduction of pollution and energy in laboratory building operations. Chapters 1 and 2 cover aspects of planning, HVAC systems, loss prevention, industrial hygiene, and personal safety that are fully applicable to the design of sustainable laboratories and should be followed.

The International Code Council (ICC) publishers of the International Building Code (IBC, 2012) referenced in Chapters 1 and 2, publish the International Green Building Standard (ICC 700, 2012), which addresses housing, and the International Energy Conservation Code (IECC, 2012), which addresses residential and commercial buildings. IECC adopted ASHRAE Standard 90.1 (ASHRAE, 2012). The project team needs to confirm with the jurisdiction having authority where the building is being proposed, whether they adopted IECC (2012), ASHRAE Standard 90.1, ASHRAE Standard 189 (ASHRAE, 2011), or another energy conservation code or standard. These are laws and must be complied with, to the extent that they relate to laboratory buildings. On the other hand, there are guidelines on building sustainability promulgated by a wide variety of organizations, including the U.S. Federal government, General Services Administration's Executive Order No. 13514, and ASHRAE Standard 189 (ASHRAE, 2011), adopted by the U.S. Department of Defense.

Currently, there are over 36 national and regional organizations that identify themselves with various aspects of sustainable design. Among those organizations, some of the most notable include the following: American National Standards Institute's Green Building Initiative (GBI) and the Green Building Assessment Protocol for Commercial Buildings (GBI 01, 2010), ASHRAE Standard 189 (ASHRAE, 2011), Standard for Design of High Performance Green Buildings and Advanced Energy Design Guide, and the U.S. Department of Energy's (DOE) Labs for the 21st Century and Building Energy Codes Programs. Each of these organizations has generated and compiled a great volume of information to guide design teams in many aspects of sustainable design and high-performance buildings. For example, the DOE's Labs for the 21st Century offers a comprehensive tool kit of best practices, design guides, performance rating system, case studies, and installable programs for recording data and performing energy analyses on a compact disc (CD). *Environmental Performance Criteria* (Labs21, 2008) and *Design Guide for Energy Efficient Research Laboratories* (LBNL

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

Publication No. 777; Lawrence Berkeley National Laboratory, 2003) are also two very useful guides.

Two organizations offer building certification programs based on sustainability. They are by Green Globe/GBI and by U.S. Green Building Council (USGBC) with Leadership in Energy and Environmental Design (LEED®). At the time of publication of this book, the USGBC has a draft standard to offer for certification of laboratory buildings, "Application Guide for Laboratories" (LEED®-AGL, pending). The EPC is the basis for LEED®-AGL development. The International Living Building Institute offers a Living Building Challenge Certification Program. The Tyson Research Center, a field biology laboratory building, achieved this certification in October 2010. This building is owned and operated by Washington University in St. Louis.

Dr. Timothy M. Smith of the University of Minnesota prepared a study for The Western Council of Industrial Workers, "Green Building Rating Systems: A Comparison of the LEED® and Green Globes Systems in the U.S." (Smith, 2006). He found a significant overlap of 80% for LEED® 2.2 and 85% for Green Globes® of available points in the evaluation systems of each program. Although both systems have similar general categories, each system has a different emphasis. "Green Globes emphasizes Energy Use above all other categories. In contrast, LEED® allocates comparatively more points to the Materials section" (p. 4). Dr. Smith explained, "Life-cycle assessment (LCA) has become a widely used tool to assess the overall environmental, energy, and health impacts of . . . building[s]" (p. 4). Dr. Smith evaluated the Green Globe® system as having insufficient LCA criteria, although LCA principles are used, but LEED® has no discussion of LCA.

LEED®-AGL has six new credits, eight modified credits, two new prerequisites, one modified prerequisite, and one modified calculation affecting three other credits, compared to LEED®-NC 2.2. Key features of the LEED®-AGL current document follow (Matthew and Williams, 2007, pp. 73–74).

1. Sustainable Sites: Reduce hazards from laboratory effluents using modeling (physical models or CFD).
2. Water Efficiency: Reduce water to waste in domestic and process water use.
3. Energy and Atmosphere: Optimize energy efficiency and protect building occupants and the environment through the use of approved laboratory ventilation systems.
4. Materials and Resources: Use environmentally responsible finishes and laboratory furniture and manage hazardous materials flows in laboratory buildings.
5. Indoor Environmental Quality: Meet requirements of ANSI/AIHA Z9.5 (ANSI/AIHA, 2012) and NSF Standard 49 (2012), ANSI/ASHRAE 110 (ANSI/ASHRAE, 1995) test for chemical fume hoods. In addition, improve indoor air quality (IAQ), model critical indoor airflows (physical models or CFD), and improve all laboratory alarm systems.
6. General: There are reductions in performance requirements in certain credits and exemptions from other LEED-NC credits.

38.2 LABORATORY CONSTRUCTION MATERIALS

Materials and methods for sustainable laboratories concern materials' reuse, recycled content, regional availability, and rapidly renewable materials' use in the construction of safe laboratories.

38.2.1 Laboratory Furniture: Sustainable Materials/Systems

There is a variety of materials used to manufacture laboratory furniture: metals, wood, composites, and plastic laminates. There are cost differences in materials, but also in manufacturing methods that vary in achieving the following sustainable goals: use of renewable resources, recycled material content; reduction in waste in the manufacture and installation; use of low embodied energy during manufacture; no toxic materials use; and emission of low volatile organic compounds (VOC) during installation and lifetime use.

So far, although laboratory furniture and casework products have many innovations to improve sustainable materials and methods, there are still limits. Good chemical resistance, strength, and durability require robust manufactured materials and finishes from metals, plastics, and high-performance synthetic coatings and sealants. At the time of publication, these incorporate few sustainable design criteria. Tables 38-1A, B, and C summarize sustainable performance factors for laboratory casework. See Chapter 2, Section 2.2.6 and Tables 2-3, 2-4, and 2-5 for information on health and safety performance factors.

In addition to sustainable characteristics, there is also the capability of laboratory furniture so it can be relocated and reused, extending its useful lifetime. Not only do the materials themselves matter, so do the

TABLE 38-1. Laboratory Cabinet Materials Comparison of Sustainability

Material	Coated Metal	Phenolic[a]	Plastic Laminate[b]	Polypropylene[c]	Stainless Steel	Wood & Veneers
Manufactured from renewable resources	No	No	No	No	No	Yes
Manufactured w/recycled material content	No	No	Some	No	No	Yes
Manufactured w/Low Embodied Energy	No	No	Yes	No	No	Yes
Low VOC emissions	Yes	No	No	No	Yes	Yes
Durability	Good	Good	Poor	Good	Best	Good
Refinish and Repairability	Good	Good	Poor	Poor	Good	Good
Material can be recycled after removal	Yes	Yes	No	No	Yes	Yes

[a]Solid phenolic resin between craft paper layers.
[b]Chemical-resistant plastic laminates are available for laboratory cabinets.
[c]Other plastic materials, such as polyvinyl chloride (PVC) are used.

TABLE 38-2. Laboratory Work Surface Materials Comparison of Sustainability

Material	Cast Epoxy	Coated Metal	Phenolic[a]	Plastic Laminate[b]	Polypropylene[c]	Stainless Steel	Wood & Veneers
Manufactured from renewable resources	No	No	No	No	No	No	Yes
Manufactured w/recycled material content	No	Yes	No	Some	No	No	Yes
Manufactured w/Low Embodied Energy	No	No	No	Yes	No	No	Yes
Low VOC emissions	No	Yes	No	No	No	Yes	Yes
Durability	Good	Good	Good	Poor	Good	Best	Good
Refinish and Repairability	Poor	Good	Good	Poor	Poor	Good	Good
Material can be recycled after removal	Yes	Yes	Yes	No	No	Yes	Yes

[a]Solid phenolic resin between craft paper layers.
[b]Chemical-resistant plastic laminates are available for laboratory cabinets.
[c]Other plastic materials such a polyvinyl chloride (PVC) are used.

method and materials used to assemble laboratory casework. Casework that has strength, is durable, cleanable, and can be repaired and refinished depends to some extent on the way joints are made, the number of joints, and on the support system for the cabinetry. These are not only common maintenance and housekeeping issues, in some types of laboratories they are critical to achieving health and safety goals. For example, in Biosafety Level 2 and above, and in microelectronics labs or other cleanrooms, cleanliness is a critical factor. Fewer cracks and irregularities that exist in laboratory casework lower the risk from harmful dust particles and organisms. In many types of labs, casework strength and sturdiness allow heavy countertop equipment to be installed and used. Laboratory casework that collapses is a hazard from the sheer weight of the unit itself, but more so from the weight, breakage, and spills of materials contained in and upon the casework. Sometimes, the failure is not in the cabinet, but in the mounting method and/or fasteners in the wall or on the casework support system. Ratings shown in the tables below are based on the experience and opinion of the authors, no one else. A product should be reviewed for these sustainable factors, quantitative data, and compared to other products from other manufacturers. This is a rapidly changing field and new products are being introduced to the marketplace frequently; it is the responsibility of the designers to be up-to-date on new developments.

38.2.2.1 Work Surfaces. Table 38-2 shows the sustainable performance qualities of materials commonly used for laboratory work surfaces. See Table 2-3 for safety performance. As noted in Chapter 2, Section 2.2.6.2, work surfaces generally bear much harsher working conditions in laboratories than cabinets and support systems. Work surfaces are far harder to repair, modify, and refinish then successfully reuse when laboratories undergo renovations. Horizontal and vertical joint locations and penetrations for utilities or other attachments render work surfaces difficult to relocate. Some work surface materials can be recycled. Extreme care must be taken to verify the level of decontamination needed and performed. See Part I, Section B for advice on decontamination.

38.2.3 Laboratory Finishes: Sustainable Materials / Systems

Health and safety considerations for laboratory finishes that resist effects of chemicals are paramount. Sustainability characteristics are secondary, but achievable (see Chapter 2, Section 2.2.7 for health and safety options for finishing wall, floor, and ceiling surfaces). In addition to chemical resistance, ease of decontamination is also an important consideration in selection of laboratory finishes. Sustainable options for wall and floor finishes are discussed below.

38.2.3.1 Wall Finishes. High-performance, institutional grade, water-soluble, latex paints are appropriate and adequate finish coatings in laboratories where there is minimal to moderate chemical use and where most chemicals used do not produce unsightly stains if spills or splashes are cleaned up quickly. Many latex products generate relatively low volatile organic compounds (VOC) emissions during application and drying periods. Latex paints can perform well on many wall substrates when surfaces are properly prepared: clean, dry, and primed. Some latex paint products are manufactured with recycled content. Some composite wall material finishes are so durable and cleanable that they do not require refinishing during the entire life span of the wall materials.

The Master Painter Institute (MPI) tests a wide range of commercial paint products for VOC generation and off gassing, as well as other critical performance factors. MPI has green performance ratings (GPR) for paints (information available at www.paintinfo.com).

38.2.3.2 Floors. The primary, underlying floor surface material and the use and chemicals used in the space both determine materials and processes recommended to protect the floor from cracking, buckling, eroding, or wearing thin. These defects and deficiencies can adversely affect personnel safety in laboratories and the ability to keep floors clean. See Chapter 2, Section 2.2.7.2.1 for details on concrete floor finishes. Of all finishes, terrazzo, a traditional floor covering method, is durable, highly sustainable, and very appropriate for laboratory use; 70 to 75% of the material is composed of naturally occurring stone aggregates, glass, or recycled plastic. The binder can be cement or epoxy-based; terrazzo off-gas rate is very low for the life of the cured floor.

38.2.4 Laboratory Recycle Materials Storage

Many laboratories have developed recycling or reuse programs and space for these functions must be allocated. Recyclables fall into two categories: nonhazardous and hazardous materials. Hazardous materials are discussed in Section 38.4. Nonhazardous materials may include paper, glass, sharps, and nonhazardous chemicals like sodium chloride. These may be collected as part of a recycling program or reuse of chemicals and glassware. That and any future plan for a recycling program require space allocated in the building, if not in each laboratory.

38.3 HEATING, VENTILATING, AND AIR-CONIDITIONING

38.3.1 Introduction

The temperature and humidity requirements in sustainable laboratories are similar to most other laboratories. There is particular emphasis on controllability of temperature and humidity in the occupied space. Individual thermostats are recommended. The means to achieve those conditions, however, may differ.

1. Reduction in energy requirement by optimizing air exchange rates, installing low-volume, high-performance chemical fume hoods, diversity of heat and ventilation loads, and special enclosures. See Chapter 2, Section 2.3 and Chapter 35, Energy Conservation, for these methods.
2. Reduction in water usage and water to waste
3. Right-sizing of HVAC equipment

The objective of sustainable design is to reduce energy and costs of operating laboratory buildings.

Experienced designers must explore all sustainable options available in design. The cost premium for sustainable design is hard to document accurately, due to multiple variants in the data. Return on investment is a more neutral measure of relative cost and savings that can be achieved. The DOE published results from operation of its 2006 laboratory at the National Renewable Energy Laboratory located in Golden, Colorado. The Science and Technology Facility (S&TF) at 71,347 ft^2 (6,628 m^2) is an advanced materials research laboratory that includes a 10,170 ft^2 (945 m^2) hazardous production materials (HPM) facility. Table 38-3 and Figures 38-1 and 38-2 are derived from DOE data reported in "Walking the Walk," in ASHRAE's *High Performing Buildings* (ASHRAE, 2008). The annual total energy graph, Figure 38-1, shows the impact of HVAC loads, 74%, in contrast to the lighting load, 8%, using advanced energy conservation systems for the S&TF.

Simple payback is the amount of time it takes for a technology feature to pay for itself, including the installation cost, but not including accrued interest.

TABLE 38-3. Annual Energy Use for the Science and Technology Facility at the National Renewable Energy Laboratory (Golden, CO) by Design, Simulation, and As Measured

	Design		Simulation	Apr '07–Mar '08 as Measured	
Ventilation[a]	25.6	62.5%	9.6	–5.2%	10.1
Cooling Plant	7.3	34.2%	4.8	–170.8%	13
Lighting	2.3	0.0%	2.3	33.5	15.7
Process/Plug[b]	19.8	–7.6%	21.3		
Heating Plant	91.9	0.0%	91.9	–48.7%	136.7

Notes: All units are in kWh/sf.
[a]Sum of energy for all supply and exhaust fans.
[b]Lighting and process/plug are combined because office lighting and plug loads are on the same meter.

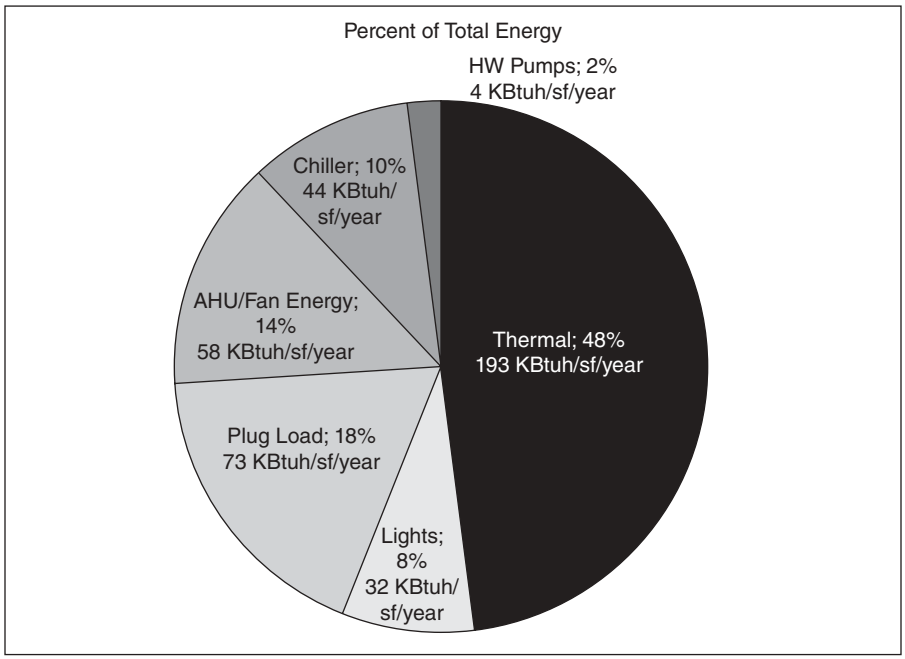

FIGURE 38-1. Annual total energy use by the S&TF laboratory.

Figure 38-2 shows six energy conservation measures that provide a simple payback in 5 years or less: energy recovery, daylight controls, chiller plant upgrade, VAV only, boiler and domestic hot water improvements, and lab air-handling units' (AHUs) evaporative section. Some payback measures range over 10 years: laboratory supplementary cooling and raised supply air temperatures, and process commercial hot water used for preheating.

The "Walking the Walk" article (ASHRAE, 2008) compares the design parameters and energy model simulation data with the actual measurements for one year in S&TF, in units of kWh/ft^2. Figure 38-1 shows there are significant deviations in actual use for cooling and heating plant energy from the simulation data,

38.3.2 Occupied and Unoccupied Schedules

Simply stated it is not cost efficient, sustainable, or energy effective to operate laboratory facilities in a full occupied mode 24 hours, 7 days a week, 365 days a year. Even though many researchers do not observe regular schedules and may visit their laboratory during unconventional hours it is not all the time. To provide energy efficiency as well allow for special use during a normally designated unoccupied period, an override system can

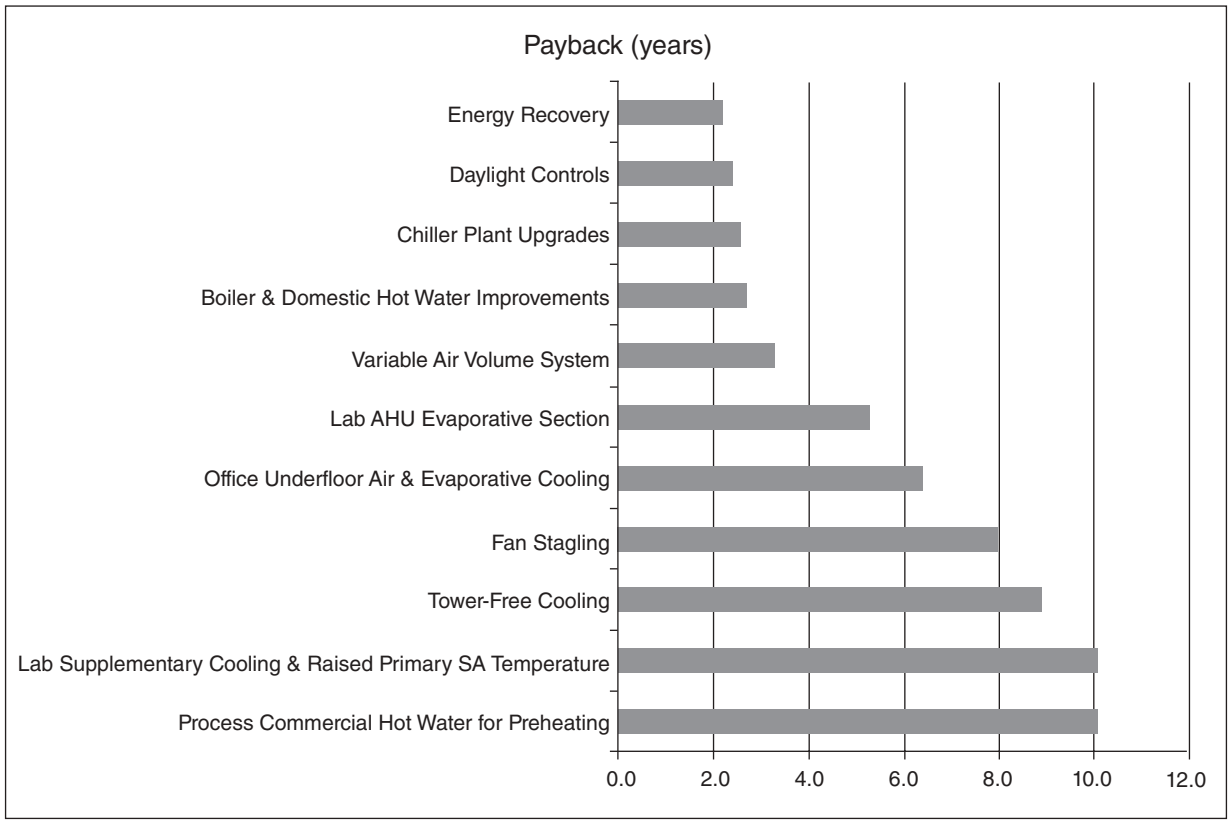

FIGURE 38-2. Simple payback (in years) of installed energy conservation systems. AHU = air-handling unit; SA = supply air.

be used that will provide full operation of the environmental systems (HVAC, lighting) in the selected area. Chapter 35, Energy Conservation, describes in detail many of the occupied/occupied strategies.

38.3.3 Net-Zero Buildings

"Net-zero" is a term commonly used for buildings in which energy consumption is equal to energy output. The only way this can be accomplished is to ensure that power consumed in the building is low by design and local power generation is provided at the building. Some common power generation techniques are as follows:

1. Photovoltaic (PV) System: These systems have been used for decades; however, now the cost per watt of power has decreased. These systems require large open areas for solar collector installations. These may be designed for roof installation or on the ground.
2. Wind Turbines: These systems too have decreased in cost per watt of power generated. They too require large open areas for collector installations on roofs or more effectively, on the ground.
3. Co- or trigeneration: This technique uses a building generator to produce energy that is then either used in the building or sold to a utility grid. Many times, waste heat is also used for heating buildings, hence the term *cogeneration*. If the waste heat is used for cooling purposes and is produced by absorption chillers, the process is called *trigeneration*.

Net-zero laboratory buildings are a real challenge to achieve, due to large, critical electrical consumption by building and scientific equipment. Typical laboratory buildings consume 3–10 times the energy required for office building use.

Selection of laboratory equipment and operating conditions can have a positive effect on the sustainable operation of laboratories. Labs21 and NIH, among other organizations, have been advancing new ideas and techniques to this end. December 13–14, 2012, NIH conducted a workshop "2012 International Conference on Sustainable Laboratories: Choosing the Right Equipment" (http://orf.od.nih.gov/PoliciesAndGuidelines/Choosing_the_Right_Equipment.htm). This conference explored choosing scientific equipment for energy efficiency and

included autoclaves, biosafety cabinets, chemical fume hoods, freezers, refrigerators, and sterilizers.

38.4 LOSS PREVENTION, INDUSTRIAL HYGIENE, AND PERSONAL SAFETY

38.4.1 Introduction

The primary goal is that any design changes for sustainability do not compromise or adversely affect principles for loss prevention, industrial hygiene, and personal safety found in Section 4 of Chapters 1–4. Particular attention should be paid to fire protection issues such as smoke, heat and flame detection, and suppression methods and systems, and to indoor chemical and pollutant source control. This care is required due to possible use of newer material combinations and composites where combustibility characteristics may be untested or unknown. A careful reading of these sections will be helpful. Chemical contamination considerations are discussed as part of Section 2 in Chapters 5 and 6.

38.4.2 Recycle Program for Hazardous Materials

There may be a program to reuse or recycle hazardous chemicals. For reuse, there may be a requirement for proper storage space, separated from materials used in laboratories. A central building area for hazardous chemical reuse storage is required.

38.5 MISCELLANEOUS SERVICES

38.5.1 Water Conservation and Quality Preservation

Many laboratory buildings use a far greater amount of domestic water than most commercial building types, which use water primarily for sanitary and kitchen functions. Some of the water usage is related to function and cannot be reduced. However, there are opportunities in laboratories for water recycling and reduction. This water may be used for cooling laboratory equipment; often it goes directly down the drain to a wastewater treatment system, rather than directed for reuse in secondary processes such as toilet flushing, landscape irrigation, and prewash cycles on washers used for laboratory glassware or research animal cages. Sustainable design encourages water conservation through reuse.

38.5.1.1 Laboratory Purified Water. Pure water systems, often found in laboratory buildings, should be investigated for water conservation opportunities. See Chapter 1, Section 1.5.7 for details of pure water system requirements. A good design solution to keep pure water faucets closed, is to install faucets that have to be manually turned on and kept in the open position for water flow. Many local RODI (RODI Systems Corp., Aztec, NM) water-polishing units eject five times the volume of water than the purified water volume. This reject water, though high in minerals, is adequate for several other functions, such as cooling tower make-up water, landscape irrigation, and toilet flushing. Consider recycling methods to reduce the enormous waste of clean water. Central RODI purification systems also eject clean water, but at lower rates. Capturing this water for ancillary use is a sustainable design innovation.

38.5.1.2 Laboratory Equipment Water-Recycling and Recirculation. Laboratory-type glass washers and animal cage washers use significant amounts of water. Some of the water is sent to drain at fairly high temperatures. Collecting the final rinse water to use for prewash cycles is a convenient and effective way to reduce water consumption. Most manufacturers provide this equipment feature at a reasonable cost.

Other types of laboratory equipment use water strictly for cooling. These include lasers, vacuum pumps, mass spectrometers, and other equipment that generate excessive heat. Common practice is to connect laboratory equipment directly to a faucet and provide a hose that goes to a floor or sink drain. Sustainable design offers a closed, recirculating chilled water loop to a single instrument or series of instruments, using heat exchangers to keep the water temperature cool and small pumps to circulate the water at the correct pressures and flow rates. Water lines are designed with pressure-reducing valves, shut-off valves, and other controls as required for each instrument in the loop, to maintain good operating conditions. This method can save millions of gallons of water in laboratory buildings filled with water-cooled instruments.

38.5.1.3 Site Water Conservation. Collection of rainwater in a cistern beneath buildings to use for site irrigation is another excellent water conservation design strategy. Other applications to consider are ways to minimize the amount of storm water runoff from buildings and site paving. Design of retention ponds with select plantings, green roofs, blue roofs, pervious pavement materials, and other design strategies can maximize the time for rainwater to leave the site and bring benefits to the overall landscape.

38.5.1.4 Wastewater Treatment. Onsite wastewater treatment reduces the impact on municipal sanitary sewer systems and allows use of treated wastewater within the building site. There are two broad categories of wastewater treatment.

- Grey water is that part of the sewage that excludes fecal matter, and can be easily disinfected, stored, and reused.
- Black water has all kinds of solid matter; thus, great care should be taken before this water is treated and reused.

To ensure success of a wastewater treatment program, there are some operational challenges that first must be considered. Laboratory researchers should not pour hazardous chemicals down the drain; all chemicals must be collected and disposed of in an appropriate and legal manner.

Supply water must be protected both inside and outside of laboratory buildings. Backflow preventers protect the domestic water supply in laboratory buildings from accidental contamination from chemicals and other contaminants. Chapter 1, Section 1.5.3 discusses methods required to protect the water supply and contain contamination.

38.5.1.5 Condensate Reuse. In AHUs, as supply air passes through the cooling coil and is cooled, the reduction in temperature reduces the dew point of air and moisture in the air is condensed. Normally, this condensate is collected in drain pans and wasted. A sustainable design feature can be to collect this condensate for reuse.

38.5.1.6 Cooling-Tower Water Use Reduction. In most large buildings, water-cooled chillers provide the cooling capacity. The heat of rejection from the refrigeration cycle is cooled by evaporation of water particles in the cooling tower. Most cooling towers have a drain pan. Accidental overflow of a drain pan can create a very large water loss and should be prevented. In addition, as water evaporates the level of particulate concentration in the sump water increases. Algae growth is possible on an open sump. The condenser water pipe is subject to corrosion. Traditionally, chemical treatment is provided to prevent this issue. A certain amount of water is routinely drained from the tower to maintain the appropriate level of chemicals and level of particulate. Several techniques are available to reduce water loss and conserve water are described in Chapter 1, Section 1.5.3.5.

38.6 LIGHTING

One common sustainable design strategy is to install an efficient lighting system with control capability. This control can be either occupancy sensors or daylight sensors. More details are described below. A reduction in the energy required for general lighting can be accomplished in laboratories by using strategically located task lighting at desks, laboratory benches, and workstations. The use of energy-efficient fluorescent tubes and ballasts along with multiple switching will also conserve electrical energy. Lighting should be maintained at the levels outlined in Chapter 1, Section 1.5. Lighting is an area where energy savings can be accomplished. The exact light level needed for various laboratory tasks is still controversial. Wherever possible, natural lighting should be used. It is therefore easy to overlight or underlight a specific area. Light levels on bench tops, in equipment rooms, and in storage areas should be reviewed.

Use of day lighting to eliminate electrical light usage in daytime or when ambient lighting is high is a very effective strategy. Light tubes are used to bring daylight even in interior spaces. A computer simulation of building operation can provide an evaluation of day lighting; a glare analysis for different fenestration systems and configurations provides an optimum solution.

Automatic light switching using occupancy or motion sensors can be very effective. Use of occupancy sensors in bathrooms is recommended to ensure an occupant is not left in dark should the automatic system switch off the light. Another method is to shut lights off based upon the building occupancy schedule. There are several novel methods for lighting control. The key here is to select a system that is reliable and simple to use otherwise there are no savings. Override switches can provide local lighting when lights are normally off. Such switches are highly recommended as they allow safe operation of a laboratory during a normal unoccupied period. In fact, all light fixtures can be interconnected electronically and can be controlled from the building energy management system.

In recent years there has been tremendous progress in efficient light source and lighting fixture design. An efficiently designed light fixture will transmit most of the light to the working surface with less loss.

Light sources have also progressed and more options are available to designers. Incandescent lights are very energy inefficient and their use should be discouraged. Compact fluorescent bulbs provide attractive cost-effective alternatives. T-8 and T-5 type lights with high-energy efficient ballasts are readily available. LED-(light-emitting diode-) based light fixtures can provide equivalent light intensity, but with a very limited use of electricity.

A team effort with all building users and designers is recommended to ensure that an attractive, energy-efficient, easily maintained light fixture is selected. Careful attention to light-fixture location should be paid; in general, light fixtures parallel to laboratory benches are more efficient.

38.7 SUBMETERING

A strong sustainable design strategy is to ensure the building continues to operate as designed, and energy and water are not wasted. Selected water, electricity, or other submeters in the building can be connected to selected loads and can be monitored on a regular basis. If an unexpected increase in usage is noticed in any submeter, building operators can explore operating parameters in that focused system. This prevents unfocussed efforts.

38.8 ADDITIONAL BACKGROUND MATERIAL

Organizations who have developed sustainable design guidelines include:

American Solar Energy Society (ASEA)

American Institute of Architects' (AIA) Committee on the Environment

Environmental Building News (EBN)

EPA's Energy Star Program

Green Building Initiative's (GBI) Athena® Environmental Impact Estimator

Green Globe's (GG) Building Certification Program

National Fenestration Rating Council (NFRC)

National Institute of Standards and Technology's (NIST) BEES Life Cycle Assessment, CONTAM Multizone Indoor Air Quality and Ventilation Analysis, LoopDA Natural Ventilation Design Tool, and EVAP_COND Simulation Models for Finned-Tube Evaporator and Condenser

Sustainable Buildings Industry Council (SBIC)

South Coast Air Quality Management District (SCAQMD)

Scientific Certification Systems (SCS)

Sustainable Forest Initiative (SFI)

U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED®) Building Certification Program

PART VI

APPENDIXES

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

APPENDIX A

EMERGENCY SHOWERS*

1. The pull ring should not be more than 69 in. (1.8 m) from the floor except where disabled persons are involved, and then the maximum should be determined functionally (Figure A-l).
2. The shower head should be at least 84 in. (2.1 m) from the floor (Figure A-l).
3. The shower head should be an "Emergency Deluge Shower" as manufactured by the Speakman Company (Speakman, 2010) or its equivalent.
4. The horizontal distance from the center of the shower head to the pull bar should not be greater than 24 in. (0.6 m).
5. The shower should provide at least 20 gal/min (1.2 L/s) flow with the operating valve in the open position.
6. Tempered water showers should be equipped with a mixing valve with an "antiscald" feature such as manufactured by Powers, Series XP Hydroguard (Powers, 2010).
7. Tempered water showers should be preset at a temperature between 60°F and 100°F (16–38°C).
8. The valve for the shower should be quick acting, such as a ball valve, and should remain open after the initial pull until manually closed.

*For additional information, see the American National Standards Institute Standard for Emergency Eyewash and Shower Equipment (ANSI.Z358.1, 2009).

See Section 2.4.1.6 for more information on emergency deluge showers.

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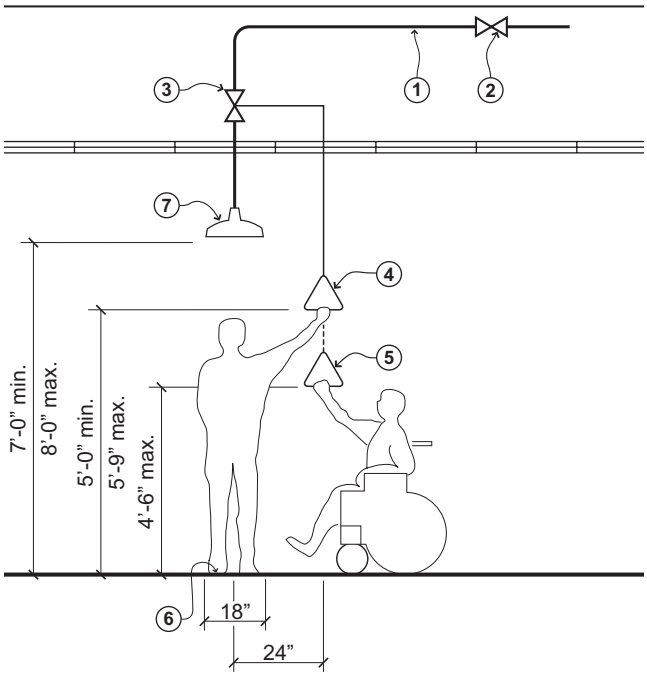

KEY

1 1 Inch I.P.S. or Larger
2 Tagged Shut-Off Valve
3 Operation Valve
4 Hand Pull
5 ADA-Compliant Hand Pull Extension
6 Area of Floor Marked Yellow
7 Deluge Shower

FIGURE A-1. Deluge shower: Diagram.

APPENDIX B

EMERGENCY EYEWASH UNITS*

1. Eyewash units shall be approved as such by the manufacturer. Haws Drinking Fountain Company's "Emergency Eyewash," or its equivalent, should be used.
2. The water supply must be potable and capable of providing 3–7 gal/min (0.2–0.5 L/s) depending on the type of eyewash used.
3. For each floor of the building or for each group of labs there should be at least one tempered eyewash unit.
4. Tempered water eyewash units should be equipped with a mixing valve with an "antiscald" feature such as manufactured by Powers, Series XP Hydroguard (Powers, 2010).
5. Tempered water eyewash units should be preset to a temperature of 60–100°F (16–38°C).
6. For disabled persons' use, the hand-held eyewash spray on a hose is the recommended unit.

*For additional information, see the American National Standards Institute Standard for Emergency Eyewash and Shower Equipment (ANSI.Z358.1, 2009).

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APPENDIX C

SIGNS

Signs posted throughout laboratory buildings and laboratories are used for many purposes. Among them are:

1. Identifying exits and safety equipment and procedures
2. Identifying electrical, piping, plumbing, and other facility-type equipment
3. Identifying hazardous materials, equipment, and special conditions

The first two purposes have been well defined, and standard methods exist for indicating exits, pipe content, electrical runs, and panels in ANSI Z535.2, "Environmental and Facility Safety Signs" (ANSI, 2007). Hazardous materials, equipment, and special conditions are covered by agency requirements for radioactive materials, lasers, biological hazards, and the like. The problem that led to the development of the sign system presented here is related to three concerns: (1) people's real use of the facilities (e.g., laboratory personnel sometimes nap in laboratory lounges without the general knowledge of others), (2) emergency responders have a need to know about facility layout and presence of hazardous materials, and (3) the availability of a logical and manageable information system to facilitate dealing with the first two concerns.

Two surveys were made of laboratories across the country, including university, government, industrial, commercial, and nonprofit establishments, to determine what sign information systems were in use. The results showed that no uniform system seemed to have worked well, including NFPA 704 (NFPA, 2012). However, many useful ideas were gleaned from the study (Gatwood et al., 1985), resulting in the "General Policy" discussion below.

The study showed the following:

1. Respondents using NFPA 704 were experiencing difficulties with training, maintenance, quantity decision, improper information, and lack of information.
2. Fire department and emergency response personnel can be expected to know that laboratories generally contain some flammable liquids, toxic chemicals, compressed gases, and other hazards.
3. Fire department and emergency response personnel may already have some familiarity with laboratories through in-service inspections, site visits to grant annual permits/licenses, plan review, and special reviews by owner/occupant.
4. Signs on doors alone may be insufficient to help a firefighter, particularly when fire and smoke render them unreadable.
5. The sign system needs to be as simple, yet as effective, as possible.
6. Fire department and emergency response personnel should not have to learn, understand, or commit to memory unique systems. The information should be self-evident.

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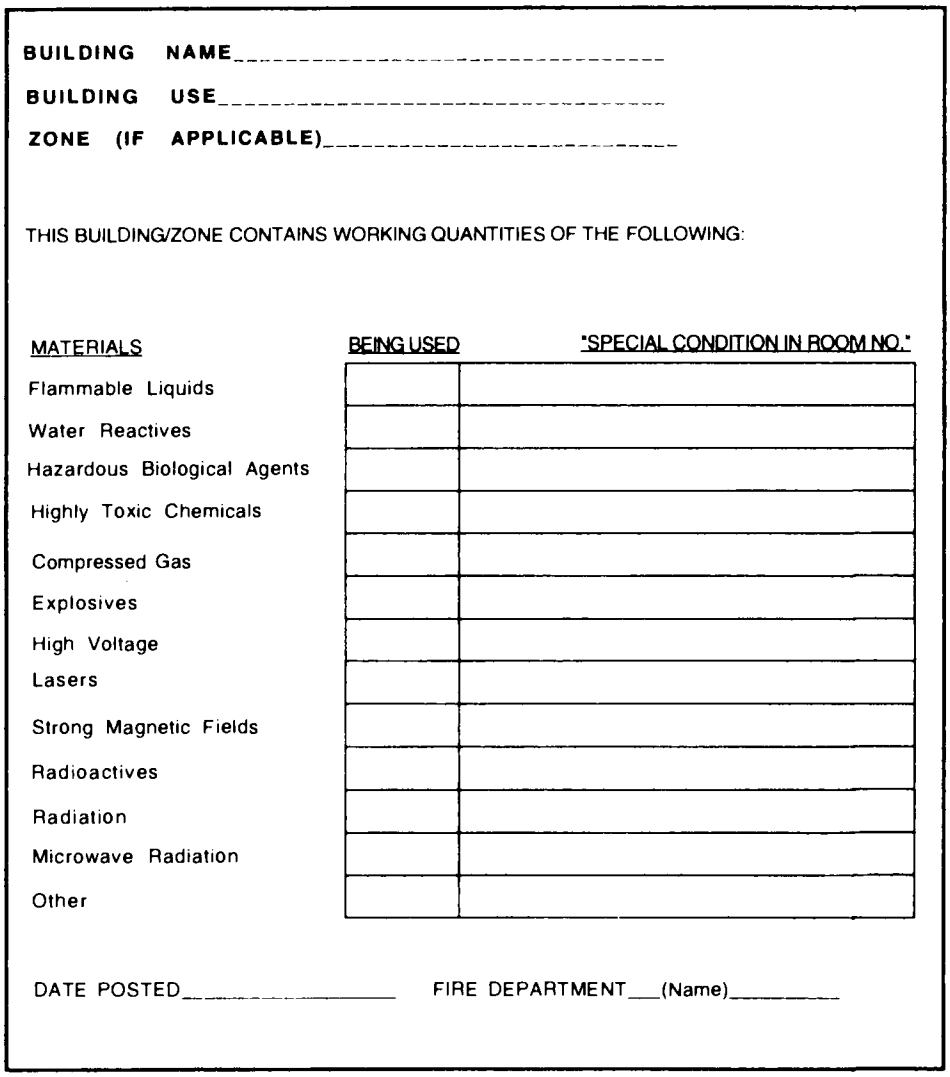
7. Frequent changes to signs should be avoided, given the administrative difficulty of maintaining signs.
8. Experiments and their associated materials often move from room to room within a research group.
9. Various jurisdictional agencies require signs that may already be present, and they should be acceptable to the sign plan. Examples are biohazards, radiation, strong magnetic fields, lasers, UV light, explosives, and high-voltage signs.
10. Emergency response and fire department personnel can be expected to enter each building at a prescribed location that should give them access to an annunciator panel and building information.
11. Signs, as seen in many laboratory facilities, have so much detailed information in multiple panels, sometimes eight or ten, that they are confusing and not very helpful in an emergency, even though the information is correctly maintained.

GENERAL POLICY

Simplicity

At the primary fire department and emergency response personnel entrance to each building containing one or more laboratories, there should be a Type I sign (Figure C-1) indicating the types of laboratories, the common hazards expected to be encountered, and a notation about special hazards and their location within the



BUILDING NAME_____

BUILDING USE_____

ZONE (IF APPLICABLE)_____

THIS BUILDING/ZONE CONTAINS WORKING QUANTITIES OF THE FOLLOWING:

MATERIALS	BEING USED	"SPECIAL CONDITION IN ROOM NO."
Flammable Liquids		
Water Reactives		
Hazardous Biological Agents		
Highly Toxic Chemicals		
Compressed Gas		
Explosives		
High Voltage		
Lasers		
Strong Magnetic Fields		
Radioactives		
Radiation		
Microwave Radiation		
Other		

DATE POSTED_____ FIRE DEPARTMENT___(Name)_____

FIGURE C-1. Type 1 sign at building entrance.

building. At this building location, if appropriate, there may be supplemental information such as building diagrams, zone diagrams, voice alarms, and protection system(s) information.

A copy of this Type I sign, where appropriate, should be posted at each zone entrance.

A second sign (Type II, Figure C-2), should be posted on the room door of any room containing a special condition or hazard, as also noted on the sign at the entrance to the building or zone.

What constitutes a special hazard or condition may be defined in general terms, such as "appreciable quantity of water-reactive metals in which a fire should not be fought with water" or "an area of a building where persons might be expected to be napping." However, specific situations should be determined on an individual basis by management and the fire department. Considerations of quantity should, of course, be a part of that procedure. Signs indicating special cases should, as mentioned, be located on the room door, at the zone entrance, and at the building's primary fire department and emergency personnel entrance.

For design personnel, this means providing space in the various parts of the laboratory building for the clear-view placement of the signs.

Before adoption of any sign system, communication with the local authority having jurisdiction, such as the local fire department, should be initiated. The sign formats shown (Figures C-1 and C-2) may be modified to adapt them to specific needs.

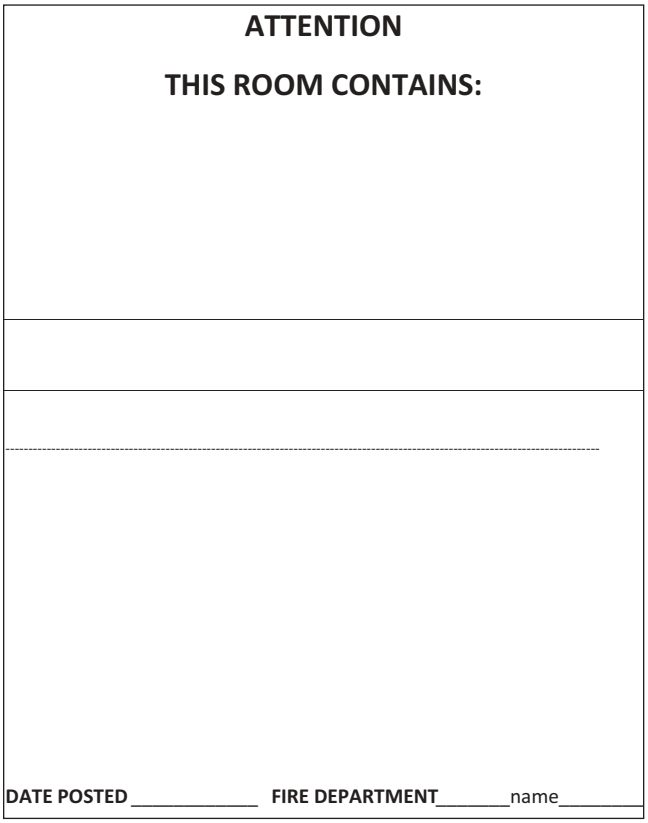


FIGURE C-2. Type 2 sign for doors of rooms containing special hazards.

APPENDIX D

STACK DESIGN

The following has been reprinted with permission from AIHA/ANSI standard Z9.5 -2012, Laboratory Ventilation, Appendix 3: Selecting Laboratory Stack Designs.

Necessary measures must be taken to protect the laboratory building and adjacent buildings from re-ingestion of toxic laboratory chemical hood exhaust back into a building air supply system. The 10 ft (3.05 m) minimum stack height called for in the body of this standard is primarily intended to protect maintenance workers from direct contamination from the top of the stack. However, the minimum height of 10 ft is not enough by itself to guarantee that harmful contaminants would not be re-ingested. Similarly, a minimum 3000 fpm (15.3 m/s) exit velocity is specified in the body of this standard, but this exit velocity does not guarantee that re-ingestion will not occur.

This appendix describes general stack design guidelines and three analysis methods for determining an adequate stack design. The first analysis method is termed the "Geometric" method, which ensures that the lower edge of an exhaust plume stays above the emitting building and associated zones of turbulent airflow. The geometric method is fully described here and is accompanied by an example. The second analysis method, briefly described, predicts exhaust dilution at downwind locations. The dilution equations are not presented here but can be obtained from the *ASHRAE Handbook—HVAC Applications*. A dilution criterion is presented in this appendix to judge the adequacy of the predicted dilutions in minimizing re-ingestion. The third analysis method described is wind tunnel or water flume modeling.

GENERAL GUIDELINES

Laboratory chemical hood exhaust stacks should have vertical, unobstructed exhaust openings. The Building Air Intake and Exhaust Design chapter of the *ASHRAE Handbook—HVAC Applications* describes appropriate rain protection devices. Goosenecks, flapper dampers, and rain caps are unacceptable as they deflect the exhaust sideways or downward, making it much more likely that re-ingestion will occur.

The stack must reach high enough to ensure that the exhaust plume is sufficiently diluted when it reaches sensitive areas such as building air intakes, entrances, operable windows, and outdoor plazas. The appropriate stack height is a function of the plume height for the exhaust system being designed and the subsequent dispersion, or concentration levels at the aforementioned sensitive locations. The dispersion modeling process (numerical or physical modeling) is discussed in a later section. The plume rise should be calculated using the equations that compute plume rise versus downwind distance. If two exhaust systems give the same plume height at the same downwind distance, the dispersion and resulting concentration levels will be identical. It should be noted that by adding 5 to 10 ft to the stack height and decreasing the exit velocity, the same plume

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rise (and dilution) can be achieved which can lead to the fan energy savings.

For a given exhaust flow rate, reducing the exit diameter with an exhaust nozzle is recommended to increase the exit velocity and rise or throw of the exhaust over the building. However, exit velocities much larger than 3000–4000 fpm (15.3 to 20.4 m/s) may result in high noise and vibration. Too small of a nozzle, or one with too rapid a decrease in area, could result in excessive pressure loss in the exhaust and the resulting combination of reduced flow due to fan system effect and reduced dilution and safety.

Combining exhausts into a common stack, either by manifolding exhausts or with very close grouping of stacks, will enhance the rise of the exhaust plume. Close grouping of stacks can be used for specialty exhausts that cannot be manifolded because of their chemical nature. Manifolding or combining exhausts can generally give greater benefit than installing an exhaust nozzle on a stack serving a single laboratory chemical hood.

Manifolding of exhausts can also provide some internal dilution of fume hood exhausts when the majority of chemical emissions are from an upset condition or large release from a single laboratory chemical hood. Such upset or large release conditions are the primary cause of odor complaints and potential health effects. However, this internal dilution is partially offset by the decreased atmospheric dilution due to the larger plume size. Nevertheless, manifolding of exhausts is still beneficial and recommended.

Variable exhaust flow rates, used to reduce energy costs, can periodically result in low exit velocities. Minimum exit velocities below 1500 fpm (7.65 m/s) are discouraged because for such low exit velocities, high winds can cause the exhaust to travel down the side of the stack instead of rising vertically. A dispersion modeling assessment can define the minimum exhaust velocity and volume flow needed to avoid fume reentry. If this assessment shows a higher exhaust velocity and/or volume flow is needed, there are other methods to achieve the desired dispersion:

- Variable flow geometry
- Induction of outdoor air
- Staging of multiple fans on a common inlet plenum
- Use of a control system and on-site weather station so that low velocities can be set during low wind and high velocities during high winds.

Adding outdoor air to the exhaust is the most common approach because it provides the larger plume rise and some internal dilution.

Air intake placement is as important as stack design. Intakes on the side of the building or at grade will usually provide greater protection from rooftop exhausts. Intakes on the roof may work if placed a sufficient distance from the exhausts. When only a single tall stack is present, an intake location near the base of the stack may be a good location. The advantage of this location is diminished if there are sources of toxic or odorous exhausts at other locations on the roof. Nearby intakes elevated above a laboratory exhaust stack should be avoided.

Rooftop obstacles, such as parapets or architectural fences, and penthouses on the same roof as the hazardous exhaust stack can also act as adjacent buildings causing wind flow disturbances that reduce the rise of the exhaust. Note that it is the difference in roof heights that is particularly important when analyzing the adjacent building effect.

FIRST STACK DESIGN METHOD—THE GEOMETRIC METHOD

The *ASHRAE Handbook—HVAC Applications* describes the geometric method. This simplified method is intended to be conservative, but there are limits on its applicability. The *ASHRAE Handbook* also describes those limits.

The geometric method is designed for isolated rectangular buildings that do not have taller buildings, dense taller trees, or taller hills close to the laboratory building. Also air intakes on the emitting building should be no higher than the top of the physical exhaust stack opening. Provided these conditions are met, the geometric method can be applied as follows:

1) Calculate the length of the recirculation zone (R) downwind of the building for each of the four basic approach wind directions. For a given direction, $R = (B_{small}^{0.67})(B_{large}^{0.33})$, where B_{small} is the smaller of the building height and width, and B_{large} is the larger of the two. As used here, the recirculation zone height is the height of the emitting building.

   Table A2 presents recirculation zone length for various building dimensions.

2) Calculate the plume rise (throw) due to exhaust momentum and add it to the stack height, to obtain the effective stack height.

   $h_f = 0.9[F_m U_H / U^*]^{1/2} / [U_H \beta_j]$ is the final plume rise, where

   $F_m = V_e^2 (d^2 / 4)$ is the momentum flux, ft^4/s^2 (m^4/s^2)

$\beta_j = (1/3) + (U_H / V_e)$ is the jet entrainment coefficient

$U_H / U^* = 2.5 \ln (H / z_o)$ is the well-known logarithmic wind profile equation,

V_e = stack exit velocity, fpm (m/s)

d = stack diameter, ft (m)

U_H = wind speed at stack top, fpm (m/s)

H = stack height above ground level, ft (m)

U^* = friction velocity, ft (m)

z_o = surface roughness length, ft (m)

Table A1 describes various z_o values for a range of sites. For example if z_o equals 0.5 m and H = 11 m, substituting into the logarithmic wind profile equation gives $U_H/U^* = 8.3$.

Table A1. Terrain Factors

Terrain	z_o, ft (m)
Flat, water, desert	0.03 (0.01)
Flat, airport, grassland	0.16 (0.05)
Suburban	2.0 (0.6)
Urban	6.0 (2.0)

The 1%-wind speed is a high wind speed exceeded only 1% of the time. These wind speeds are available for numerous locations in the *ASHRAE Handbook—Fundamentals*, chapter on Climatic Design Information.

3) The effective height of the stack is the physical stack height plus the added plume rise due to momentum.

4) The geometric method, as stated here, specifies that the bottom of an exhaust plume should clear the emitting building, including penthouses, and the recirculation zone downwind of the building. The bottom of the plume extends downward at a 5 : 1 slope (5 units horizontal and 1 unit downward) from the effective stack height (physical height plus added plume rise). This should be done for all four of the basic approach wind directions. Table A3 shows flowrates required to meet the geometric method, given a 10 ft (3.5 m) stack height and a 3000 fpm (15.3 m/s) exit velocity (as per this standard), a 1%-wind speed of 15 mph (24 k/h), and various horizontal distances to clear. The horizontal distance is the distance between the stack and the downwind building edge plus the recirculation zone length.

The same method can be used to determine a taller stack that also complies.

EXAMPLE CALCULATION FOR THE FIRST STACK DESIGN METHOD—THE GEOMETRIC METHOD

A laboratory building is 100 ft (30.5 m) wide, 200 ft (61 m) long, and 60 ft (18.3 m) high. A manifolded laboratory exhaust with a flowrate of 10,000 cfm (4.7 m^3/s) is located in the center of the roof. For wind approaching the 100 ft (30.5 m) wide side, B_{small} is 60 ft (18.3 m) and B_{large} is 100 ft (30.5 m). The length of the recirculation zone is $R = (60^{0.67})(100^{0.33})$ = 71 ft (21.7 m). The horizontal distance that must be cleared by the plume equals 100 ft (30.5 m) from the center to the edge of the building plus 71 ft (21.7 m) for the recirculation zone, or 171 ft (52.2 m). The required effective stack height to clear the building and recirculation zone is 171/5 (using the 5 : 1 slope) = 34.2 ft (10.4 m).

The added stack height due to momentum is calculated next. The stack diameter is 2.06 ft (63 m) based on a 3000 fpm (15.3 m/s) exit velocity and a 10,000 cfm (4.7 m^3/s) flow rate. Using a 15 mph (24 k/h), 1320 fpm (6.7 m/s) 1%-wind speed, the added stack height = 3 * 2.06 * 3000/1320 = 14 ft (4.3 m). Given a physical stack height of 10 ft (3.05 m) based on the minimum required to meet this standard, the effective stack height is 14 + 10 ft = 24 ft (7.32 m).

The required effective height computed above is 34.2 ft (10.4 m), which is not met with a 10 ft (3.05 m) physical stack height. The designer can increase the physical height to 20 ft (6.1 m). As an alternative, the designer can increase the momentum of the air by introducing outside air to the system. If the physical stack height remains at 10 ft (3.05 m), the diameter would need to increase to 3.5 ft (1.1 m), increasing flow rate to about 30,000 cfm (14.1 m^3/s). Also, increasing to 30,000 cfm (14.1 m^3/s) will increase in-stack dilution by a factor of 3:1. This in-stack dilution, whether achieved by manifolding exhausts in the building or by adding roof air, can be very valuable to achieving safe results. The other wind direction (aimed toward the long side of the building) should be checked, but for this example this wind direction is the worst case.

High volume flow in itself is not a guarantee of adequate dilution. For a given source spill rate in kilograms/second, a higher exhaust volume flow Qe increases the in-stack dilution, but somewhat reduces the atmospheric dilution because the atmosphere is now presented with a larger volume of gas to disperse.

Tables A2 and A3 assist in estimating a stack height that ensures that the plume avoids recirculation zones and the edge of the building.

Table A2. Length of Downstream Recirculation Zone, Feet (Each Story Is 15' High)

Bldg.Dimensions	1 Story	2 Stories	3 Stories	4 Stories	5 Stories	6 Stories	7 Stories
Height in Feet	15	30	45	60	75	90	105
Length or Width							
50	22.3	35.5	46.6	53.1	57.2	60.7	63.9
75	25.5	40.6	53.3	64.6	75.0	79.7	83.3
100	28.1	44.6	58.6	71.0	82.5	93.2	101.6
150	29.8	51.0	67.0	81.2	94.3	106.5	118.1
200	29.8	56.1	73.6	89.3	103.7	117.1	129.9
250	29.8	59.6	79.2	96.1	111.6	126.1	139.8
300	29.8	59.6	84.2	102.0	118.5	133.9	148.5
500	29.8	59.6	89.4	119.2	140.3	158.5	175.7
1000	29.8	59.6	89.4	119.2	149.0	178.8	208.5

Formula for figure is:

Length of downstream recirculation zone is $B_{small}^{(0.67)} * B_{large}^{(0.33)}$ where B_{small} is the smaller of height and width or length and B_{large} is the larger of the two (from ASHRAE, 1997).

Where B_{large} is >8 B_{small}, use $B_{large} = 8\ B_{small}$

Table A3. Volume Necessary to Achieve Throw Off Edge of Building and Recirculation Zone, cfm Assume Stack Is 10 ft (3.05 m) High and Fan Exit Velocity Is 3000 fpm (15.3 m/s) With 15 mph (24 k/h) Wind Speed

Distance to Edge of Building & Recirc. Zone	Feet to Throw Horizontally	Flow Needed, cfm
	75	1,267
	100	5,068
	150	20,272
	200	45,612
	250	81,088
	300	126,699

SECOND STACK DESIGN METHOD—THE NUMERICAL METHOD

A more detailed analysis that accounts for dilution within the plume can be used if the required stack heights or flowrates are too large from the geometric method. Minimum dilution can be predicted using equations from the *ASHRAE Handbook—HVAC Applications*. The equations are not discussed in detail here. These equations apply only to intakes below stack top. The stack height used in these equations is the physical stack height only. "Effective stack height," including the effect of plume rise, should not be used. The EPA screening dispersion model, SCREEN3, can also be used in certain situations to supplement the *ASHRAE Handbook* equations.

The numerical methods are continually evolving. Designers are advised to consult current sources for specific calculations. The discussion here illustrates issues; it does not teach a design procedure.

For the example case discussed above [10 ft (3.05 m) stack, diameter = 2.06 ft (0.628 m), exit velocity = 3000 fpm (15.24 m/s), flowrate = 10,000 cfm (4.7 m^3/s), receptor at end of wake recirculation zone 171 ft (52.2 m) away], the predicted minimum dilution from the *ASHRAE Handbook* is 455 : 1. If the diameter is increased to 3.5 ft (1.07 m) associated with a larger flow rate of 30,000 cfm (14.1 m^3/s), the minimum dilution decreases to 264 : 1.

At first glance, the smaller flowrate stack that yields the larger dilution would seem to be preferred. However, the larger 30,000 cfm (14.1 m^3/s), flowrate provides an internal dilution of 3 : 1 compared to the original 10,000 cfm (4.7 m^3/s). When comparing the two cases, the larger flowrate case has a total dilution of 3 * 264 = 792 : 1, which is better than the lower flowrate case and would provide lower chemical concentrations at an air intake for a given chemical release rate. Allowable spill rate to meet the 0.05 ppm at the receptor location would be 11.2 L/m of toxic vapor. The original design with d = 2.06 ft (0.63 m) has a higher dilution Dcrit of 455 but the reduced volume flow only allows a spill volume rate of 6.4 L/m. In effect, the factor of 3 volume flow increase in the stack with the fan allows about a factor of 1.75 increase in allowable spill rate.

In conceptual terms, exit velocity and volume flow rate are "equal partners" in plume rise and the resulting increase in safety through greater dilution. However, in practical terms, exit velocities can only be increased by doubling or tripling while manifolding or adding roof air to the stack can easily result in a 10-fold increase in dilution.

Dilution in the context of dispersion of laboratory exhaust is a deceptively difficult concept because one

must account for both the dilution within the exhaust system, D_e, which is present at the stack and the dilution from the stack to a downwind location, D. The concept can be simplified by normalizing D by the volume flow rate through the exhaust stack, Q. By normalizing D, only the dispersion, which occurs between the exhaust stack and the downwind location, needs to be considered.

The normalized value can be presented in one of two ways, either as a normalized dilution or a normalized concentration value. A normalized dilution value can be obtained by multiplying D by the ratio of the actual volume flow rate and a standardized volume flowrate [i.e., 1000 cfm (4.7 m^3/s) * (Q_{act} / Q_{std})]. The result is a dilution value that is independent of the actual volume flowrate through the exhaust stack, making it possible to compare the effectiveness of various exhaust stacks with different volume flowrates, because all of the values are referenced to the same 1000 cfm (0.47 m^3/s) volume flowrate.

A normalized concentration value is obtained by applying the definitions of concentration and dilution provided in the *ASHRAE Handbook—HVAC Applications*, [C/m = 1/ (D * Q)]. The result is a normalized concentration value that is the ratio of the concentration present at the downwind location and the mass emission rate of the emitted chemical, expressed in units of $\mu g/m^3$ per g/s. This value is completely independent of the volume flowrate through the exhaust stack, and thus can be used to readily compare the effectiveness of exhaust stacks with various volume flowrates. Another advantage of this method is that if the emission rate of a chemical is known, you can simply multiply the emission rate by the *C*/m value to obtain a pollutant concentration. This concentration can then be compared directly with established health and odor limits.

DESIGN CRITERIA

When designing stacks with the numerical method, it is necessary to have a design criterion for selecting a stack design. Development of a dilution criterion can be difficult since the types and quantities of laboratory chemicals can vary significantly from laboratory to laboratory. As a starting place, it is suggested here to have the stack provide protection similar to what a laboratory chemical hood would provide a worker standing at the hood. As described in this standard, a laboratory chemical hood should have an ANSI/ASHRAE 110 test performed by a manufacturer, and the ANSI/ASHRAE 110 rating should be AM 0.05 or lower. This rating translates to the worker being exposed to 0.05 ppm or lower of tracer gas while 4 liters per minute (4 L/min.) of tracer gas are being emitted from within the laboratory chemical hood. The same 4 L/min. of tracer gas are being emitted from the laboratory chemical hood exhaust stack. The recommended design criterion is that the 0.05 ppm concentration also be the maximum concentration at the air intake. (The time constant for exposure concentrations mentioned in this standard is measuring over a 10-minute span of time.)

The detailed calculations are not presented here, but it can be confirmed that the 4 L/min. emission rate and an allowable air intake concentration of 0.05 ppm corresponds to a normalized concentration design criterion of 750 $\mu g/m^3$ per g/s or a 2800:1 dilution for a 1000 cfm (0.47 m^3/s) flowrate exhaust, 280:1 for a 10,000 cfm (4.7 m^3/s) flow rate, and a 93:1 dilution for a 30,000 cfm exhaust. These suggested design criteria is somewhat more lenient than the smaller criteria suggested in the *ASHRAE Handbook—HVAC* Applications, chapter on Laboratories, which has recommended that air intake concentrations should be less than 3 ppm due to an evaporating liquid spill in a fume hood and exhausted at a rate of 7.5 L/s. The ASHRAE criteria translate to a normalized concentration design criterion of 400 $\mu g/m^3$ per g/s or a 5000:1 dilution for a 1000 cfm flowrate exhaust. For facilities with intense chemical utilization, design criteria specific for that facility can be developed using the chemical inventory.

In the stack examples above, the 10,000 cfm (4.7 m^3/s) case had a predicted dilution of 455:1, which meets the 280 : 1 criterion for a 10,000 cfm (4.7 m^3/s) flowrate. The 30,000 cfm (14.1 m^3/s) case had a predicted dilution of 264 : 1, which also meets the 93 : 1 criterion for this flowrate, by a larger margin than the 10,000 cfm (4.7 m^3/s) stack.

GRAPHICAL SOLUTION REFERENCED FOR THE SECOND STACK DESIGN METHOD USING THE HALITSKY CRITERIA

Two graphical solutions can be consulted that show a solution to the dilution calculations. The first is Ratcliff and Sandru (*ASHRAE Transactions*, 105, part 1, paper Ch-99-7-1, 1999) and the second is Petersen, Cochran, and LeCompte (2002 *ASHRAE Transactions*). The solutions in both papers are for a Halitsky Criteria spill, 0.028 ppm, rather than the criterion derived from the ANSI/ASHRAE 110 test specification. Quite a bit of expertise is required to interpret the graphs. As an example, in the second paper, one point calculated and shown on the graph is that a zero height stack with a flow of 50,000 cfm (23.5 L/s) and an exit velocity of

3000 fpm (15.24 m/s) would require an offset distance of 120 ft (36.6 m) to the nearest receptor site using the 0.028 ppm exposure limit at the receptor. These graphs were derived from Chapter 43 of *ASHRAE 1999 Handbook—Applications Manual* equations for critical wind speeds and dilutions. Zero-height stacks are quite common because stacks that end below parapet walls, below the height of adjacent penthouses, or that end below adjacent screen walls or screens will act as a zero-height stack. Receptor sites would include operable doors and windows, and any location where pedestrian access was allowed as well as to outside air intakes.

THIRD STACK DESIGN METHOD—PHYSICAL MODELING USING THE WIND TUNNEL OR WATER FLUME

If the stack heights determined from the first two methods described above are undesirable or if the geometry or topography of the building site makes simple analysis methods unreliable, a scale model of the building and surroundings should be physically modeled in an atmospheric wind tunnel or water flume. Physical modeling provides more accurate, and typically less conservative, predictions than the numerical or geometric methods. Physical modeling is the safest method to choose stack heights in new buildings or in buildings being retrofitted.

Wind-tunnel modeling is often the preferred method for predicting maximum concentrations for stack designs and locations of interest when energy and equipment optimization is desired. It is the recommended approach because it gives the most accurate estimates of concentration levels in complex building environments. A wind-tunnel modeling study is like a full-scale field study, except it is conducted before a project is built. Typically, a scale model of the building under evaluation, along with the surrounding buildings and terrain within a 1000-ft radius, is placed in an atmospheric boundary layer wind tunnel. A tracer gas is released from the exhaust sources of interest, and concentration levels of this gas are then measured at receptor locations (i.e., air intakes, operable windows, etc.) of interest and converted to full-scale concentration values. Next, these values are compared against the appropriate health or odor design criteria outlined in ANSI Z9.5 Section 5.3.4 to evaluate the acceptability of the exhaust design. ASHRAE (2009) and Snyder (1981) provide more information on scale-model simulation and testing methods.

Dilution criteria are still necessary to evaluate the results of physical modeling. The design criteria discussed above provide initial guidance. A more complete evaluation of appropriate design criteria should be conducted when the chemical usage is expected to exceed minimal levels. In addition, the design criteria should take into account the 20% factor outlined in ANSI Z9.5 Section 5.3.4.

APPENDIX E

MATRIX OF BUILDING CONSIDERATION FOR SPECIFIC LABORATORY TYPES

This appendix has been prepared as a summary reference for key safety and health issues that should be addressed in common laboratories. The matrix that follows (Table E1) can be used as a checklist for laboratory design and a reference for the reader to the particular section in the book for further discussion of the item. For each item, we have provided guidance as to its applicability in various types of laboratories.

- **HR** (highly recommended) indicates items we believe are applicable to the design, and in many cases are probably required by regulation. They require careful consideration, and rejection of their application to a particular design should be made at the highest level of authority on the project.
- **RP** (recommended practice) applies to those items that may not be required by regulation, but we believe represent good safety practice. For example, fire suppression systems are preferred in a pilot plant, but may not be feasible.
- **SE** (special evaluation needed) is advised when the applicability of some items l requires a special evaluation of the particular design and needs of the laboratory . For example, the use of emergency showers in a cleanroom will depend on the types of chemicals used in the room.
- **NA** (not applicable) refers to those items that are definitely not recommended nor applicable to a particular laboratory. In some cases, NA is used to discourage the use of certain materials in a type of laboratory. For example, flammable liquid storage is not recommended in a physics laboratory; this is to discourage the use of flammable liquids in this type of laboratory.

If the reader has any doubts about the particular applicability of an item, they should refer to the section text in the appropriate chapter for the rationale behind the recommendation.

Guidelines for Laboratory Design: Health, Safety, and Environmental Considerations, Fourth Edition. Louis J. DiBerardinis, Janet S. Baum, Melvin W. First, Gari T. Gatwood, and Anand K. Seth.

TABLE E1. Matrix of Building Consideration for Specific Laboratory Types

KEY: **HR** = Highly recommended and often required by regulators; **RP** = recommended practice; **SE** = special evaluation needed; **NA** = not applicable

Building Considerations	**5** General or Analytical Chemistry	**6** High-Toxicity Laboratory	**7** Nanotechnology Laboratory	**8A** Aeronautical Engineering - Wind Tunnel	**8B** Jet/Rocket Propulsion Laboratory	**8C** Hydraulic Engineering Laboratory	**8D** Material Analysis/Testing Laboratory	**8E** Electrical Engineering Laboratory	**8F** Foundry Laboratory	**8G** Internal Combustion Laboratory	**9** Pilot Plant	**10** Physics Laboratory	**11** Controlled Environment	**12** High-Pressure Laboratory	**13** Radiation Laboratory	**14** Biosafety Laboratory	**15** Clinical Laboratory
Evaluate distribution of MEP and services	HR	HR	HR	HR	SE	HR	HR	SE	SE	HR	HR	HR	HR	HR	HR	HR	HR
Directional air flow in laboratories	HR	HR	HR	RP	RP	NA	RP	SE	HR	RP	HR	RP	HR	NA	HR	HR	HR
Supply air velocity and quality	HR	HR	HR	RP	RP	RP	RP	RP	RP	RP	HR	RP	HR	RP	HR	SE	HR
Evaluate location of supply air intake to the building	HR	HR	HR	RP	RP	RP	RP	RP	RP	RP	HR	RP	HR	RP	HR	HR	HR
Location of supply air in room	HR	HR	HR	RP	RP	RP	RP	RP	HR	RP	HR	RP	HR	RP	HR	HR	HR
Temperature control	RP	RP	RP	RP	RP	RP	RP	RP	HR	RP	RP	RP	HR	RP	RP	RP	HR
Humidity control	RP	RP	RP	SE	RP	HR	RP	RP	RP	RP	RP	RP	SE	NA	RP	RP	SE
Emergency power supply	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	HR	HR	HR	RP	RP	HR	HR
Fire detection system	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
Fire suppression system	HR	HR	HR	SE	HR	SE	HR	RP	SE	HR	HR	SE	RP	SE	HR	HR	HR
Fire alarm system	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
Special Lighting	SE	SE	SE	SE	SE	RP	RP	RP	RP	RP	SE	SE	SE	SE	SE	SE	HR
Laboratory egress	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
Universal access for disabled persons	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	HR	RP	HR	RP	HR	RP	HR
Access Restrictions	RP	RP	RP	HR	HR	RP	RP	RP	HR	RP	HR	SE	HR	HR	HR	SE	HR
Laboratory furniture location	RP	RP	RP	SE	SE	HR	RP	RP	HR	RP	RP	RP	RP	RP	RP	RP	RP
Location of chemical fume hood or biosafety cabinet	HR	HR	HR	NA	RP	NA	HR	NA	NA	SE	HR	SE	SE	HR	HR	RP	RP
Laboratory chemical fume hood	HR	HR	SE	NA	RP	NA	HR	NA	NA	SE	SE	SE	SE	HR	SE	SE	SE
Perchloric acid fume hood	SE	SE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	SE
Radioisotope fume hood	NA	NA	SE	NA	NA	NA	NA	NA	NA	NA	HR	SE	NA	NA	HR	SE	SE
Biological safety cabinet	NA	NA	SE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	HR	SE
Glovebox	NA	HR	SE	NA	SE	NA	SE	NA	NA	NA	SE	SE	NA	SE	SE	SE	SE
Local exhaust ventilation	SE	SE	SE	NA	HR	NA	SE	NA	HR	HR	SE	SE	SE	NA	SE	SE	SE
Filtration of exhaust air	NA	SE	SE	NA	HR	NA	SE	NA	NA	SE	SE	NA	NA	SE	SE	HR	SE
Emergency gas shut-off	HR	HR	HR	NA	RP	NA	RP	NA	HR	HR	HR	RP	HR	RP	HR	SE	HR
Ground fault circuit interruptors	RP	RP	RP	RP	RP	HR	HR	RP	RP	RP	RP	RP	HR	RP	RP	RP	HR
Master electrical disconnect switch	RP	HR	RP	RP	RP	RP	RP	HR	HR	HR	RP	HR	HR	HR	RP	SE	HR

Teaching Laboratory	Gross Anatomy Laboratory	Pathology Laboratory	Autopsy Laboratory	Morgue Facility	Open or Team Laboatory	Animal Research Laboratory	Microelectronics & Clean Room	Printmaking Studio	Photographic Darkroom/Imaging Labs	Support Shops	Hazardous Chemical Waste Room	Radioactive Waste Room	Biological Waste Room	Laboratory Storeroom - General Chemical	Flammable Liquids/Bonded Alcohol	Compressed Gases	Biological Specimens	Archeology, Geology Specimens	Laboratory Shop Storeroom
16	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**27**	**27**	**28**	**28**	**28**	**28**	**28**	**28**
HR	HR	HR	SE	HR	HR	SE	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	RP	RP	RP
HR	HR	HR	HR	HR	SE	HR	HR	RP	HR	RP	HR	HR	HR	RP	HR	RP	RP	RP	RP
HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	RP	RP	RP	RP	RP	HR	RP	RP	RP	RP
HR	HR	RP	HR	HR	HR	HR	HR	RP	HR	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP
HR	RP	RP	HR	RP	HR	HR	HR	RP	HR	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP
RP	RP	RP	RP	RP	RP	HR	HR	RP	SE	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP
RP	RP	RP	RP	RP	RP	HR	HR	RP	SE	RP	RP	RP	RP	RP	RP	RP	RP	RP	SE
RP	NA	RP	SE	SE	RP	HR	HR	NA	HR	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
HR	RP	RP	RP	RP	HR	HR	HR	HR	HR	HR	HR	HR	HR	RP	HR	RP	HR	RP	RP
HR	HR	HR	HR	HR	HR	HR	HR	HR	SE	HR	HR	HR	HR	HR	HR	SE	HR	HR	HR
HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
NA	SE	SE	SE	RP	SE	SE	RP	RP	SE	RP	NA	NA	NA	RP	SE	SE	RP	RP	RP
HR	HR	HR	HR	HR	SE	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
HR	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	SE	RP	RP	RP
HR	HR	SE	HR	HR	RP	HR	HR	RP	HR	SE	RP	RP	HR	HR	HR	HR	SE	SE	SE
HR	RP	RP	HR	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	NA	NA	RP	RP	NA
HR	NA	RP	NA	NA	HR	RP	HR	RP	NA	RP	HR	HR	RP	RP	NA	NA	NA	NA	NA
HR	NA	RP	NA	NA	HR	SE	SE	NA	NA	SE	HR	HR	RP	RP	NA	NA	NA	NA	NA
SE	NA	SE	NA	NA	SE	NA	NA	NA	NA	NA	SE	NA	NA	NA	NA	NA	NA	NA	NA
SE	NA	NA	NA	NA	SE	NA	NA	NA	NA	NA	NA	HR	NA	NA	NA	NA	NA	NA	NA
HR	SE	RP	SE	NA	SE	RP	NA	NA	NA	NA	NA	NA	SE	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	SE	NA	SE	NA	NA	NA	SE	SE	NA	NA	NA	NA	NA	NA	NA
SE	HR	SE	HR	HR	SE	SE	RP	SE	SE	SE	HR	HR	SE	SE	NA	NA	SE	NA	NA
NA	NA	SE	SE	RP	SE	SE	RP	NA	NA	SE	NA	NA	SE	NA	NA	NA	NA	NA	NA
HR	NA	NA	NA	NA	HR	NA	HR	NA	NA	SE	RP	RP	NA	NA	NA	NA	NA	NA	NA
HR	RP	RP	RP	RP	HR	RP	RP	RP	RP	RP	RP	RP	RP	RP	NA	NA	RP	RP	RP
HR	NA	SE	NA	NA	HR	NA	HR	SE	SE	SE	RP	RP	RP	SE	NA	NA	NA	NA	NA

(*Continued*)

TABLE E1. (*Continued*)

KEY: **HR** = Highly recommended and often required by regulators; **RP** = recommended practice; **SE** = special evaluation needed; **NA** = not applicable

	General or Analytical Chemistry	High-Toxicity Laboratory	Nanotechnology Laboratory	Aeronautical Engineering - Wind Tunnel	Jet/Rocket Propulsion Laboratory	Hydraulic Engineering Laboratory	Material Analysis/Testing Laboratory	Electrical Engineering Laboratory	Foundry Laboratory	Internal Combustion Laboratory	Pilot Plant	Physics Laboratory	Controlled Environment	High-Pressure Laboratory	Radiation Laboratory	Biosafety Laboratory	Clinical Laboratory
Emergency showers	HR	HR	HR	SE	SE	NA	HR	NA	SE	SE	HR	NA	HR	SE	HR	HR	HR
Emergency eye wash	HR	HR	HR	SE	SE	NA	HR	NA	HR	RP	HR	RP	HR	NA	HR	HR	HR
Handwashing facilities	RP	RP	RP	NA	RP	NA	HR	NA	HR	RP	RP	RP	HR	NA	RP	HR	HR
Chemical spill control	RP	RP	RP	NA	SE	NA	HR	NA	NA	RP	HR	RP	HR	NA	RP	SE	HR
Fire resistive construction methods and materials	HR	HR	HR	NA	HR	NA	RP	NA	HR	HR	HR	RP	HR	HR	HR	RP	HR
Experiment alarm systems	RP	RP	RP	RP	RP	RP	NA	NA	NA	RP	RP	RP	HR	HR	RP	NA	SE
Hazardous chemical disposal	HR	HR	HR	NA	NA	NA	RP	NA	NA	SE	HR	NA	HR	NA	HR	SE	HR
Chemical waste treatment	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	HR	NA	NA	SE	HR
Flammable liquid storage	RP	RP	RP	NA	RP	NA	RP	NA	NA	HR	RP	RP	NA	RP	RP	SE	HR
Special hazard chemicals	NA	HR	HR	NA	RP	NA	RP	NA	NA	NA	SE	SE	HR	SE	SE	SE	SE
Compressed gas cylinders	SE	RP	RP	HR	RP	RP	HR	NA	NA	RP	SE	HR	HR	HR	SE	RP	RP
Emergency cabinet	HR	HR	HR	NA	RP	NA	RP	NA	RP	RP	HR	RP	HR	RP	HR	RP	HR
Change or gowning room	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	RP	NA
Durable, cleanable work surfaces	RP	RP	RP	RP	RP	RP	HR	NA	HR	RP	RP	RP	RP	RP	HR	HR	HR
Durable, cleanable floor and wall materials	RP	RP	RP	RP	NA	RP	RP	NA	HR	RP	RP	RP	RP	RP	HR	HR	HR
Protection of laboratory vacuum system	NA	NA	RP	NA	NA	NA	RP	NA	NA	RP	RP	RP	SE	NA	HR	HR	SE

Teaching Laboratory	Gross Anatomy Laboratory	Pathology Laboratory	Autopsy Laboratory	Morgue Facility	Open or Team Laboatory	Animal Research Laboratory	Microelectronics & Clean Room	Printmaking Studio	Photographic Darkroom/Imaging Labs	Support Shops	Hazardous Chemical Waste Room	Radioactive Waste Room	Biological Waste Room	Laboratory Storeroom - General Chemical	Flammable Liquids/Bonded Alcohol	Compressed Gases	Biological Specimens	Archeology, Geology Specimens	Laboratory Shop Storeroom
HR	HR	HR	HR	SE	HR	HR	HR	HR	SE	HR	HR	NA	NA	HR	NA	NA	SE	NA	NA
HR	HR	HR	HR	HR	HR	HR	HR	HR	SE	HR	HR	HR	NA	HR	NA	NA	RP	NA	NA
RP	HR	HR	HR	HR	RP	HR	SE	HR	HR	HR	HR	HR	HR	HR	NA	NA	RP	RP	NA
RP	NA	SE	NA	SE	RP	NA	RP	SE	SE	SE	HR	HR	SE	HR	HR	NA	RP	NA	SE
HR	RP	RP	RP	RP	HR	RP	HR	RP	RP	RP	HR	HR	RP	HR	HR	RP	HR	RP	RP
NA	NA	SE	NA	NA	RP	SE	RP	NA	SE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
HR	NA	SE	NA	SE	HR	SE	HR	HR	HR	SE	HR	HR	NA	HR	HR	NA	NA	NA	NA
NA	NA	SE	NA	NA	NA	SE	SE	HR	RP	SE	NA	NA	NA	SE	NA	NA	NA	NA	NA
RP	NA	SE	NA	NA	RP	NA	RP	HR	SE	HR	HR	HR	NA	NA	HR	NA	RP	NA	NA
NA	NA	SE	NA	NA	NA	SE	SE	SE	SE	SE	HR	NA	NA	SE	HR	SE	NA	NA	NA
SE	NA	RP	NA	NA	SE	RP	RP	NA	NA	RP	HR	HR	NA	NA	NA	HR	NA	NA	NA
HR	RP	RP	RP	RP	HR	RP	HR	RP	RP	RP	RP	RP	RP	RP	NA	NA	RP	NA	NA
NA	RP	SE	HR	HR	NA	HR	HR	SE	RP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RP	HR	HR	HR	HR	RP	HR	HR	RP	RP	RP	RP	RP	RP	RP	NA	NA	NA	NA	NA
RP	HR	HR	HR	HR	RP	HR	HR	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP
RP	NA	SE	SE	NA	RP	SE	HR	NA	NA	NA	NA	NA	HR	NA	NA	NA	NA	NA	NA

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Note: **Bold** indicates main discussions or chapter titles.

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