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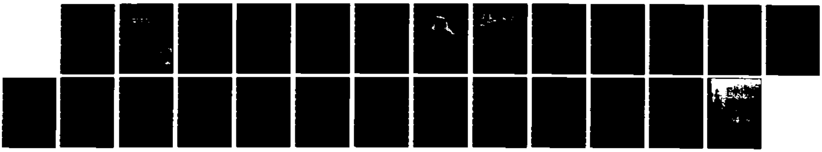

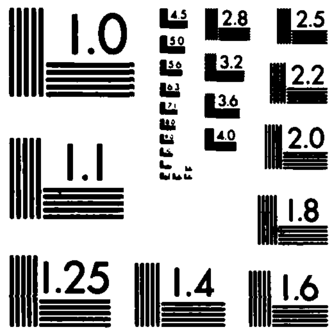

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Report USAFSAM-TR- 83-14

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A LABORATORY COMPARISON OF PORTABLE COOLING SYSTEMS FOR WORKERS EXPOSED TO TWO LEVELS OF HEAT STRESS

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July 1983

Final Report for Period August 1981 - January 1982

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
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NOTICES

This final report was submitted by personnel of the Clinical Sciences Division and Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 2729-00-CD.

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The voluntary informed consent of all subjects used in this research was obtained in accordance with AFR 169-3.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two commercially available liquid cooling systems (LCSs) were tested on subjects wearing the current USAF groundcrew chemical defense ensemble and working in the heat. Each cooling system consisted of an ice-water heat sink, a pump, and a vest or vest-and-cap through which cool water circulated. Subjects walked on a treadmill to produce a time-weighted metabolic rate of about 480 W. Environmental conditions (T_{db}/T_{wb}) were: hot = 45/31°C and warm =

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20. ABSTRACT (Continued)

32/22°C. Under the hot condition neither LCS produced any difference from the uncooled control, and all subjects were forced to stop within 40-50 min because of high temperatures, excessive heart rates, or exhaustion. Under the warm condition the LCSs did allow T_{re} to equilibrate; one system which could be recharged with ice enabled subjects to continue work to the 160-min limit of the protocol. Discussion covers logistic problems and reliability of the two systems. The conclusion is that LCSs are a viable concept for USAF operations, but that better heat sinks must be found and field tested before acceptance.

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A LABORATORY COMPARISON OF TWO PORTABLE COOLING SYSTEMS FOR WORKERS IN THE HEAT

INTRODUCTION

The protection required to conduct military operations in a chemical warfare environment dictates that each soldier be encapsulated in a relatively impermeable ensemble. Unfortunately, the physiological cost for such protection is high, and unacceptable decrements in performance often result. The current USAF chemical defense (CD) ensemble limits the wearer's ability to dissipate body heat and, therefore, markedly shrinks the safe time-temperature-workload envelope. Personnel wearing CD clothing have consistently demonstrated an inability to perform prolonged, physically strenuous activities in warm-to-hot climates. The most promising solution to this dilemma appears to be the provision of auxiliary cooling.

Early developmental efforts aimed at providing personal cooling resulted in a choice between an air-ventilated suit (AVS) or a liquid-conditioned garment. Studies at the Royal Aircraft Establishment (RAE) in Farnborough during the mid-1960's conclusively demonstrated the superiority of liquid cooling for heat exchange, and the RAE abandoned development of the AVS in 1975. More recently, the National Research Council's Committee on Chemical Protective Clothing Systems concluded that "Air ventilation systems are usually adequate for low work rates but liquid cooling is generally required for high work rates" (1) and recommended the development of a lightweight, portable liquid cooling system. Many of the groundcrew members who will require auxiliary cooling must also remain highly mobile while working and, therefore, need a portable cooling system.

The Life Support System Program Office identified two commercially available liquid cooling systems (LCSs) and requested qualification tests on this equipment in 1981. The objective of the thermal tests, performed at the USAF School of Aerospace Medicine (USAFSAM), was to quantify the ability of these cooling systems to reduce the physiological strain on men working in the heat while wearing the USAF near-term groundcrew CD ensemble, and to assess performance characteristics which would be of use in selecting the most effective system for the USAF purposes.

The systems which were tested are manufactured by ILC Dover (ILC) (Fig. 1) and Life Support Systems Incorporated (LSSI) (Fig. 2). Both use ice as the heat sink and cool the torso by establishing a thermal gradient between the body surface and cool liquid circulating in the garment. The LSSI system also has a liquid-cooled cap. A detailed description of these test items has been prepared by the Tactical Air Warfare Center (USAFTAWC); see Appendix A.

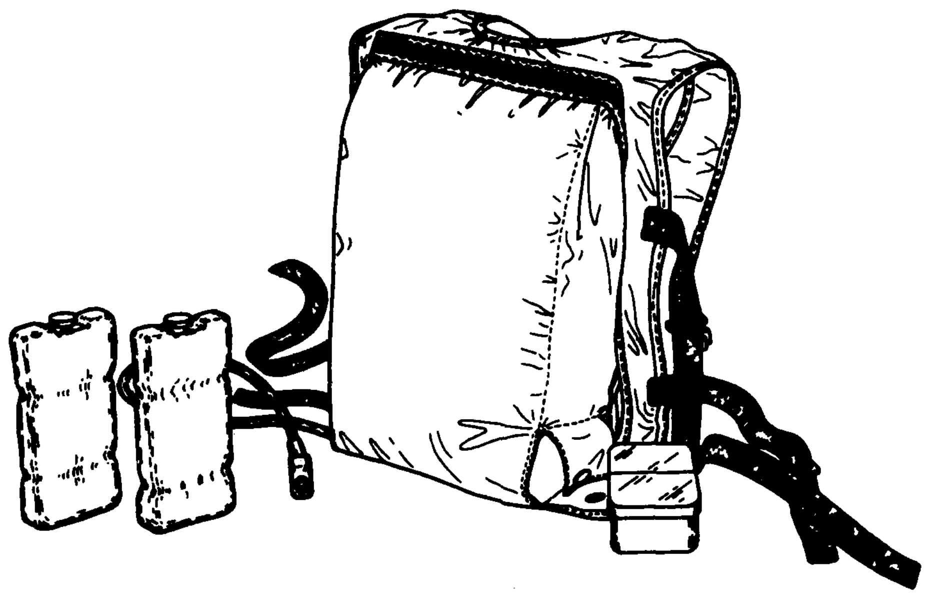

Figure 1. Drawing of the ILC Dover "Cool Vest" system showing the cooling garment with battery and two ice cartridges. The circulation pump and the integrated ice water pouch are not shown in this drawing.

COPPER MANIKIN TESTING

Methods

The performance of each liquid-cooled system was measured at the U.S. Army Research Institute of Environmental Medicine (USARIEM) in the Military Ergonomics Division on a completely wet (maximal sweating) copper manikin. The manikin consists of six electrically heated sections: head, torso, arms, hands, legs, and feet. The manikin was dressed in a cooling garment and the complete USAF groundcrew CD ensemble and placed in a standing position in a large temperature- and humidity-controlled chamber; conditions were (T_{db}/ T_{wb}): (a) hot (45/31°C) or (b) warm (32/22°C). The heat loss from the copper manikin was determined by measuring the power in Watts required to maintain a constant manikin surface temperature. In this study, electricity was supplied to the torso to maintain it at an average temperature of 35°C; the head section was also heated to 35°C in tests on the LSSI LCS. The "cooling period" started at time zero when the ice packs were inserted into the heat exchanger and the pump motor was switched on.

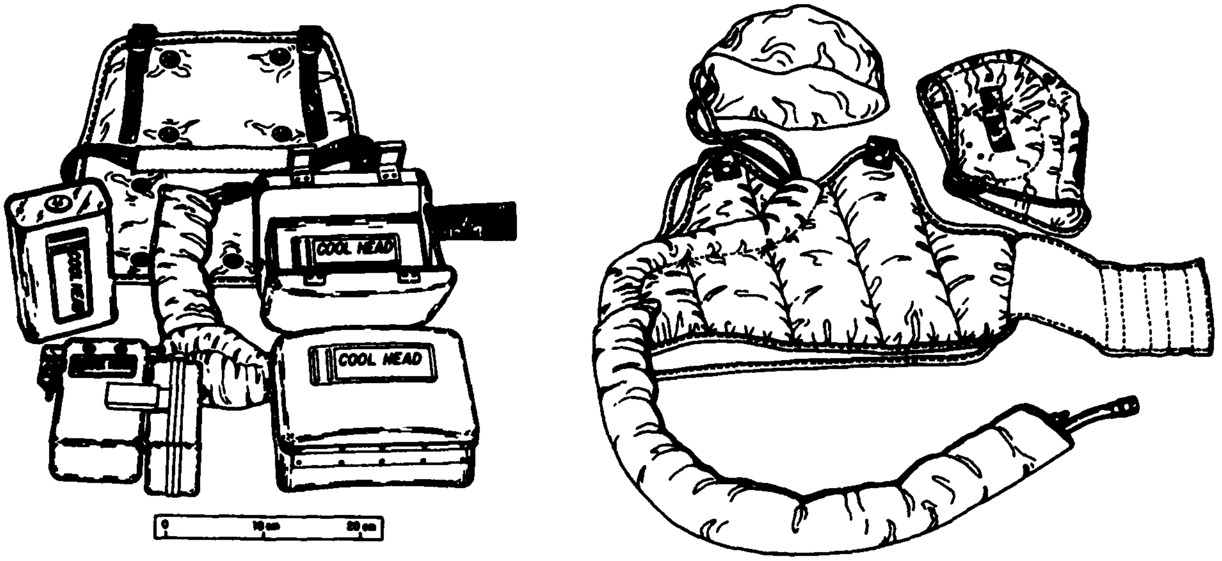

Figure 2. Drawing of the LSSI "Cool Head" system. The cooling garments, both cap and vest, are shown on the right next to an insulating overcap. The circulation pump, battery, two heat exchangers with ice cartridges, and a suspension harness are shown in the drawing on the left.

Results and Discussion

The heat exchange provided by both the ILC and the LSSI LCSs is plotted against time in Figure 3. Heat loss from the manikin's surface was essentially the same at wet-bulb globe temperature (WBGT) indexes of 24.7 and 35.9°C, indicating that the heat sinks were well insulated from the outside environment. The cooling supplied by the ILC and LSSI LCSs over the initial 2 h averaged 74 W and 75 W in the 24.7°C WBGT environment, and 66 W and 68 W in the 35.9°C WBGT environment. Cooling provided by both systems diminished over time, as expected in any system which incorporates a fuseable heat sink (ice). Cooling has been shown to increase with agitation of the ice cartridge (Appendix B). Thus, the amount of heat transfer measured on the passive copper manikin would be less than that measured on a man in motion.

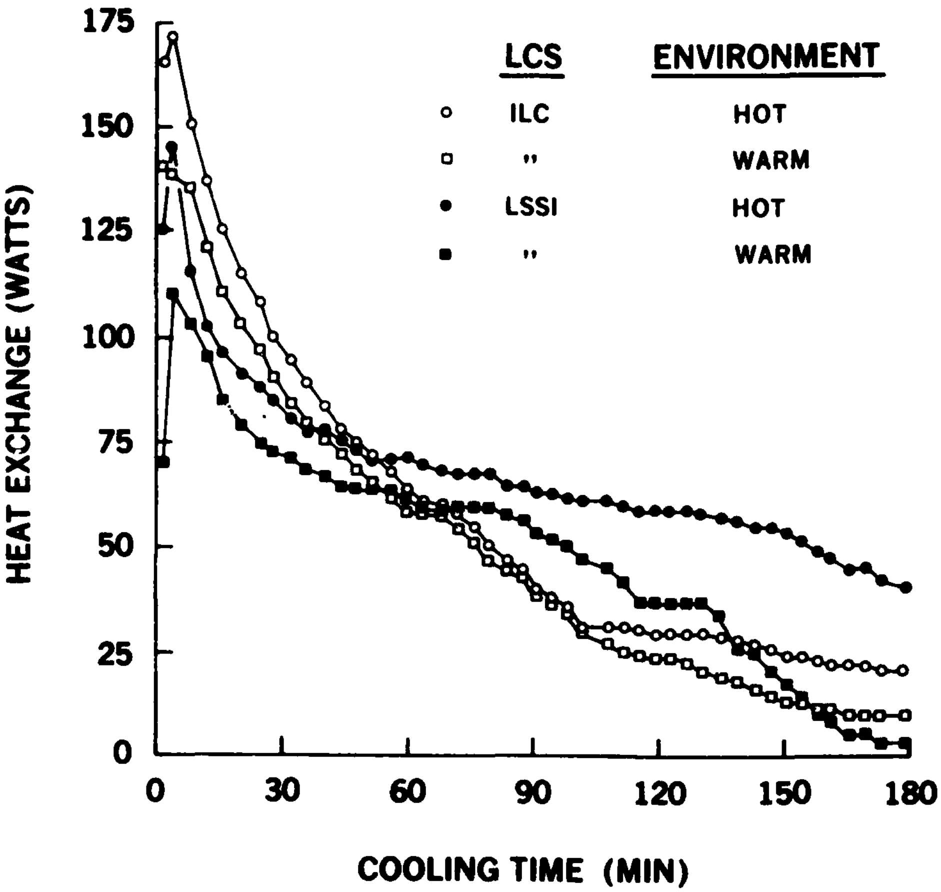

Figure 3. Heat exchange provided by the ILC and LSSI liquid cooling systems (LCS), in a warm (WBGT = 24.7°C) and hot (WBGT = 35.9°C) environment, to a completely wetted copper manikin. Cooling watts are plotted against "cooling time," which started when the ice had been inserted into the heat exchanger and the pump motor switched on.

MANNED TESTING

Methods

Physiological responses were measured on nine healthy young men working in the heat. Each subject reported to the laboratory and was weighed (nude), instrumented, and weighed after dressing. Clothing consisted of the current USAF groundcrew CD ensemble (insulation about 2.60 Clo) with the cooling garments worn next to the skin to produce three conditions: (a) the ILC vest (Condition ILC), (b) the LSSI vest and cap (Condition LSSI), or (c) neither (control) (Condition C). Instrumentation included a rectal thermistor inserted 10 cm for measuring rectal temperature (T_{re}), three ECG electrodes for measuring heart rate (HR), and four skin thermistors (on the chest, arm, thigh, and calf) to measure mean skin temperature ($\bar{T}_{sk}$) according to the method of Ramanathan (5).

Baseline recordings were taken with the subject seated for 10 min in a comfortable environment. The subject then entered the chamber, which was conditioned as for (a) and (b) manikin tests (T_{db}/T_{wb}): hot (45/31°C) or warm (32/22°C). Infrared lamps were used to raise the black globe (6 in.) temperature (T_{bg}) by 5°C in both environments, thus producing a WBGT of 35.9°C and 24.7°C, respectively. There was little air movement in the chamber.

The cooling system was activated (Conditions ILC and LSSI only) when the subject entered the chamber, and he immediately began walking on a treadmill at a speed of 3.3 mph up a 5% grade. The mathematical model of Givoni and Goldman (2) predicts that for this task an average (70 kg) man expends 498 - 549 kcal/h (579 - 638 W), depending upon the load carried. The work/rest cycle (Fig. 4) simulated the work load experienced by the mat-laying personnel on a rapid runway repair (RRR) team. The resulting time-weighted metabolic rate (M), calculated as $M = (120\ M_e + 45\ M_r)/165$ where M_r equals the resting metabolic rate (100 kcal/h) and M_e = 498 - 549 kcal/h, was 390 - 427 kcal/h (454 - 497 W). This regimen continued for a total of 165 min, or until one or more of the following termination criteria was reached: (a) HR exceeded 180 bpm, (b) T_{re} exceeded 39.0°C, or (c) the subject was unable to continue.

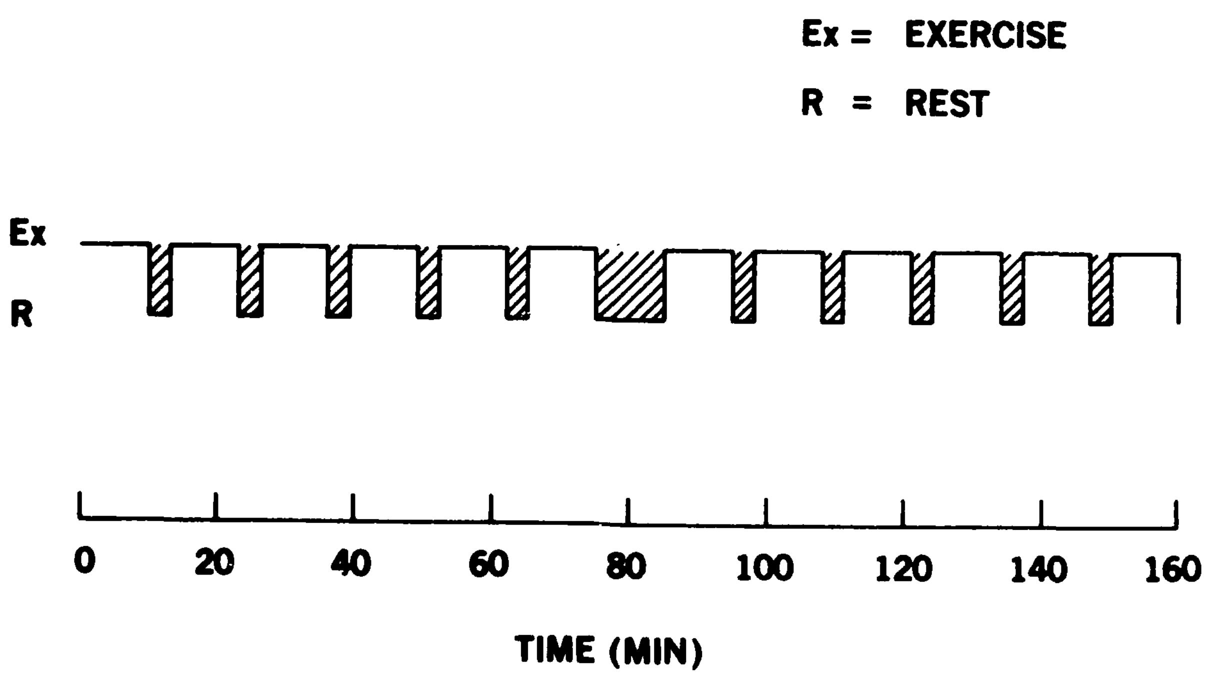

Figure 4. The schedule used for treadmill exercise (3.3 mph, 5% grade) in this experiment resulted in a time-weighted metabolic rate of 390 - 427 kcal/h. See text for details.

The LCSs were operated in a manner which maximized cooling throughout the exposure. The ILC system was supplied with 1.5 L of water at approximately 10°C, and three ice packs were inserted into the cooling bag; the external diverter valve was set to the fully open position for maximum circulation of the water over the heat sink. The LSSI system was operated in the "dual cartridge" configuration, and the temperature control valve was also set to the fully open position for maximum cooling. Both systems were precooled for 15 min, before donning, by inserting ice cartridges into the heat exchanger and circulating fluid through the garment. A fully frozen set of ice packs was inserted into the heat exchanger just before the subject entered the chamber.

Time constraints prohibited testing all subjects under each set of temperature-ensemble conditions. Table 1 shows under which conditions each subject was tested and their physical characteristics.

TABLE 1. PHYSICAL CHARACTERISTICS OF SUBJECTS AND CONDITIONS IN WHICH TESTED

Subject	Height (in.)	Weight (lb)	Surface area (m^2)	Experimental Conditions[a] 35.9°C WBGT			24.7°C WBGT		
				C	ILC	LSSI	C	ILC	LSSI
CA	68	206	2.09	X	X	X	X		
DB	67	135	1.71				X	X	X
TD	71	169	1.97	X	X	X			
LD	74	180	2.10	X	X	X	X		
LF	66	138	1.71	X	X	X	X	X	X
TM	74	229	2.40	X	X	X			
VP	70	140	1.79	X	X	X			
DT	69	150	1.83	X	X	X	X	X	X
RW	70	158	1.88	X	X	X			

[a] Subjects were exposed to an environmental chamber which was conditioned to give a wet-bulb globe temperature (WBGT) index of either 35.9°C or 24.7°C. Three ensembles were tested under these conditions: a control (C) where a USAF groundcrew near-term chemical defense ensemble was worn alone, and two where either the ILC Dover (ILC) or Life Support Systems Incorporated (LSSI) liquid cooling system was also worn.

The criteria used in this experiment for terminating a subject's exposure restricted our ability to perform parametric analyses on some of the data. The termination criteria exerted a nonuniform influence on the data in the hot (WBGT = 35.9°C) environment. For example, many of the subjects were removed from the chamber due to a high HR when their T_{re} was still quite low. Thus, mean T_{re} values for the remaining subjects became artificially higher and HR lower. For this reason, no particular statistics are quoted on the data collected in the hot environment; rather a qualitative discussion of the data (Figs. 5-11) is offered. Data collected in the warm (WBGT = 24.7°C) environment were not affected by the use of these termination criteria and were, therefore, tested using an analysis of variance.

Results

In a laboratory evaluation of this type it is important to select relevant set of test conditions. We began testing under a "worst case" set of environmental conditions where the heat load was quite severe (WBGT = 35.9°C). Neither of the test items provided a significant thermal advantage over control under these conditions. We then retested this equipment in a less stressful environment (WBGT = 24.7°C) without changing the work load. Although a certain amount of heat storage appeared to be obligatory, the auxiliary cooling provided by the LSSI LCS eventually allowed T_{re}'s to equilibrate between 38.2 and 38.4°C. Physiological responses to the two heat stress conditions were obviously quite different and are described separately.

Hot (WBGT = 35.9°C)

Rectal temperature. Mean values of T_{re} ($\bar{T}_{re}$) are given in Figure 5. There was no difference in starting values for the three conditions (T_{re} at t = 0 was 37.3°C). After beginning treadmill exercise, T_{re} rose at a rate of 2.4°C/h, and this rise was not influenced by either of the LCSs; at 39 min of exposure T_{re} was 38.5°C. Thus, the amount of heat removed by these LCSs represented an insignificant portion of the total heat load imposed on the wearer, and body heat storage continued unimpeded.

Skin temperatures. Figure 6 gives the data for $\bar{T}_{sk}$ under each of the experimental conditions. Both LCSs decreased $\bar{T}_{sk}$ during the initial 30 min of exposure, but at 39 min these differences were insignificant. Without cooling, initial chest temperature (T_{ch}) was 34.7°C, rising to 38.5°C during the work-heat exposure. With cooling, T_{ch} started at 30.1 and 32.2°C for ILC and LSSI, respectively, decreasing as the pump was activated on entrance into the chamber; by 39 min the respective values were 32.1 and 31.0°C. No differences were evident between the two LCSs.

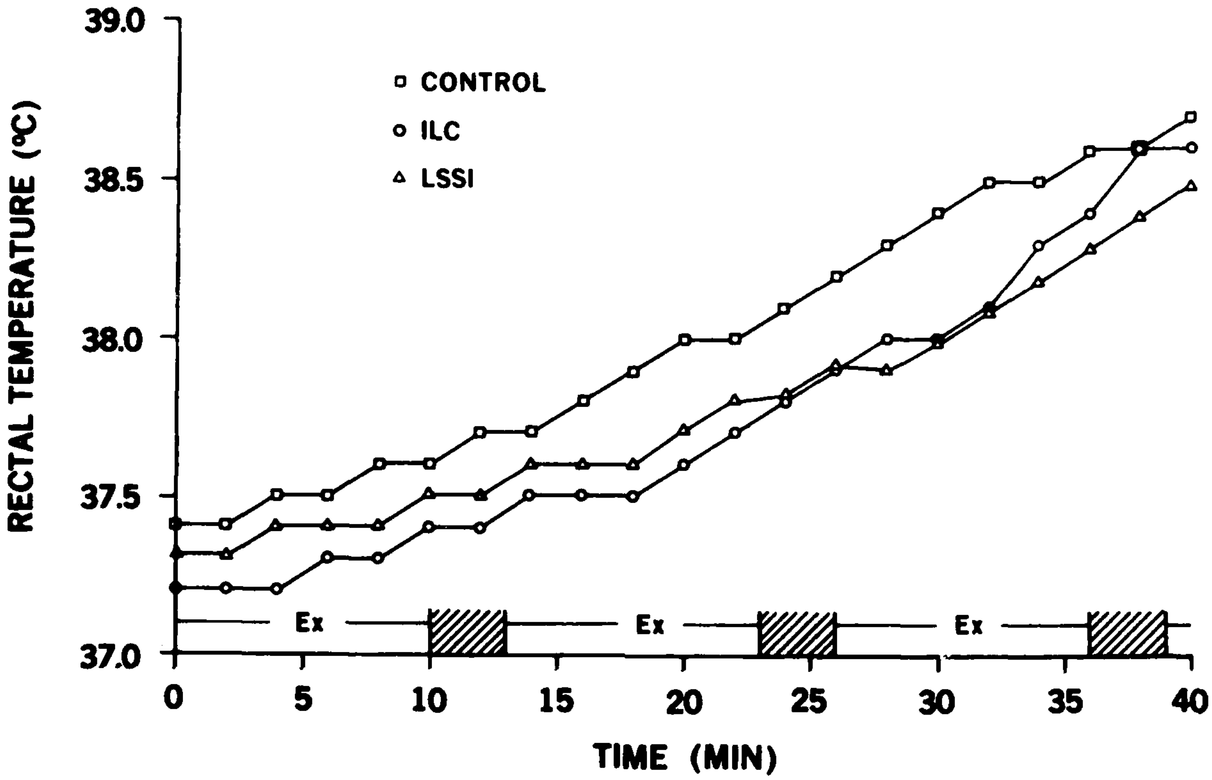

Figure 5. Rectal temperatures for two liquid cooling systems (ILC and LSSI) and the control condition in a hot (WBGT = 35.9°C) environment.

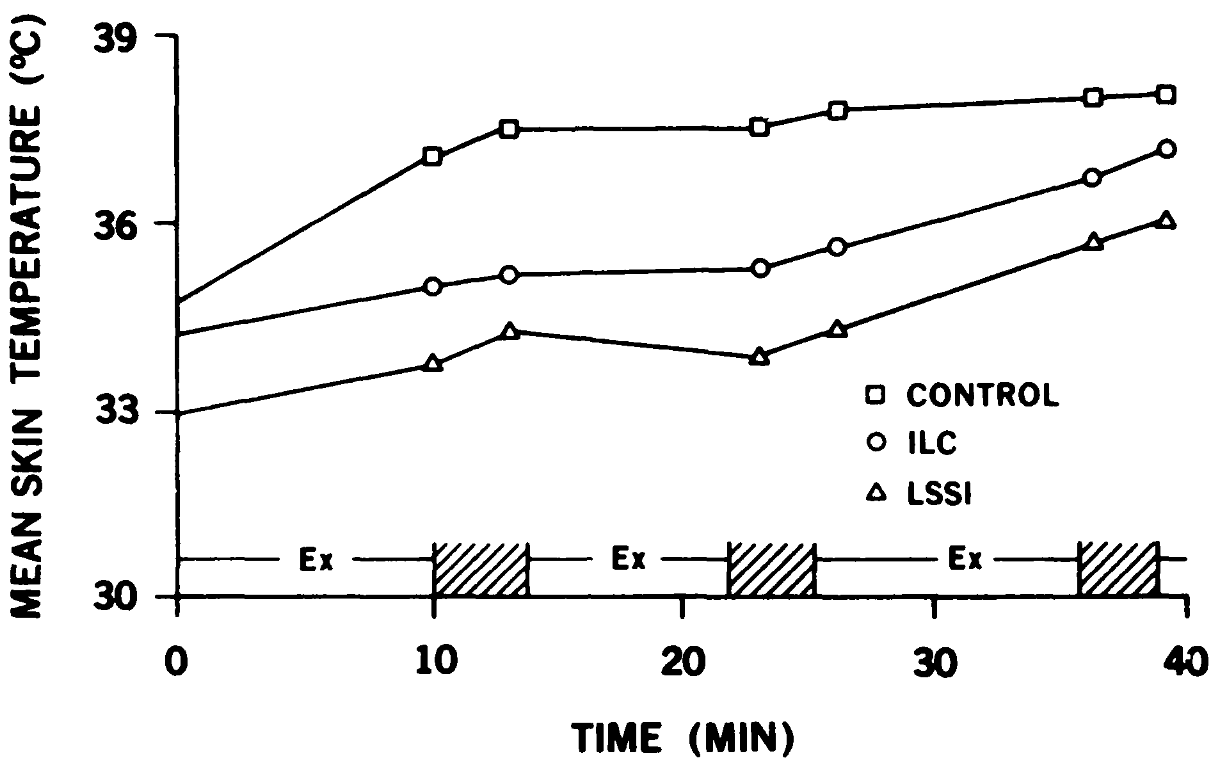

Figure 6. Mean skin temperatures for two liquid cooling systems (ILC and LSSI) and the control condition in a hot (WBGT = 35.9°C) environment.

Heart rate. During the first three exercise bouts the mean HR rose by roughly 50 bpm (Fig. 7). There were no differences in mean HR at the start of the experiment (124 bpm) or at the end of the third exercise bout (170 bpm).

Thermal sweating. No differences among conditions were observed in sweat rates or evaporation (Table 2).

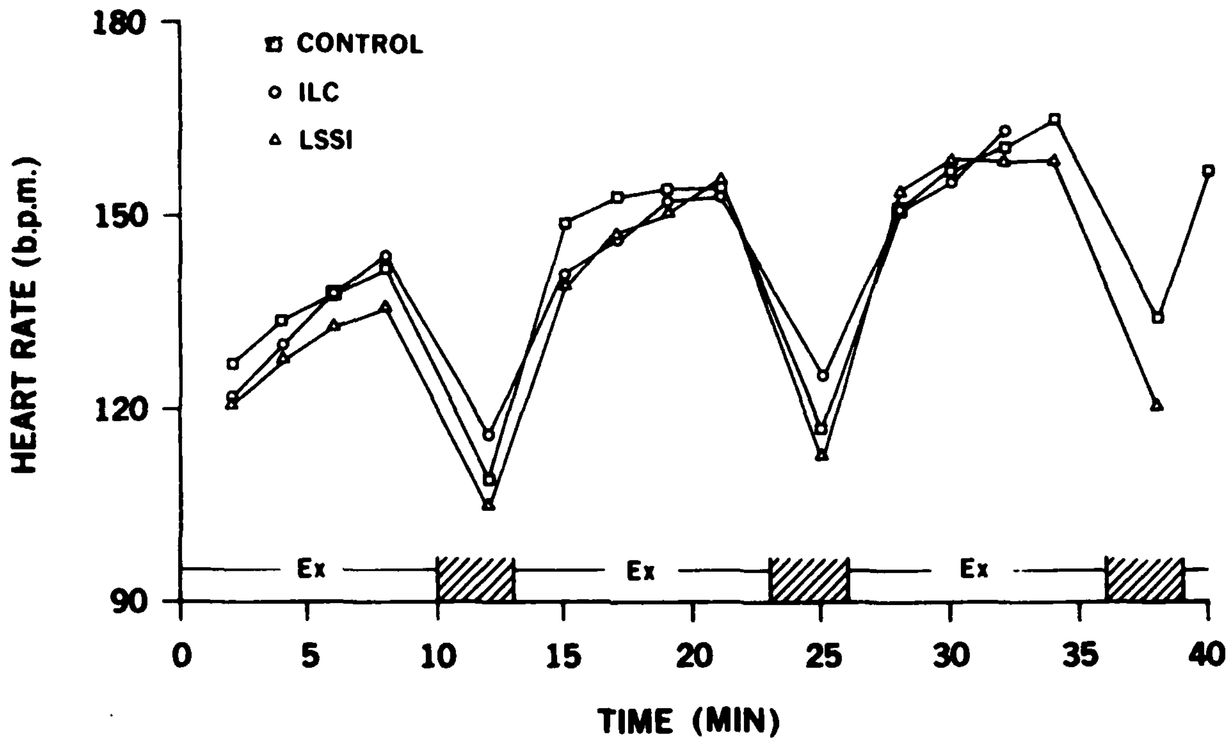

Figure 7. Heart rate responses of men exercising in a hot (WBGT - 35.9°C) environment with (ILC and LSSI) and without auxiliary cooling.

Tolerance times. The cooling systems caused no change in the exposure time at which tolerance limits were reached (Fig. 8). The percentage of subjects who reached a specific end point is given for each condition in Table 3. Whereas under control conditions most subjects (87%) either limited their own exposure or were removed due to a high HR, T_{re} was more often a limiting factor when an LCS was worn.

Warm (WBGT = 24.7°C)

Rectal temperature. Mean values of T_{re} are given in Figure 9. At the start of the experiment T_{re} for the three experimental groups did not differ (37.2°C). Rectal temperature rose at a rate of 1.7°C/h without an LCS and reached a mean value of 38.8°C in 52 min. Both the LCSs significantly reduced the rate at which T_{re} increased: the ILC LCS by 35% (1.1°C/h) and the LSSI LCS by 47% (0.9°C/h). There were no significant differences between the ILC and LSSI LCSs during the first hour of the experiment. The ice cartridges had completely melted in both LCSs within 75 min. Since the ILC heat sink could not be recharged without removing the overjacket and fatigue shirt, all subjects wearing it were removed from the chamber at that time. The LSSI system, on the other hand, could be easily recharged with ice and so exposures were continued. Equilibrium levels of T_{re} ranged between 38.2°C and 38.4°C during the final 1.5 h of exposure with the LSSI LCS.

TABLE 2. MEAN WEIGHT LOSSES

WBGT	Condition	Total weight loss (kg)	Total weight loss (% Body Wt)	Total weight loss (% Body Wt/h)	Evaporative weight loss (% Total)	Nonevaporative weight loss (% Total)	Sweat rate (kg/h)
	Control	1.011 ± 0.187	1.34 ± 0.27	2.48 ± 0.53	34.5 ± 11.4	65.5 ± 11.8	1.877 ± 0.368
35.9°C	ILC	1.049 ± 0.188	1.32 ± 0.24	1.81 ± 0.28	18.8 ± 4.9	81.2 ± 4.9	1.425 ± 0.183
	LSSI	1.107 ± 0.206	1.37 ± 0.22	1.89 ± 0.38	18.1 ± 4.7	81.9 ± 4.7	1.509 ± 0.258
	Control	1.083 ± 0.067	1.56 ± 0.24	1.87 ± 0.24	19.9 ± 6.0	80.1 ± 6.0	1.353 ± 0.262
24.7°C	ILC	0.683 ± 0.409	0.96 ± 0.57	0.78 ± 0.48	65.0 ± 25.0	35.0 ± 25.0	0.559 ± 0.346
	LSSI	1.980 ± 0.093	2.80 ± 0.11	1.05 ± 0.07	41.9 ± 2.2	58.1 ± 2.2	0.742 ± 0.061

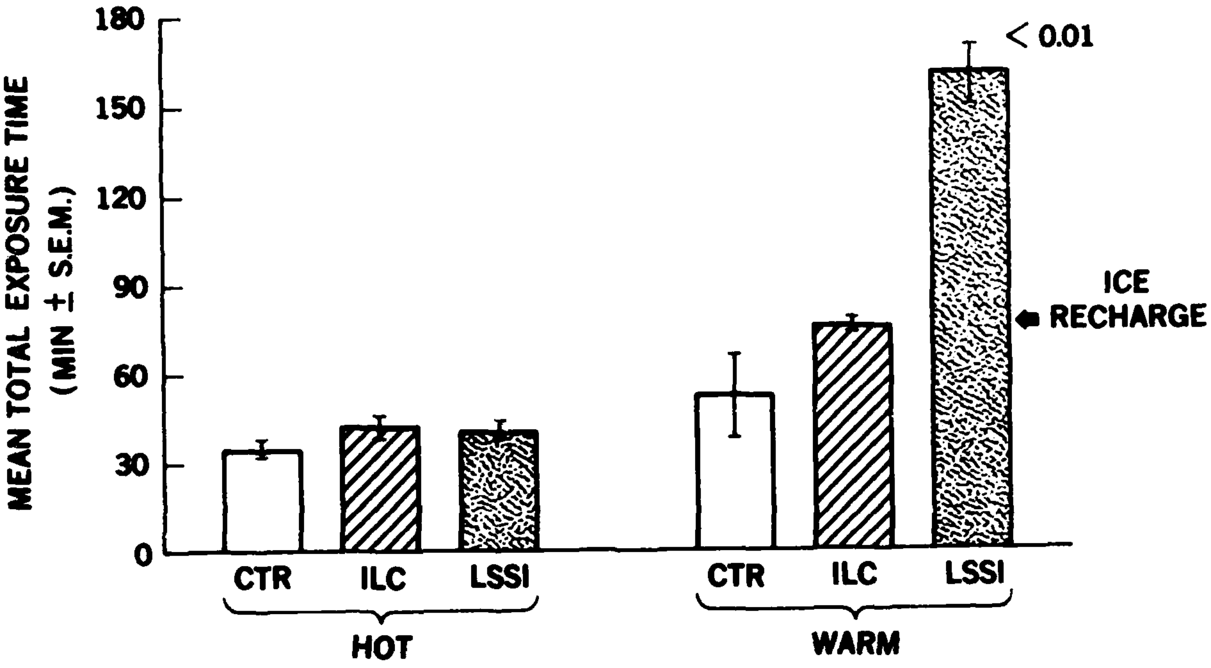

Figure 8. Mean total exposure times for two liquid cooling systems (ILC and LSSI) and the control condition in a warm (WBGT = 24.7°C) and hot (WBGT = 35.9°C) environment. The ice cartridges in the LSSI system were replaced at 75 min of exposure to the warm environment.

TABLE 3. EXPERIMENTAL END POINT PERCENTAGES[a]

End point[b]	Control 35.9°C	Control 25.7°C	ILC 35.9°C	ILC 25.7°C	LSSI 35.9°C	LSSI 25.7°C
HR	50	60	29	0	29	33
T_{re}	13	20	29	0	57	0
SLE	37	20	42	0	14	0
Ø	0	0	0	0[c]	0	67

[a]The percentage of subjects tested under each set of conditions who reached a given experimental end point.

[b]All exposures were terminated if heart rate (HR) exceeded 180 bpm, rectal temperature (T_{re}) exceeded 39.0°C, the subject self-limited exposure (SLE), or completed the prespecified protocol (Ø, see Fig. 4).

[c]All subjects tested under this condition were removed from the chamber because the cooler could not be recharged without removing the protective overgarments.

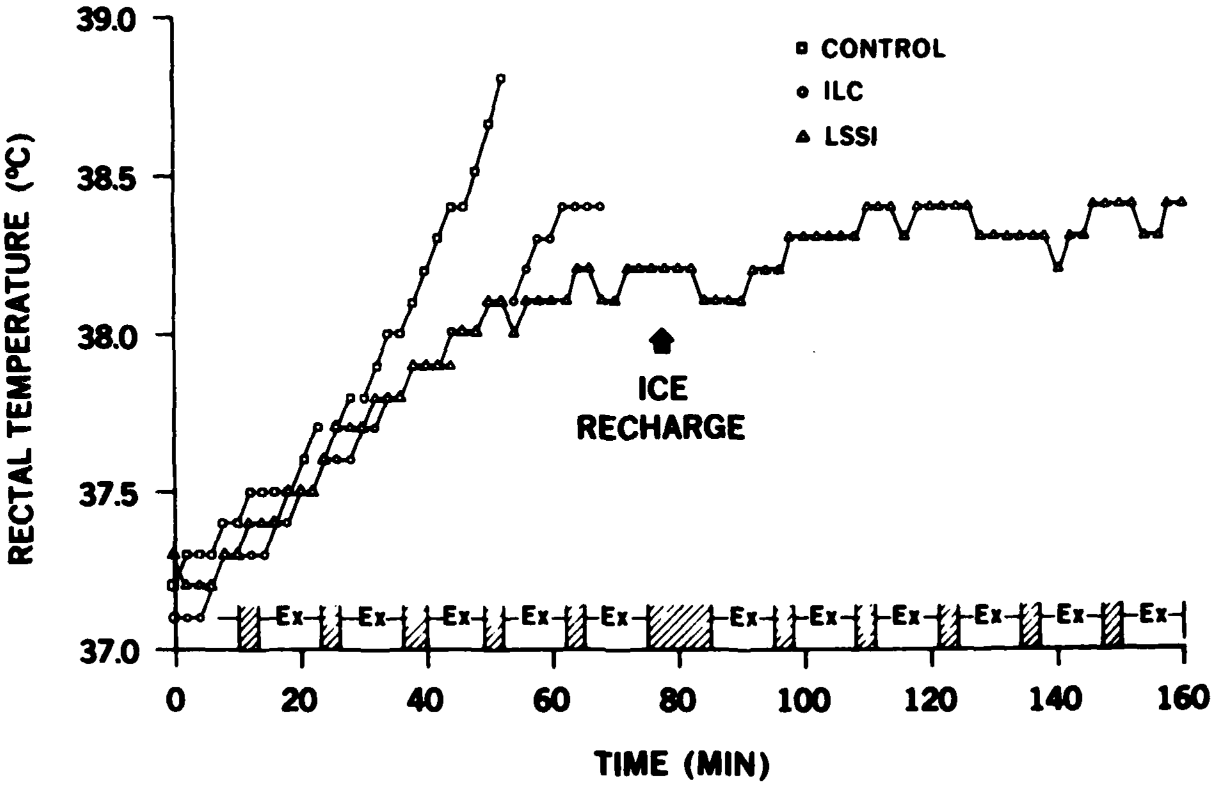

Figure 9. Rectal temperatures for two liquid cooling systems (ILC and LSSI) and the control condition in a warm (WBGT = 24.7°C) environment.

Skin temperatures. Mean skin temperatures appear in Figure 10. Before entering the chamber the mean values for arm, thigh and calf temperatures were the same for all experimental groups. Both sites on the leg gave a mean value of 34.2°C, while the mean arm temperature was 34.8°C. Within 40 min the mean values of arm, thigh, and calf temperatures had exceeded 37.0°C without an LCS, whereas with cooling none of these skin temperatures reached 37°C at any time. Chest temperatures were lower at the start of the experiment with the ILC LCS (30.5°C) and LSSI LCS (32.6°C) than without a LCS (34.9°C) and remained roughly 8.8°C lower throughout the experiment with the LCSs than without.

Heart rate. At the beginning of the experiment mean HR (118 bpm) did not differ between experimental groups (Fig. 11). By the end of the fourth exercise bout the mean HR was 164 bpm without cooling and 150 bpm with either LCS. During the final 1.5 h of exposure with the LSSI LCS the mean HR was 146 - 160, with full recovery to pre-exposure rates during many of the 3-min rest periods.

Thermal sweating. Results are summarized in Table 2. The mean sweat rate was reduced to 41% and 55% of the control value (1.353 kg/h) by the ILC and LSSI LCSs, respectively.

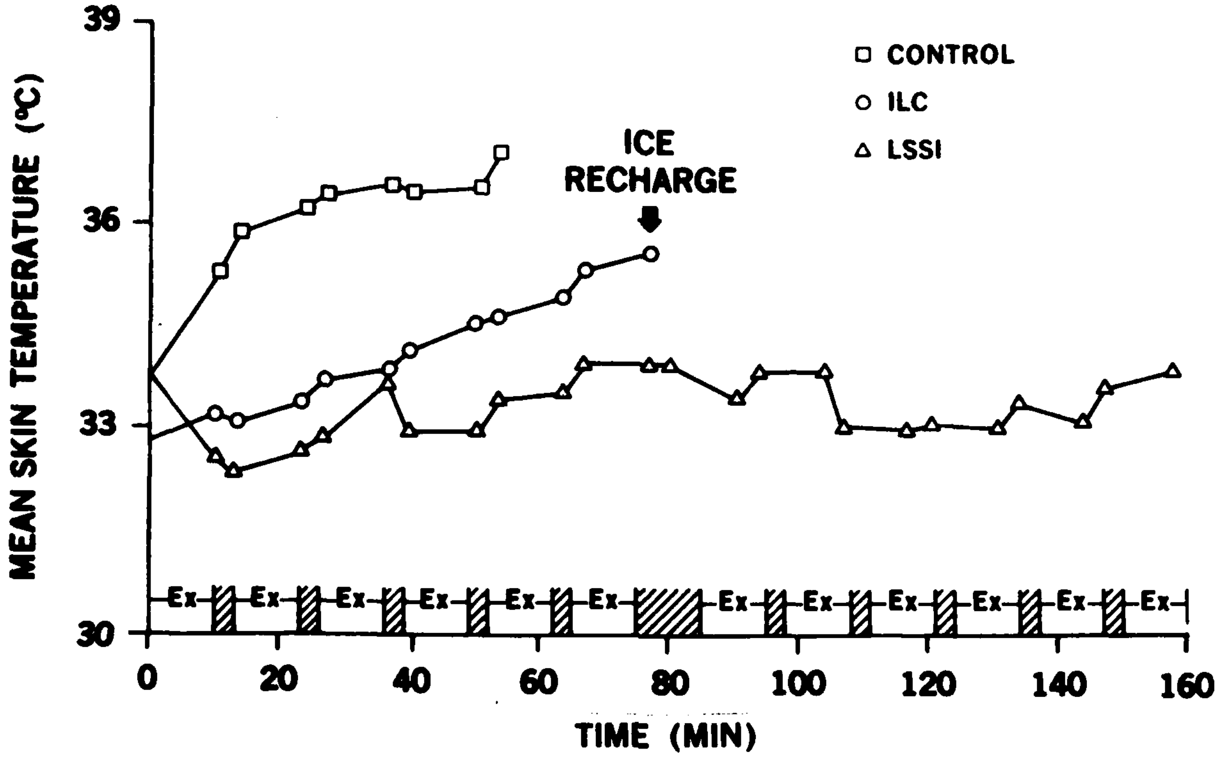

Figure 10. Mean skin temperatures for two liquid coolings systems (ILC and LSSI) and the control condition in a warm (WBGT = 24.7°C) environment. Only the ice in the LSSI system was replaced at 75 min of exposure. See Discussion for details.

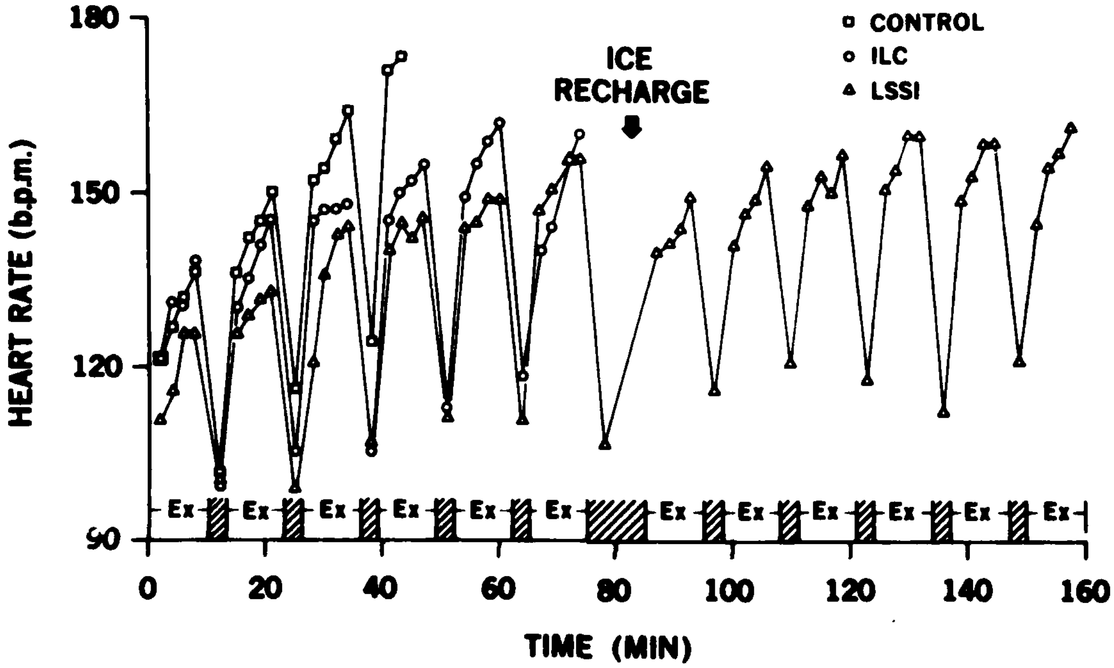

Figure 11. Heart rate responses of men exercising in a warm (WBGT = 24.7°C) environment with (ILC and LSSI) and without auxiliary cooling.

Tolerance times. The mean exposure time at which an experimental end point was reached for each condition is shown in Figure 8. Table 3 gives the percentage of subjects who were removed for a specific reason. Without auxiliary cooling all of the subjects were removed at a mean exposure time of 52 min, primarily because HR exceeded 180 bpm. The mean tolerance time for the LSSI condition was 155 min. Two of the three subjects tested in the LSSI LCS completed the total 165 min of exposure required by the protocol. All of the subjects tested in the ILC LCS were removed after the sixth work bout, without reaching an experimental end point.

Discussion

The U.S. Air Force has sought to identify equipment available from industry which would be suitable in an operational environment and minimize, if not eliminate, the thermal burden imposed by the current CD ensemble. Here we report the results of a laboratory test which evaluated two commercially available LCS designs. Such testing serves two purposes: (a) to quantitatively determine whether or not significant differences in performance exist between the test items, and (b) to qualitatively examine the suitability of design for operational use.

The combination of a 35.9°C WBGT environment and a time-weighted metabolic rate of roughly 410 kcal/h (477 W) represents the most severe conditions in which either LCS has been tested. Webbon et al. (6), however, have tested the LSSI LCS at 32.5°C WBGT and 300 kcal/h without protective overgarments and reported that the LSSI LCS reduced Hall and Potte's physiological index of strain (3) by 50%. They suggested that an insulating overgarment would allow this system to be effective at a WBGT of 35° - 37°C, but our data do not support this. In the hot environment, the average rates of heat removal by the ILC and LSSI systems were 66 W and 68 W, respectively. The insulation provided by the CD overgarments apparently did not reduce the environmental heat gained enough to make either LCS effective. At WBGT = 35.9°C, heat was stored by the body as rapidly with auxiliary cooling as without, and the physiological strain became intolerable within 45 min. Therefore, under these severe conditions physiological tolerance was not enhanced by either LCS.

When the environmental heat load was less severe (24.7°C WBGT), both LCSs significantly reduced physiological strain. The LSSI system was more effective in this respect; both T_{re} and HR reached reasonable plateau values, which for T_{re}, T_{sk}, and HR were 38.3°C, 33.0°C, and 146 - 160 bpm, respectively. Sweat rates were also significantly reduced. Such a physiological state can be tolerated for a prolonged period; fatigue, rather than heat stress, is more likely to become the limiting factor.

The physiological data obtained in this experiment establish two important points: (a) that available portable liquid cooling systems can greatly enhance the ability of men to tolerate working in moderate heat while wearing a highly insulative overgarment, and (b) a severe environmental heat load (WBGT > 35 °C) negates the thermal advantage from these particular systems.

If USAF personnel must be prepared for extreme environmental heat stress, cooling garments with greater coverage of the body surface area will have to be incorporated as well as portable heat sinks with a greater cooling capacity and heat transfer rate.

Neither of the systems tested is operationally suitable for the purposes of the U.S. Air Force. We analyzed each system with the following considerations in mind: (a) the ability to integrate the system with the current CD ensemble, (b) the reliability of the system, and (c) the ability to logistically support and maintain the system.

Researchers at the Defence and Civil Institute of Environmental Medicine (DCIEM) in Canada have evaluated the same ILC "Cool Vest" system tested here (4) and rejected it because "the unit could not be configured to work beneath the outer layers of clothing necessary for (man) protection, next to the skin." The manufacturers have not corrected this deficiency. Furthermore, the ILC ice packs cannot be recharged without doffing the CD protective overjacket. The LSSI system can be operated and recharged without clothing removal, but it requires double (proximal and distal) connectors in order to safely doff contaminated outer garments. Therefore, neither system could be integrated with the current USAF CD ensemble without first makirg important design modifications.

The reliability of the ILC system was excellent, whereas that of the LSSI system was extremely poor. Tubes connecting the LSSI heat exchangers to one another frequently kinked, and the resulting increase in resistance to flow decoupled the coolant pump. Additionally, the connectors themselves (like the air valve on a cycle tire) allowed air to enter the system and decouple the pump.

The ability to logistically support and maintain an LCS which uses ice as the heat sink has been seriously questioned because: (a) the volume of ice contained in either system was only sufficient for approximately 40 min of effective cooling (Fig. 3), and (b) the ice cartridges required more than 9 h to freeze at a temperature of -23°C. The number of ice cartridges required to maintain operation of such systems and the logistics requirements are considered by the operational MAJCOMs to be unreasonable.

In summary, the concept of portable liquid cooling for groundcrew members appears feasible. Such a system could greatly enhance the endurance of men who must work in the heat for prolonged periods while wearing a CD protective ensemble, but field testing under realistic conditions will be required to show whether or not these advantages can actually be gained. Further development and redesigning of this equipment will also be necessary before it can be regarded as operationally suitable for military use. Such programs of development are being actively pursued at both USAFSAM and the Army's Natick Research and Development Laboratories.

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APPENDIX A

DESCRIPTION OF TEST ITEMS

1.2.1. ILC Dover Model 1902 Cool Vest.

The ILC Model 1902 Cool Vest is a completely portable liquid cooling garment worn to aid in maintaining worker comfort and safety in warm environments for extended periods of time. A centrifugal pump is used to circulate chilled water throughout a series of passages within the vest. All mechanical components are packaged within the vest to provide an effective compact system. Cooling is provided by an insulated cooling bag which is capable of sorting cubed ice, crushed ice, or reusable ice packs, and gives up to 1 hour of cooling during heavy work cycles. The bag can be filled and emptied while worn. The vest contains a unique channel system providing a continuous circulation of water. The pocket housing, pump, ice bag, and battery pack can be worn on the back or chest, enabling the user to wear it alone, with a breathing system, or under a protective clothing ensemble. Power is provided by an 8-volt rechargeable battery giving up to 4 hours of continuous operation. Battery charger and additional battery packs are available. The fully loaded system weighs 12 pounds, which includes 7 pounds of ice and water (manufacturer's specs). The vest is capable of being donned by the individual and can be adjusted through a full range of sizes.

1.2.2. LSSI Cool Head System.

The LSSI unit is a modular system consisting of a headliner, vest, cooling source, control display unit, and power supply. It uses a closed-loop system which circulates a liquid consisting of water and propylene glycol. Cooling is provided via a heat exchanger and refreezable cooling cartridge which can provide up to 1 hour of cooling at extreme conditions. A second heat exchanger/cooling cartridge unit can be added to extend wear time. Power is provided by a 6-volt battery which is available in both rechargeable and throw-away versions. The system weight, including heat exchange/cooling cartridges, is approximately 14 pounds (manufacturer's specs).

APPENDIX B

EFFECT OF AGITATION ON HEAT TRANSFER

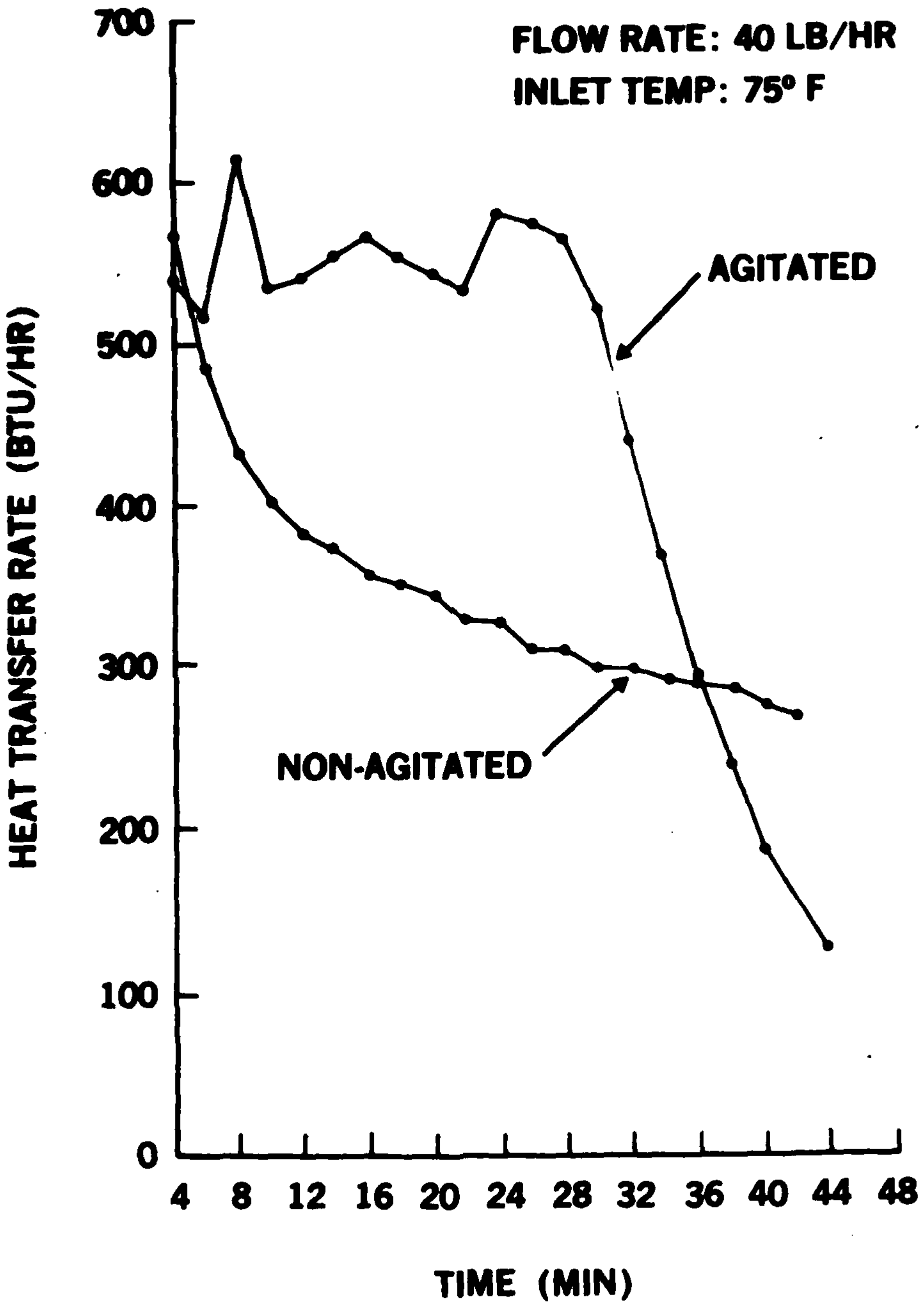

Figure B-1. Increases in the heat transfer rate generated by the LSSI "Cool Head" system when ice cartridges are agitated. (Unpublished data provided by Life Support Systems Incorporated, Mountain View, California.)