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MICROCLIMATE COOLING SYSTEMS: A SHIPBOARD EVALUATION OF COMMERCIAL MODELS

NAVY CLOTHING AND TEXTILE RESEARCH FACILITY

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The Navy Clothing & Textile Research Facility (NCTRF), under contract to the Navy Science Assistance Program (NSAP), evaluated the feasibility of using commercial microclimate cooling systems (MCS) in high heat areas onboard Navy ships by conducting an evaluation aboard the USS LEXINGTON (AVT 16) from 30 March to 9 April 1987. The following cooling systems were evaluated: three liquid-cooled MCS - the LSSI Cool Head, the LSSI Portapack, and the ILC Cool Vest; and two air-cooled MCS - the Encon Air System, with and without a vortex tube. Both air systems and the LSSI Portapack MCS were tethered. The remaining two MCS's were portable, battery-operated, backpack systems. A control test with no cooling system was also run. The evaluation consisted of having test subjects wear the MCS during their normal duty and collecting physiological, subjective, and logistical data. During the test period, environmental conditions were relatively mild: the Wet Bulb Globe Temperature (WBGT) did not rise above 34°C, and the average WBGT was 24°C. Of the four systems tested, the ILC Cool Vest was the overall favorite of the crewmen due to its simple construction, low profile and ease

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of operation. Few operational difficulties were encountered with this system. (U)

The results of this evaluation showed that, given adequate support: a. commercial MCS can be effectively used to relieve heat stress onboard Navy ships; b. shipboard personnel accept the use of MCS as a means of relieving heat stress in high heat areas; c. personnel overwhelmingly preferred the ILC Cool Vest; and D. the ILC Cool Vest and the Encon Air Vortex system had the fewest operational difficulties and were the easiest to operate. (U)

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1. Introduction

The Navy Clothing & Textile Research Facility (NCTRF) conducted a study to determine the feasibility of using commercially available microclimate cooling systems (MCS) to reduce heat stress in hot shipboard environments. Two concepts of cooling - air and liquid - were evaluated. We tested two portable liquid-cooled systems, the ILC Cool Vest and the LSSI Cool Head. Both were battery-operated and consisted of a torso vest through which a fluid circulated. In addition to the vest, the LSSI Cool Head contained a cooling cap. We also tested a tethered version of the LSSI Cool Head, the Portapack, which consisted of vest, cap, and portable cooling unit that could be carried by the individual. Because there are no commercially available portable air-cooled systems, the air systems we evaluated required a tether cord attached to a compressor. We tested an Encon Air Vest with and without a vortex tube, which is a device in which air is spun and split into a warm and a cold air stream. The cold air is then fed directly into the vest.

Our evaluation consisted of physiological measurements, subjective questionnaires, and determination of logistical support and maintenance for the cooling systems. Testing was conducted in early spring 1987 aboard the training aircraft carrier, USS LEXINGTON (AVT 16). The results of the evaluation favorably supported the use of personal cooling systems to reduce heat stress in hot shipboard spaces. The simple, portable ILC Cool Vest was overwhelmingly preferred by the subjects over the more complicated, portable LSSI system. The ILC system also required less maintenance and logistic support. Despite significant cooling, the tethered Encon air system was not well-received, because its tether cord tended to restrict free movement about the space. This report provides some background into the heat stress problem onboard ships, details the methodology and the results of the evaluation, and recommends general use of the cooling system onboard ships.

2. Background

Heat stress on land and at sea has always been a concern for the Navy. Shipboard heat stress results both from the climatic environment and from heat generated within the spaces, especially in the engine and catapult rooms and numerous supply areas. Current methods of dealing with shipboard heat stress include: improvements to shipboard lagging, repair of steam leaks, increased use of air showers, and rotation of personnel based upon the allowable stay times dictated by the Physiological Heat Exposure Limit (PHEL) curves (1,2).

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(1) U.S. Navy. Manual of Naval Preventive Medicine. Chapter 3, Ventilation and thermal stress ashore and afloat. NAVMED P-5010-3, Bureau of Medicine, 1974, pp. 18-24.

(2) Dasler, A.R. Physiological Heat Exposure Limits (PHEL). OPNAVINST 5100.20C, Supplement, Apr 1984.

Personnel working in the hot spaces have also sought relief from heat stress by removing heavy protective clothing. While providing some comfort, this subjects the person to the possibility of burn injury and could be dangerous for both the individual and the operation of the ship.

Another method of providing relief from heat stress is the use of MCS's, which provide cool air or liquid directly to the individual through a garment worn close to the skin. There are basically two categories of MCS - liquid systems and gas systems. The liquid MCS's operate by circulating a cooling liquid through a torso vest and extracting heat from the body through conduction. The heat is transferred to a cold substance, i.e., a heat sink, by the circulation of the cooling liquid. The commercially available gas-operated systems consist mainly of either air drawn directly from a compressed air source and fed into an air vest or air that has been conditioned (cooled) before being fed into the air vest. Through convection and evaporation, heat is transferred from the body to the cool air.

Laboratory evaluations (3,4,5,6) have demonstrated that MCS's effectively reduce the thermal strain induced by the combination of work, clothing, and environment. With MCS's, work times can be increased and physiological strain, as measured by core temperature and heart rate, can be decreased. Commercial MCS's do appear to have their limitations, however. With the combined effects of high temperature, moderately heavy workloads and heavily insulated garments, such as the Army's Chemical Warfare ensemble, the current MCS's can become overburdened and, under these conditions, their ability to reduce physiological strain is still considered somewhat limited (7,8).

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(3) Pimental, N.A. Effectiveness of microclimate cooling systems. Navy Clothing & Textile Research Facility report, June 1987.

(4) __________. Evaluation of two commercial microclimate cooling systems. Technical Report No. 164, Navy Clothing & Textile Research Facility, Natick, MA, In Press.

(5) Pimental, N.A., H.M. Cosimini, M.N. Sawka, and C.B. Wenger. Effectiveness of an air-cooled vest using selected air temperature and humidity combinations. Aviation, Space, and Environmental Medicine 58:119-24, 1987.

(6) Shapiro, Y., K.B. Pandolf, M.N. Sawka, M.M. Toner, F.R. Winsman, and R.F. Goldman. Auxiliary cooling: comparison of air cooled vs. water cooled vests in hot-dry and hot-wet environments. Aviation, Space and Environmental Medicine 53:785-89, 1982.

(7) Cosimini, H., J. Cohen, B. DeCristofano, R. Goff, V. Iacono, M. Kupcinskas, and T. Tassinari. Determination of the feasibility of two commercial portable microclimate cooling systems for military use. Technical Report No. Natick/TR-85/033L, US Army Natick Research and Development Center, Natick, MA 1985.

(8) Terrian, D.D., and S.A. Nunneley. A laboratory comparison of portable cooling systems for workers exposed to two levels of heat stress. Technical Report No. USAFSAM-TR-83-14, USAF School of Aerospace Medicine, Brooks AFB, TX, 1983.

Commercially available MCS's have been successfully utilized in industry at power stations and processing plants to reduce heat casualties of personnel working in hot environments. In an effort to examine this method of reducing heat stress, the Navy Science Assistance Program (NSAP), on behalf of the Commander in Chief, Atlantic Fleet (CINCLANTFLT), sought to investigate the feasibility of using commercially available MCS in selected spaces onboard Navy ships. In response to NSAP's request, NCTRF was tasked to conduct the evaluation onboard Navy ships having heat stress problems.

3. Description of Microclimate Cooling Systems

Five commercially available cooling systems from three manufacturers were evaluated. To assure that the systems were in proper working order, all components for each MCS were evaluated in the laboratory prior to the shipboard evaluation. To provide protection from the possibility of fire, all exterior surfaces of the systems were covered with a Kynol/Nomex fabric.

Table I contains a weight comparison of the five systems. The values in the table represent the weight of the cooling system components carried by the subjects. The lightest system was the ambient air system (3.6 lbs), while the heaviest system was the LSSI backpack system (16.8 lbs).

Table I. Weight comparison for portable cooling system components carried by the individual.

	ILC (lbs)	LSSI (lbs)	LSSIP (lbs)	ENCON (lbs)	AIR (lbs)
Vest	2.1	2.4	2.4	1.6	1.6
Motor/pump	0.9	2.0	-	-	-
Heat exchanger	0.6	5.0	-	-	-
Battery	1.9	2.2	-	-	-
Ice/Canister	6.0	5.2	-	-	-
Circulating Water	2.1	*	-	-	-
Vortex Tube	-	-	-	0.8	-
Hose (assume 10' carried by man)	-	-	2.0	2.0	2.0
TOTAL	13.6	16.8	4.4	4.4	3.6

* Included in the weight of Vest and Heat Exchanger

Note: Systems tested were as follows: ILC = ILC Cool Vest, LSSI = LSSI Cool HEAD, LSSIP = LSSI Portapack, ENCON = Encon Air Vortex System, AIR = Ambient Air System. All systems are described below.

3.1 ILC Cool Vest

The ILC Cool Vest Model 19 system, depicted in Figure 1, consists of a circulating liquid vest powered by a battery-operated motor/pump assembly. The system is manufactured by ILC Dover, Frederica, DL. Heat is removed from the body through the use of a circulating liquid vest. The vest comes in one size, covers the torso and consists of a heat-sealed, polyurethane-coated nylon with an inner bladder through which water flows. Water is the liquid used throughout the system. The heat exchanger consists of a vinyl bag filled with ice and water and contained in a backpack assembly within the vest itself. (For this evaluation a 1/8" sheet of foam insulation was placed between the vinyl bag and the vest to isolate the bag from the test subject's skin.) As the water circulates through the vest and bag, heat is transferred from the body to the water and ice, resulting in a gradual melting of the ice. The backpack can be worn either on the front or back of the individual. For this evaluation, it was worn on the back to achieve a better ergonomic balance.

Temperature of the water/ice mixture in the vinyl bag was monitored with a thermistor connected to a Yellow Springs Instrument (YSI) junction box. When the temperature of the mixture reached 60°F, some of the water was drained out of the system and replaced with ice. The manufacturer recommends that 4 lbs of ice and 1 quart of water be placed in the system; more ice could be used for longer periods of work. Laboratory tests at NCTRF showed the maximum amount of ice that could be placed in the bag was 8 lbs, but then the bag was difficult to close. Because six lbs of ice enabled easy closing of the bag, this amount was chosen for all tests. The ice, which was obtained from the ship's freezer, consisted of cubes measuring a nominal 1 x 1.25 x 1.25".

The ILC system was powered by an 8-volt, 2.6 amp-hr rechargeable gel-cell battery and pump/motor assembly, which were also contained in the backpack. Prior to the evaluation, batteries under an appropriate load were checked in the laboratory with a voltmeter. The manufacturer states that the system can be operated for up to 3 hours before changing the battery. For this evaluation, the batteries were changed every 2 hours, or sooner if we noticed the flow through the system had significantly decreased.

The cost of the ILC system as tested was $680 and consisted of one Model 19 vest, 2 batteries and 1 battery charger. (NOTE: On 1 July 1987, ILC lowered the price of their system, which would now cost $359.) The following quantities of systems were used in this evaluation. All items were purchased in 1986.

Item	Unit Cost	Quantity
Vests	$525	8
Batteries	$60	16
Battery Chargers	$35	12
Ice Cubes (trays)	-	100

3.2 LSSI Cool Head

As depicted in Figure 2, the LSSI Cool Head is a liquid system consisting of a vest, head cap and heat exchanger unit (HEU). It is manufactured by Life Support Systems, Inc., Mountainview, CA. The circulating liquid used in the system is a mixture of propylene glycol and water with a freezing temperature of -10.5°C (13°F). Liquid is circulated through the vest/cap and heat is transferred into two frozen liquid canisters connected in series in the HEU. The vest/cap comes in one size and is constructed of a heat-sealed, polyurethane-coated nylon with interior channels through which the liquid flows. Circulation is provided by a battery-powered pump/motor assembly. Liquid is circulated from the pump, to the cap, to the vest, to the HEU's and back to the pump. The HEU's and the pump/motor assembly are contained in either a backpack or portable pack (Portapack) configuration. The backpack is worn either on the front or back of an individual and connected to the vest with a short length of connective hose. For this evaluation, the backpack was worn on the back. The Portapack is a separate unit that is placed on the floor near the individual and is connected to the vest with multiples of 6- or 12-foot hoses. To compensate for the additional heat gain along the extension hose, we tested the Portapack configuration with three frozen canisters.

The battery for the LSSI MCS's is a 6-volt, 4 amp-hr unit. The manufacturer of this unit recommends that the batteries be charged for at least 12 hours. Prior to the evaluation, all batteries were charged and checked with a voltmeter. Batteries not achieving a potential of at least 6 volts were not included in the evaluation. All of the acceptable, fully charged batteries were then tested under an appropriate load with a voltmeter. Those units not attaining at least a 5.2-volt potential under load were also eliminated from the evaluation. The average potential of the fully charged batteries was 5.6 volts. To further assure proper operation, randomly selected batteries were tested in the laboratory by measuring the voltage discharge when the battery was connected to the pump for a period of 2 hours. After each recharge onboard ship, the potential of the batteries was checked again. Batteries were changed after 2 hours, or sooner if we noticed the flow of coolant through the system had significantly decreased.

The canisters were frozen in the ship's food freezer which was maintained at 5°F ± 5°F. The temperature of the coolant fluid in the HEU was monitored with a thermistor connected to a YSI junction box. The thermistor was inserted in the HEU with the sensor portion of the thermistor in contact with the bag containing the coolant fluid. To assure constant cooling during the evaluation, we replaced the canisters when the coolant temperature reached 60°F. Following the test, the used canisters were returned to the ship's freezer.

When the quick disconnects from the vest to the backpack were uncoupled during doffing, the unit leaked a small amount of fluid, causing air to infiltrate the system. Consequently, after several uses we had to replenish the lost fluid and purge the system of air. The manufacturer supplied a kit for this purpose with instructions on how to refill the system.

The average cost of the LSSI backpack system as tested was $2511. This included a backpack/vest assembly (fully charged), four canisters, two rechargeable batteries, one battery charger, one refill kit and one additional quart of recirculating fluid. The LSSI Portapack system with 12 feet of tether cord costs an additional $603. (Note: effective July 1, 1987 the cost of the above systems would be $2376 and $2979.) The following quantities of LSSI systems were available for use in this evaluation.

Item	Unit Cost	Quantity	Date Purchased
Backpacks/Vest Assembly	$2162	4	(3) 1986, (1) 1982
Portapacks	$329	3	1986
Canisters	$9	52	(40) 1986, (12) 1982
Batteries	$98	19	(11) 1986, (8) 1982
Battery Charger	$48	18	(12) 1986, (6) 1982
Refill Kit	$51	2	1987
Circulating Fluid (gal)	$72	6	1987
Tether Cord (ft)	$5	24	1987

3.3 Encon Vortex System

The Encon Air Vortex System Model 02-6360, depicted in Figure 3, consists of an air vest connected to a vortex tube. It is manufactured by Encon Corporation, Houston, TX. The vest comes in two sizes, regular and extra large, and is constructed of a Buna-N-coated nylon shell with a perforated interior and an inner air distribution system for both the front and rear of the vest.

> In a vortex cooler, high pressure air enters a stationary generator and is released with a vortex motion, spinning along the tube's walls toward the hot air end at sonic speeds up to 1,000,000 rpm. Air near the surface of this spinning vortex becomes hot, and some of it exits through the needle valve in the hot end. The air that does not escape through the hot air needle valve is forced back through the center of the warm air vortex. Because the air forced back through the sonic-velocity hot airsteam moves at a slower speed, a simple heat exchange takes place. The inner, slower-moving column of air gives up heat to the outer, faster-moving column. When the slower, inner column of air exits through the center of the stationary generator and out the cold exhaust, it has attained an extremely low temperature. (9)

(9) Vortec Corporation. Products for Productivity. Cincinnati, OH, 1986.

The cold air from the vortex tube is fed into the vest, while the warm air is directed away from the user. The temperature and flow rate of the air into the vest can be inversely controlled with the control valve located on the vortex tube. The valve rotates 1/4 turn from minimum to maximum cooling. The system is powered by a compressed air line. The manufacturer recommends anywhere from 80-100 psig @ 20 scfm. To insure that all systems would operate at a constant input and that the ship would be able to supply the required air, a pressure of 80 psig was selected for the operation of the system.

In addition to the vest and vortex cooler, this Facility supplied an air regulator with water trap, a 5 micron filter, 50' of 3/8" diameter hose, and the required fittings at each test site. Also, since this system was tethered, we had to provide a means for the user to disconnect rapidly in an emergency situation. For this purpose, we fabricated a breakaway fitting located at the connection to the vest. The fitting was constructed from a commercially available quick disconnect with the outer sleeve replaced by a section of rubber hose. The breakaway force was set to 40 lbs by adjusting the tension on a hose clamp encompassing the rubber hose.

To monitor the temperature of the air being fed into and out of the vortex tube, we placed thermistors in the air lines of the vortex tube. Dry and wet bulb temperatures were measured on the vortex inlet air; only dry bulb temperature was measured on the vortex cold air outlet (vest inlet). Figure 4 illustrates the location of the vest temperature measurement. Due to expansion as the air diffused through the air vest, the air temperature steadily decreased. Although the temperature measured in the vest supply line was not the exact air temperature reaching the skin surface, it did represent the closest region to the skin that could be measured without encountering widely fluctuating temperatures resulting from the expansion and diffusion of the air as it entered the vest. The instrumentation for the measurement of the wet bulb temperature of the cold air outlet would have added another tethered cord and/or fitting for the test subject to contend with. We felt this would unduly affect the subject's evaluation of the system and therefore did not use it.

The basic cost of the Encon air vest, vortex tube and belt was $402. The average cost of the system we tested was $625, which included air vest, vortex tube, air lines, air filters, regulators and miscellaneous fittings. The following quantities of systems were used in this evaluation. All items were purchased in 1986.

Item	Unit Cost	Quantity
Air vests (regular)	$200	4
Air vests (X-large)	$200	5
Vortex tubes	$196	9
Belts	$6	9
Hose (3/8" dia)	$1/ft	250'

Filters	$65	8
Regulators	$60	4
Breakaway fittings	$18	8

3.4 Ambient Air System

Because compressed air cools as it expands, some degree of body cooling can be achieved with high temperature, unsaturated ambient compressed air with no vortex tube (3). To determine the effectiveness of using this method of cooling, we fabricated a system consisting of the Encon air vest fed directly from the shipboard compressed air line. The pressure regulator was set to maintain an air flow of 15 scfm. In addition to the air vest and regulator, a 5 micron filter, 50' of hose and a breakaway fitting were also supplied with this system.

The temperature of the air was monitored in a similar manner to that used in the vortex air system. The cost of this system was $200 for the Encon air vest. The cost of the system as tested was $420, which included the Encon vest, pressure regulator, air filter, hose and miscellaneous hardware.

3.5 Thermacor Cooling System

Another type of gas MCS that has recently become available is based upon the heat absorption capacity of a liquified gas as it vaporizes during depressurization. The system, marketed by Thermacor Corp., consists of a vest, a tank of pressurized freon (R-114) and a thermally regulated distribution system. This Facility considered testing the freon system during the shipboard evaluation. However, we first sought guidance from the Navy Medical Command (NMC) to determine the safety of using freon in a relatively enclosed space. NMC did not recommend its use. Specifically, NMC objected to the use of freon 114 within shipboard spaces because of:

a. The potential of freon 114 to dissociate into more toxic substances when it comes in contact with heated surfaces normally found in shipboard spaces.

b. The possibility that, because freon is heavier than oxygen, it could displace oxygen to sufficiently low levels, thereby creating an hypoxic environment that could produce asphyxiation.

c. The possibility that personnel would "sniff" the freon and lose their coordination.

(3) Pimental, N.A. Effectiveness of microclimate cooling systems. Navy Clothing & Textile Research Facility report, June 1987.

4. Test Methods

4.1 Ship Selection

To select an appropriate ship for this evaluation, we discussed the heat stress problem with personnel from NSAP and CINCLANTFLT. Ships were screened for their respective history of heat-related problems and their availability for shipboard testing in the specified timeframe. From this initial screening, four potential ships were identified:

a. USS NASHVILLE (LPD 13)
b. USS CORAL SEA (CV 43)
c. USS SARATOGA (CV 60)
d. USS LEXINGTON (AVT 16)

Factors that were considered in the final selection of a ship were: the number and availability of test volunteers, the flexibility of the sailing schedule, the ease with which the ship could accommodate the technical aspects of this evaluation, and the size of the ship as it related to onboard support equipment. Because of their size, the USS CORAL SEA, the USS SARATOGA and the USS LEXINGTON would have provided the largest number of personnel to test in the shortest period of time. They would also have had the greatest amount of equipment to support MCS. As an aircrew training ship, the USS LEXINGTON had the additional benefit of a more flexible schedule and could more easily accommodate the test requirements than a war ship. Because of this flexibility and because of its convenient departure date, the USS LEXINGTON was selected as the ship on which the evaluation should be conducted.

4.2 Test Design

Testing was conducted from 30 Mar to 9 Apr 87 on board the USS LEXINGTON during a roundtrip cruise from Pensacola, FL to Corpus Christi, TX. A total of 29 volunteer subjects were tested in the following spaces, which had been designated by the ship as having previous heat stress problems.

Space	Shift	# of Subjects	Duties
Aft Engine Room	0800-1200	4	Lower Level, Messenger, Top Watch
Aft Engine Room	1600-2000	4	Lower Level, Messenger, #2 Throttle
Main Control	1600-2000	4	Lower Level, Messenger, #1 Throttle, #4 Throttle
#1 Fireroom	1600-2000	3	Auxiliaryman, Messenger, Top Watch
#2 Fireroom	1600-2000	3	Auxiliaryman, Messenger, Top Watch

#3 Fireroom	0800-1200	4	Auxiliaryman, Burnerman, Messenger, Switchboard
Laundry	1200-1430	3	Laundry, Press, Supervisor
Scullery	1030-1330	4	Banger, Catcher, Pitcher, Right Fielder

Subjects were tested during their entire duty shift, which, except for laundry and scullery personnel, was normally 4 hours. Shifts for the laundry and scullery personnel were anywhere between 2 and 4 hours. To minimize diurnal body temperature effects, the subjects were tested the same time each day.

Prior to reporting for their normal duty, the subjects reported to our test center where, as described below, measurement devices were attached and questionnaires filled out. Following pre-evaluation measurements, the subjects donned the appropriate cooling system over their T-shirt and were instructed in its use. (For this evaluation, subjects wore either a T-shirt and denim trousers or a T-shirt and coverall with the top rolled down to the waist.) They proceeded to their work space where the MCS were filled with ice and water (ILC) or canisters (LSSI), or connected to the compressed air lines (ENCON). The subjects adjusted the control valve on each system to their own comfort level. Battery and cooling system maintenance was made as previously described in Section 3. Operational difficulties were noted throughout the test. At the completion of their duty, the subjects returned to the test center where they doffed the systems, completed post-test measurements, and were verbally debriefed.

Control tests with no cooling vest were conducted on the first 14 test subjects. However, due to the low heat load (environmental and metabolic), control tests did not seem warranted and were not conducted on the other subjects. The remaining test time was devoted to evaluating a larger number of subjects and cooling systems. Table II lists the types of cooling systems evaluated in random order by the test subjects. As is evident, there were numerous combinations of systems evaluated by the 29 subjects. This varying number was the result of several factors, including time constraints for the subjects and feasibility of using a tethered system within the space. Further, after several tests, the air system with no vortex tube was eliminated from the testing because it did not provide sufficient cooling. In some instances, the feasibility using a tethered system was determined only after one test with an umbilical; all other tethered systems were therefore not tested on that particular individual.

In summary, we collected data on 28 subjects using the LSSI Cool Head, 29 using the ILC Cool Vest, 16 using the Encon Vortex, 4 using the ambient air system, 13 using the LSSI Portapack, and 14 using no cooling. The one subject who did not evaluate the LSSI Cool Head did not show up for his last day of testing. Nine subjects were tested with the LSSI Cool Head and ILC Cool Vest only. These systems were chosen because they are both liquid-cooled, portable, backpack systems and were considered the most likely candidates for Navy procurement.

Table II. Cooling systems evaluated by test subjects onboard USS LEXINGTON.

Test Series	MCS Systems Tested						Total Subjects Tested
1	LSSI	ILC	VOR	AIR	PORTA	CONTROL	0
2	LSSI	ILC	VOR	AIR	-	CONTROL	3
3	LSSI	ILC	VOR	-	PORTA	CONTROL	6
4	LSSI	ILC	VOR	-	-	CONTROL	2
5	LSSI	ILC	-	AIR	-	CONTROL	1
6	LSSI	ILC	-	-	PORTA	CONTROL	1
7	LSSI	ILC	-	-	-	CONTROL	1
8	LSSI	ILC	-	-	PORTA	-	1
9	LSSI	ILC	VOR	-	PORTA	-	4
10	LSSI	ILC	-	-	-	-	9
11	-	ILC	VOR	-	PORTA	-	1
						Total	29

4.3 Measurements

Dry bulb temperature (DB) and wet bulb globe temperature (WBGT) were measured using a Wibget Heat Stress Monitor (Reuter-Stokes, Inc.). DB and WBGT readings were taken at least three times during each duty shift. If environmental conditions varied within a space, measurements were taken at several different locations. Rectal temperature was measured with a YSI (Model 401) thermistor inserted about 10 cm beyond the anal sphincter. Skin temperatures were measured with YSI (Model 409) thermistors strapped to the chest, arm, and leg. Rectal and skin temperature measurements were collected on a portable, computer-controlled data acquisition system (Hewlett Packard (HP) Scanner 2413A data acquisition and control unit and HP 71B computer). Heart rate was measured from three chest electrodes (CM5 placement) with a digital, portable heart rate monitor (Computer Instruments Corp.). Cognitive performance was measured with an interactive, computerized, performance assessment battery. Included in the battery were tasks for pattern recognition, logical reasoning, reaction time, and dexterity. Periodically during each test, subjects were asked to rate their thermal sensation on a nine-point scale ranging from "very cold" to "very hot." Following each day's session, subjects completed questionnaires on each cooling system, ranked the systems in order of preference, and were interviewed. Appendix B contains sample questionnaires.

4.4 Statistical Procedures

The physiological, performance, and subjective data were analyzed by use of repeated measures analysis of variance. Tukey's test was used to locate significantly different means. Significance was accepted at the 0.05 level. Statistical analyses were done on the data from the 11 subjects who performed the control test and the LSSI backpack, ILC, and Vortex cooling tests. Statistics were also performed on the data from the 28 subjects who used the ILC and LSSI backpack cooling systems.

4.5 Operational Feasibility

To determine if the commercial systems could be used onboard ship, we had to monitor several key logistical items.

a. Air line set up - The setting up of the tether lines for the operation of the air MCS included the location of low pressure air lines, the selection of compatible fittings, the installation of regulator and filter, and the careful routing of the air lines so as not to disrupt the personnel on duty.

b. Battery usage - The number of batteries used during a test was monitored. The time when batteries were changed was also noted.

c. Ice/canister usage - The amount of ice or canisters used during a test and the time of change were noted.

d. Operational difficulties - Any difficulties in the operation of the systems were noted. The difficulties included those experienced by both the user and the test team personnel.

5. Results

5.1 Physiological Evaluation

Due to unseasonably cold weather, environmental conditions during the course of the evaluation were relatively mild. Overall WBGT averaged 24°C (76°F); the range was 16-34°C (61-93°F). Overall DB averaged 31°C (88°F); the range was 22-42°C (72-108°F).

Even during the control tests with no cooling, rectal temperatures did not increase by more than 0.2°C (0.4°F) over the 4-hour duty shifts. Rectal temperature did not significantly differ between the control test and any of the cooling tests, nor among any of the cooling tests. However, there was a significant difference in chest temperature. For the 11 subjects who ran a control test and also tested the ILC, LSSI backpack, and Vortex systems, chest temperature was lowest with the ILC system (22.2°C), similar for the Vortex and LSSI backpack (27.3 and 28.8°C), and highest for the control test (33.5°C). In all cases where the ILC was compared with the LSSI backpack, chest temperature was significantly lower with the ILC. (Note: Because we did not use insulated thermistors, the chest temperature may have been greatly influenced by the cold liquid or air in direct contact with the measuring device.)

Much of the test subjects' duties involved standing in one location (watching gages, supervising, pressing, etc.). The heart rates reflected this low metabolic work rate. Heart rates averaged 82-86 b/min for both the control and the cooling tests. These were not statistically different.

5.2 Performance and Subjective Evaluation

For the four tasks included in the performance assessment battery, there were no differences in either speed or accuracy between the control test and cooling tests. On the thermal sensation scale, all cooling systems were rated "slightly cool." Control tests were rated significantly higher ("slightly warm").

The subjects' overall ranking of preference for the MCS's they tested is listed in Table III. Of the 10 subjects who used the LSSI backpack, ILC, Vortex, and LSSI Portapack cooling systems, nine rated the ILC system as their first choice. Overall, the Vortex was the second choice, the LSSI Portapack was third, and the LSSI backpack was fourth. Of the 10 subjects who used only the ILC and the LSSI backpack systems, all of them preferred the ILC. When all the data were evaluated together, 26 of the 29 subjects preferred the ILC Cool Vest; the remaining subjects selected the Vortex System as their overall number one choice.

After each test, subjects completed a questionnaire and were interviewed. The majority of the subjects preferred the ILC system over the other cooling systems. They had many positive comments about the system: it was lightweight and not too bulky, provided consistent cooling, was easy to operate, and had no tubes or cords to get tangled. Even though the investigators and not the subjects set up the cooling systems and provided ice and battery changes, several subjects commented that the ILC system would be much easier to maintain than the LSSI. They liked the ILC's ability to use either ice cubes or freezer packs; only a few thought that ice and freezer space would be a problem onboard ship. They thought the ILC's on/off toggle switch and adjustable cooling control were accessible and easy to operate. However, several subjects suggested the toggle switch be relocated to the front of the vest to prevent accidental shut off. Several subjects mentioned the ILC vest tended to slip down in the back, pulling the vest up against the neck. A waist strap and a deeper neckline might prevent this. Subjects did not like the metal clips which fasten the vest around the torso; they would have preferred a Velcro closure. They also suggested extra padding on the shoulders for both the ILC and the LSSI backpack systems (padding with a rubberized, nubby surface might also reduce backpack slippage).

Table III. Overall ranking of preference for Microclimate Cooling Systems.

SYSTEMS TESTED	TEST SERIES * A	TEST SERIES * B
	Overall Ranking	Overall Ranking
ILC Cool Vest	#1	#1
LSSI Backpack	#4	#2
Vortex	#2	**
LSSI Portapack	#3	**

* refers to types of cooling systems evaluated by test participant (see Table 2). A = All four systems evaluated (Test Series 3 and 9, n=10); B = ILC Cool Vest and LSSI Cool Head evaluated (Test Series 7 and 10, n=10).

** System not tested

Many subjects stated they would not use the LSSI backpack system under any circumstances, or only under extreme conditions. They thought this system was too heavy and much too bulky for shipboard use. Only two of the 29 subjects liked the head cooling. The others stated they could not feel the cooling unless the cap was held closely against the head by significantly tightening the chinstrap, but they found the chinstrap uncomfortable and irritating. (Note: The two subjects who liked the head cap had very short hair.) Several subjects complained of getting snagged by the tubes connecting the cap to the vest. The subjects liked the way the LSSI vest fastened around the torso (stretchy fishnet fabric with Velcro closure). Because the LSSI's power switch and cooling control knob are on the back, they were hard to reach. It was difficult to distinguish the "on", "off", and "fill" positions of the power switch. The cooling control knob rotates clockwise/counter-clockwise, and it was not easily distinguishable as to which direction increased the flow of liquid. However, as personnel become more familiar with the system through continued use, the problem with the control knobs should be reduced or eliminated.

Most of the subjects stated that, due to the tether cord, they could not use the air or the Vortex cooling systems. They did, however, like the feel of the air cooling and the lightweight vest.

5.3 Air System Performance

Temperatures taken both in the compressed air lines and at the outlet entering the air vests indicated that the Encon vest with the Vortex tube would provide substantial personal cooling. The inlet air on the Encon air vortex system averaged 33°C (91°F) DB with a dewpoint (DP) of -4°C (24°F). The DB of the air entering the vest was never above 10°C (50°F) and in several instances was below the 0°C measurement limit of the test instrument.

The air from the ambient system averaged 36°C (97°F) DB and -5°C (22°F) DP in the pressurized line. The air flowing into the vest averaged 32°C (91°F) DB. As previously stated, the temperature of the air was measured just before the air entered the vest. Since the ambient compressed air continued to expand after it entered the vest, the actual cooling air temperature at the skin surface could not be determined. However, assuming that the measured vest temperature of both air systems was proportional to the temperature felt at the skin and that the mean skin temperature of clothed individuals is 33°-35°C, then the vortex system contained up to nine times more sensible cooling capacity than the ambient compressed air system. As discussed above, we found the air system was not cooling as well as we had anticipated and after four tests, we discontinued this system evaluation.

5.4 Logistics

5.4.1 Ice/Canister and Battery Support

In this evaluation, because of the remote location of the freezer, supplying canisters or ice to the LSSI and ILC systems repreeented a significant effort. The LSSI canisters were placed upright on a pallet in the freezer, allowing approximately 2 inches between adjacent canisters. Although the ship's freezer was maintained adequately cool for freezing (5°F), it still took between 12 and 18 hours to completely freeze the canisters. During the freezing process, nine of the 52 canisters developed leaks through the top expansion seal. The ice used in the ILC vests was made in standard ice cube trays. Because of the limited amount of space in the freezer, the ice trays could not be spread over a wide area; the trays were therefore stacked, 6 deep, on top of freezer boxes. The top trays of ice took approximately 7 hours to freeze, while the trays in the middle of the stack took between 12 and 18 hours to completely freeze due to poor air circulation.

The average time was approximately 1/2 hour for one person to collect, pack and transport the ice to the test site for four subjects. Since the ice and canisters froze at different temperatures, 0°C (32°F) for ice vs -10°C (13°F) for canisters, they were transported to the test site in separate coolers (Coleman 24 quart). The ice or canisters in the systems were changed when the temperature of the coolant reached 15.5°C (60°F), as measured with a thermistor in contact with the coolant. For the 4-hour tests, the average change time for the ILC and LSSI backpack systems was 3.1 and 2.3 hours, respectively. Thus the ILC system offered a 35% longer cooling time per charge than the LSSI backpack system. Supplying ice for four people for one 4-hour duty required 48 lbs of ice (12 lbs per person). This included the initial load of ice plus one recharge. Supplying four people with the LSSI canisters required, on the average, 16 canisters (42 lbs).

Because both the LSSI and ILC systems were powered by batteries, the batteries had to be maintained on full charge at all times. The test center, however, was not electrically set up to maintain a bank of chargers; therefore, the batteries were recharged at several sites throughout the ship. This was an inconvenience that could be avoided if the systems were to be used on a continuous basis and a charge center could be maintained. To guarantee that the batteries obtained a full charge, they were charged for at least 12 hours. Recharging the ILC batteries presented no difficulties. Two of the 19 LSSI batteries did not hold their charge after 12 hours off the charger (1 purchased in 1986, 1 purchased in 1982).

To prevent a complete discharge of the batteries, they were operated for a maximum of 2 hours. New batteries were installed after 2 hours, or earlier if the system had stopped operating or had slowed down. Table IV gives a breakdown of the time of failure for the batteries. The LSSI backpack system required 11 battery changes before the scheduled 2-hour change, whereas the ILC system required only one change prior to the 2-hour time. The LSSI Portapack system required 8 changes before 2 hours.

Table IV. Commercial Microclimate Cooling System battery changes for 4-hour watches (Data from scullery, laundry, and pressroom not included).

Change Time (hrs)	Total Number of Battery Changes: ILC Cool Vest	LSSI Cool Head (backpack)	LSSI Cool Head (portapack)
0.0 - 0.5	0	4	1
0.6 - 1.0	0	3	2
1.1 - 1.5	0	4	4
1.6 - 2.0	1	0	1
2.0+ *	19	11	2

* Time for scheduled battery change was 2 hours.

5.4.2 ILC Operational Difficulties

Relatively few difficulties were experienced with the ILC system. Those that were encountered were minor and did not significantly affect the test. In a few instances, the switch on the ILC unit was inadvertently shut off after the operator either hit the switch with his hand or passed by an object that shut off the switch. In one case, water leaked from the top of the ziplock bag on the ILC unit when the individual bent over to work on a device. One ILC system developed a pinhole leak in the bag. The leak was not large enough to stop the test or prevent the subject from performing his duties.

5.4.3 LSSI Operational Difficulties

Of the 5 cooling systems tested, the LSSI backpack and Portapack systems presented the greatest number of difficulties in all phases of operation. Of the 52 canisters brought onboard ship for the evaluation, 3 popped the expansion seal during shipment, 2 developed leaks at the expansion seal during shipment, 2 were severely dented during shipment, 1 developed a leak due to corrosion, and 9 leaked fluid through the expansion seal during freezing.

A significant amount of time was spent trying to keep the LSSI systems operational. In nine instances the LSSI unit ran for a period of time and then stopped. After the control unit was given a significant rapping, the system started running again. The stoppage was apparently due to an air lock in the system which was dislodged when the unit was rapped. Since the flow indicator was located on the back, the subject did not realize that the unit had shut off until after he had started to feel warm.

As described previously, the LSSI units needed to be replenished with fluid and purged of air after a few periods of use. The fluid replenishment and air purging procedure, which was demonstrated to CINCLANTFLT and NCTRF personnel by an LSSI representative, consisted of the following procedure.

a. Head-Vest Fluid Replenishment

1) Lay Head-Vest flat with yellow panel facing up. Eliminate folds or crimps. Keep headliner in a bowl shape.

2) Connect umbilical to pump/motor assembly.

3) Adjust Temp Control Valve to "Change Cartridge" position.

4) Turn pump/motor to "ON".

5) As fluid begins to flow, gently shake and turn headliner to remove air bubbles.

6) After all air bubbles have cleared headliner exit tube, set headliner down.

b. System Fluid Replenishment

1) Connect fill bottle to pump/motor assembly.

2) Turn temperature control to full warm, press power switch to the fill position and run pump/motor assembly for 1 minute.

3) Turn pump/motor assembly power switch OFF and remove fill bottle in 15-30 seconds to prevent excessive liquid from flowing out of pump/motor assembly reservoir into fill bottle.

Although the instructions were followed, there were five occasions when the system was overfilled. Overfilling was not apparent until the frozen canisters were being placed into the units. At that time, it was extremely difficult to close the HEU. The units then had to be bled of the excess fluid. This procedure required time (approximately 4 minutes) and delayed both the start of the test and the sailor's performance of his duties. In two instances an effort was made to close the HEU's during an overfill situation, resulting in cracked HEU cases.

When the LSSI system was tested on a subject of small build, the vest straps had to be tightened so much that the flow channels in the vest were pinched closed and the coolant flow stopped. Although the individual complained of lack of cooling, the crimped line was not recognized until after the test had been aborted. This "pinching off" of flow in the vest had been experienced in other studies (7).

In one case, the control unit on the LSSI system stopped working in the middle of a test. Neither replacement of the battery nor purging the system of air bubbles restarted the unit. A new control unit was placed in service, resulting in a testing delay of approximately 45 minutes.

On two occasions after the systems were used several times, the hasp holding the battery on the LSSI control units failed to securely hold the battery. Both units had to be replaced.

In two separate instances, the hoses on the LSSI Portapack system and LSSI backpack system were inadvertently pulled out, resulting in the delay of a test. Due to the numerous hoses contained on the Portapack system and the inability to visually determine whether the hoses were properly connected, the difficulty was not immediately apparent.

Most subjects using the LSSI system complained that no cooling was felt on the head. Some apparent causes of this were: the insulating factor of the hair, chinstraps that were not tightened enough, and chest straps that were pinching off flow to the cap. Those who tightened the chinstrap to feel the cooling complained that the strap was too uncomfortable.

The LSSI system projected out extensively from the back (5"). Therefore, several individuals had difficulty maneuvering through shipboard spaces or could not pass through a given space without removing their backpack.

5.4.4 Encon Vortex and Ambient Air Operational Difficulties

The tether cord on this system was cumbersome and frequently became tangled and caught on objects as the individual moved to different locations. The fittings, regulators and filters used with the system required approximately 45 minutes' setup time for each test location. In a situation where this system would be employed at one location all the time, this setup time would not represent a major difficulty. There were no malfunctions of this system during the evaluation.

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(7) Cosimini, H., J. Cohen, B. DeCristofano, R. Goff, V. Iacono, M. Kupcinskas, and T. Tassinari. Determination of the feasibility of two commercial portable microclimate cooling systems for military use. Technical Report No. Natick/TR-85/033L, US Army Natick Research & Development Center, Natick, MA, 1985.

6. Discussion

To determine the operational feasibility of using commercial cooling garments in a shipboard environment, NCTRF conducted a shipboard evaluation of three basic commercial MCS's onboard the USS LEXINGTON. The evaluation consisted of monitoring subjective and physiological parameters and determining required logistical support in the engine spaces, laundry and scullery.

There were many factors that contributed to our evaluation of the success of a MCS onboard ship. Some of these factors were considered more critical (primary) than others (secondary). The following tabulation is a rating of primary and secondary factors contributing to the final MCS selection.

a) Primary Factors
- User acceptance as determined by test volunteers' comments.
- Ability to consistently deliver cooling to an individual.
- Ease of operation.
- Simplicity of construction.
- Reliability of components.
- Size and weight of system.

b) Secondary Factors
- Logistical difficulties associated with supplying the basic operating components, i.e., ice or canisters and batteries.
- Component failure due to possible operator error, such as, disconnected hoses, defective batteries, inability to properly operate control knobs.

Because of the mild environmental conditions during the evaluation, we could not consider the reduction in heat stress - as indicated by physiological measurements - as a primary factor. Under hotter conditions, this factor would have been given significant weighting.

Based on the subjects' overall preference after they had tested all cooling systems, the ILC system was the overwhelming favorite, with 26 of 29 votes for the number one rating. The reasons stated for the high preference of the ILC system were its low profile, simple operating characteristics, and significant cooling. After the ILC, the next preferred system was the Encon vortex. However, this system contained a tether cord; and because of the hazard it posed with shipboard operational components, most subjects stated that they would not be able to work with a tether cord. The least preferred system was the LSSI backpack system. The weight, bulkiness, and interrupted cooling of the LSSI system were the reasons for its unpopularity.

Due to the mild environmental conditions, physiological measurements of heart rate and rectal temperatures were not significantly different among the cooling systems and the control tests. However, previous laboratory tests have shown that the cooling systems do provide substantial reduction of heat stress when worn with utility clothing in moderately hot environments

(3,4,5,6). Other than the required logistical support and maintenance, there is little reason to believe that the systems would not provide adequate cooling to individuals working in hot shipboard environments.

Because of the low heat stress incurred during the shipboard evaluations, we conducted a laboratory comparison between the LSSI and ILC MCS's in the summer of 1987 (4). Nine male test subjects were first heat acclimated and then performed five different tests: two with the ILC Cool Vest, two with the LSSI Cool Head, and one control with no cooling. Environmental conditions were 43°C (110°F) dry bulb and 45% relative humidity (WBGT = 36°C, 96°F). During the 3-hour heat exposure, subjects wore the Navy utility uniform and walked on a level treadmill at 1.6 m/sec (3.5 mph), with 5 minutes of seated rest every half hour. This represented a mild-to-moderate work effort. The results from the test indicated that both cooling systems were similarly effective in reducing physiological strain and increasing tolerance time in the heat. Tolerance time increased from an average of 114 minutes with no cooling to at least 180 minutes with each of the two cooling systems. At 120 minutes, when either MCS was worn, rectal temperature had been lowered by approximately 0.5°C compared with the control test.

From a logistics point of view during the shipboard evaluation, the Vortex air system was the easiest to use. The system was also the least bulky for the individual; it weighed only 4.4 lbs. However, because its tether cord restricted movement somewhat, it was not the most favored system. Logistical difficulties with the system included the need to hook up and route the air supply line to the work station and the problem with cord entanglement. Cord entanglement could be reduced through the use of swivel disconnects on the hoses and also with the use of shorter hoses with more air taps in the hot spaces.

Supplying ice or canisters to the ILC and LSSI systems required a continuous effort. Because of the remote location of the freezer, the ice and canisters required for all subjects had to be gathered before each test sequence. This process could be cumbersome if an entire space were to be outfitted with the cooling system. The LSSI canisters presented more of a

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(3) Pimental, N.A. Effectiveness of microclimate cooling systems. Navy Clothing & Textile Research Facility report, June 1987.

(4) ________ . Evaluation of two commercial microclimate cooling systems. Technical Report No. 164, Navy Clothing & Textile Research Facility, Natick, MA, In Press.

(5) Pimental, N.A., H.M. Cosimini, M.N. Sawka, and C.B. Wenger. Effectiveness of an air-cooled vest using selected air temperature and humidity combinations. Aviation, Space, and Environmental Medicine 58:119-24, 1987.

(6) Shapiro, Y., K.B. Pandolf, M.N. Sawka, M.M. Toner, F.R. Winsmann, and R.F. Goldman. Auxiliary cooling: comparison of air cooled vs. water cooled vests in hot-dry and hot-wet environments. Aviation, Space, and Environmental Medicine, 53:785-9. 1982.

burden than the ice because of the need to return the canisters to the freezer for reuse; the melted ice could be disposed of at the test site. (Because ice cube trays were refilled at the time of ice pickup, only one trip to the freezer was necessary for the ILC system.) If the systems were to be used in a routine manner during normal shipboard operation, dedicated freezers could be located in an area more convenient to the hot spaces. This would significantly reduce the negative impact of having to return the LSSI canisters to a remote freezer location.

Supplying fully charged batteries for each test sequence was also time-consuming for the test team. To maintain the batteries during this test sequence, one test team member had to be responsible for hooking up the batteries at the end of each test. Further, the test center did not contain a sufficient number of outlets to connect each charger. To support the cooling systems in a realistic situation, a small room with adequate power and outlets could be dedicated to the daily recharging of batteries.

The LSSI system required the most attention to insure that the system was operating properly. There were numerous component failures during the operation of both the LSSI backpack and Portapack systems. The primary problems included:

1) Because of air in the lines, the LSSI system occasionally stopped running altogether and required a rap to get it started, resulting in a delay in the start of the test.
2) Canisters leaked through the expansion seal as they were frozen and were no longer usable.
3) The refilling of the system frequently resulted in an overfill situation which would require time to release fluid from the system prior to use and which would cause the HEU to crack if the canister was forced into it.

Secondary problems included:

1) Despite pre-evaluation check-out of the LSSI batteries (see Section 3.2), several of the batteries would not hold their charge for the 2-hour time specified by the manufacturer. Many failed within the first half hour. This might have been partially due to the age of some of the batteries (purchased 1982).
2) Hoses were inadvertently disconnected.

In addition to these equipment failures, most of the subjects complained about the weight of the backpack system (16.8 lbs) and felt its bulkiness restricted their movement in some shipboard spaces. The subjects noted the cooling cap did not provide any perceivable cooling and complained the chinstrap was uncomfortable and irritating. Because of the inconvenient location of the on/off and control switches, the subjects had difficulty operating the system alone and could not easily distinguish which direction on the control switch increased the coolant flow.

Compared with the LSSI system, the ILC Cool Vest was much easier to operate and maintain. The ILC system used reliable components and simple methods of construction. The ILC system weighed 13.6 lbs, 20% less than the LSSI backpack system, and was not judged to be as cumbersome as the LSSI backpack. Although the ILC system weighed less than the LSSI system, it contained a larger ice reserve (6 lbs vs 5.2 lbs) and required less frequent ice changes (3.1 hrs vs 2.3 hrs). The greater cooling capacity of the ILC system would be a benefit in that stay times between coolant changes could be increased. The ILC batteries were reliable and provided sufficient power to enable the system to run for the entire test period without stopping. Other than for the scheduled battery, ice and water changes, there was no need to interrupt the test to refill or purge the system at any time. All of the working components were contained inside the backpack; therefore, there were no problems with hoses inadvertently being disconnected. The ILC system also had the advantage of operating with ice, which could be disposed of at the work site after it melted. Also, the cost of the ILC system was much less than the LSSI backpack system, \$680 vs \$2511 (prices we paid prior to cost reduction in July 87).

In summary, the ILC system was rated as the MCS of choice. The primary factors contributing to this rating included:

1) The system was overwhelmingly preferred by 26 out of 29 test subjects.
2) The system provided a 35% greater cooling capacity - as determined by frequency of coolant changes - than the LSSI system. Cooling was delivered in a consistent manner, with only scheduled battery and ice changes interrupting the test.
3) It was easy to operate with little or no training.
4) It had very few malfunctions, all of which were minor.
5) It was not judged to be too heavy or too bulky for shipboard use.

The LSSI systems (Backpack and Portapack), on the other hand, failed many of our primary evaluation factors.

1) The Portapack and Backpack were not preferred by any test subject and were rated as the third and fourth choices, respectively, of the four cooling systems.
2) They provided inconsistent cooling as a result of pinched-off lines, air in lines, ineffective cooling cap, etc.
3) They required a great deal of effort to keep them operational. Systems had to be refilled or purged periodically, resulting in several overfill situations and cracked HEU's. Lines became pinched off or filled with air, resulting in test delays to determine and resolve the problem.
4) Components were not very reliable. Canisters leaked or popped the expansion seals; batteries and control units failed; structural components (e.g., HEU's, hasps for batteries) broke.
5) The bulkiness of the system precluded some subjects from easily maneuvering through shipboard spaces without removing their backpacks.

The Encon system was also rated highly in all of our evaluation factors.

1) It provided consistent cooling.
2) It was easy to operate.
3) It had no equipment malfunctions.
4) It was lightweight.
5) It was rated as the second most preferred system. User acceptance, however, was limited because of the tether cord which restricted freedom of movement.

7. Recommendations

The results of this evaluation have shown that, provided sufficient support is available to maintain the systems, commercially available MCS's can be effectively used onboard ship to provide personal cooling and alleviate heat stress in hot compartmental spaces. To minimize the support required, the system should be kept as simple as possible and use reliable components. Of the four systems tested, the ILC Cool Vest and Encon Air Vortex System were preferred by the test subjects and provided the highest degree of reliable operation. These two systems, therefore, are recommended by NCTRF for future procurement consideration by the Navy.

The ILC Cool Vest was chosen as the best portable system by the crewmen. This system was also the simplest portable system tested. For efficient use of the system onboard ship, the following support services should be made available.

a. Each vest will require 6 lbs of ice for each 1.5-2.5 hours of operational time. To provide the required ice, we recommend that freezers or ice-making machines be strategically located near the areas of MCS use.

b. Each vest will require one 8-volt battery for each 2-3 hours of operation. The rechargeable batteries supplied by the manufacturer are recommended for use. These batteries require 6-8 hours to recharge on a 115AC power source. For proper recharging, a recharge location should be provided that will allow sufficient space, outlets and power to recharge the units on a continuous basis. A recharge center located near the MCS freezer would more easily support the system.

c. Proper care should be given to maintain long-term use of the systems. The following operational items should be considered.

1. Although the units are relatively easy to use, all personnel wearing the system should be given adequate instructions on proper operation. For prolonged use, periodic washing, in accordance with the manufacturer's instructions, is recommended.

2. Space should be allowed onboard ship for the storage of the units when not in use. For prolonged periods of storage, all water should be drained from the systems and clean, compressed air should be used to dry the vest to prevent bacterial growth.

In addition to these support services, the following structural modifications to the Cool Vest unit have been recommended by the test subjects during this evaluation and NCTRF thinks they warrant further investigation.

a. In place of the metal vest fasteners, Velcro straps could be used to tighten the vest to the body.

b. The on/off control switch should be relocated so that it is easily reached and not accidentally turned off during operation.

c. A waist belt could be incorporated to prevent the system from riding up in the front due to the weight of the backpack.

d. Shoulder padding could be used to provide better weight distribution.

e. The system should be provided with a fire-retardant outer covering similar to the type used in this evaluation.

Although the use of the Encon Air Vortex System was hampered by the tether cord, this system did provide ample personal cooling; and, other than the tether cord, presented no operational difficulties. This system could be used effectively onboard ship provided the difficulties with the tether cord are minimized. NCTRF recommends the following actions be taken with this respect.

a. The system could be used only for individuals requiring minimal movement, such as burnermen, throttlemen.

b. Several connect locations should be employed throughout the workspace to enable a crewman to use the vortex system with only short lengths of tethered lines. This action will minimize the possibility of cord entanglement in confined spaces. With more air lines, personnel could disconnect and reconnect their tether lines and become more mobile within the space.

c. The use of swivel disconnects at both ends of the tether cord would also minimize the possibility of cord entanglement.

d. To allow rapid exit from the space in case of emergency, breakaway fittings should be used.

e. It is also recommended that the exterior of the air distribution vest be covered with a fire-retardant material similar to the type used in this evaluation.

The results of this evaluation have clearly shown that both the ILC Cool Vest and the Encon Air Vortex System provide adequate personal cooling and were favorably received by the test subjects. Due to the difficulties with the tether cord on the air vortex system, NCTRF recommends that, if a system is required immediately for shipboard use, the ILC Cool Vest be selected as the general cooling system. With some minor modifications the ILC system could provide a completely adequate system for Navy use.

8. Acknowledgements

The Navy Clothing and Textile Research Facility would like to thank Mr. Richard Walchli and Dr. Scott McGirr of the Navy Science Assistance Program for their support in the evaluation. The help from LCDR Greg Colegate at the initiation of the project is also appreciated. Special thanks are extended to LCDR Greg Moore of CINCLANTFLT for his coordination of, and his participation during, the shipboard evaluation. We would also like to thank Dr. Jim Driskell and Dr. Pat Moskal from the Naval Training System Center for their invaluable assistance in providing the performance assessment battery and in training us in its administration and interpretation. The efforts of CDR John Scholl, MMCM William Werner, LCDR Donald Mason and Assistant Supply Officer HMI Norma Baugh from the USS LEXINGTON were greatly appreciated. Also, a sincere thank you is extended to the men on the USS LEXINGTON who participated in this evaluation.

APPENDIX A. ILLUSTRATIONS

Figure 1. ILC Cool Vest.

(Note: System shown without fire-retardant covering.)

Figure 2. LSSI Cool Head.

(Note: System shown without fire-retardant covering.)

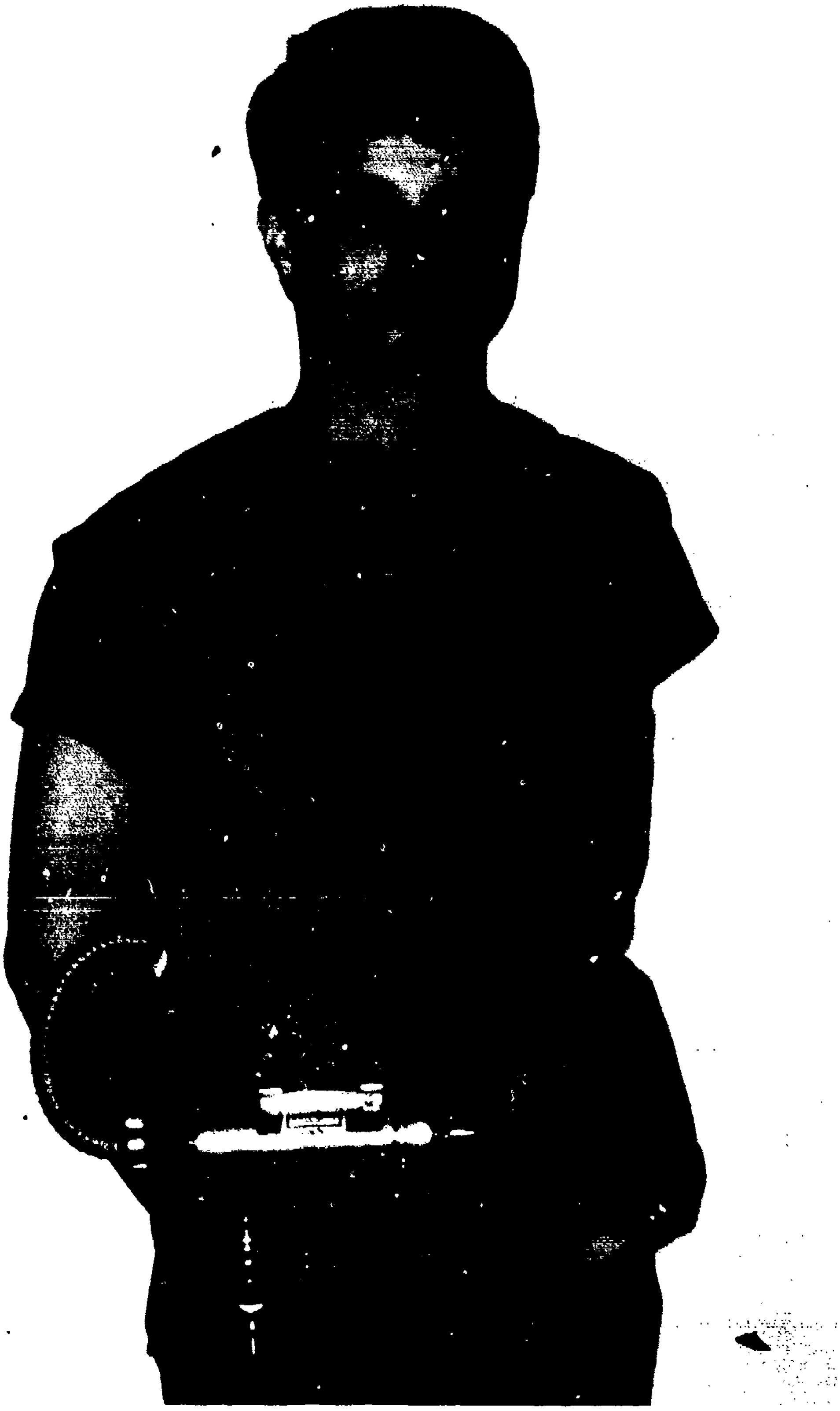

Figure 3. Encon Air Vortex System.

(Note: System shown with fire-retardant covering.)

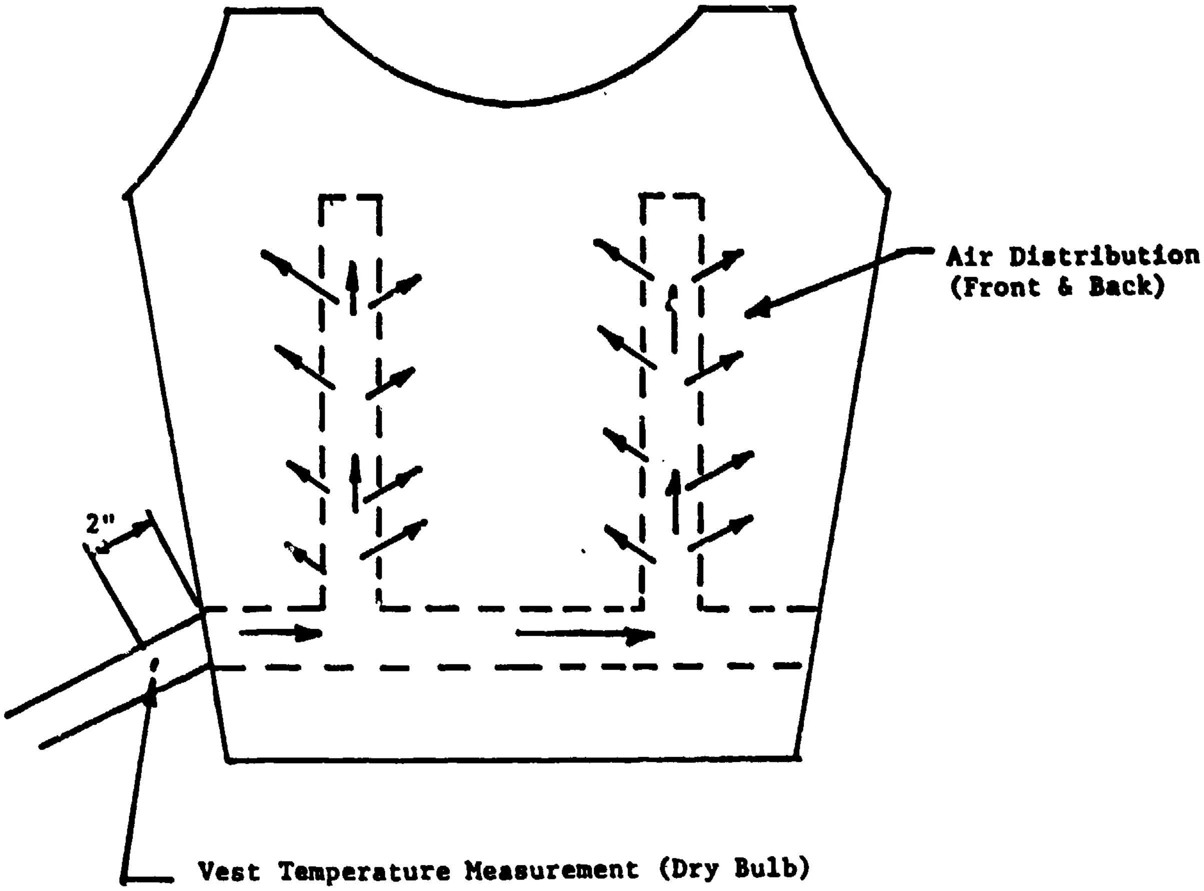

Figure 4. Encon Air Vest Temperature Measurement Location.

APPENDIX B. SAMPLE QUESTIONNAIRES

COOLING-VEST PREFERENCE QUESTIONNAIRE

Experimenter Information

EXPERIMENTER:______________________ DATE:__________

TIME:______________________

TEST CONDTIONS:______________________

COOLING VEST:______________________

SHIP/SPACE:______________________

Subject Background Information

Please provide the following information.

NAME:______________________

SOCIAL SECURITY NUMBER:______________________

In the space provided below, list the duties that you performed while you wore the cooling vest.

APPENDIX B

ENVIRONMENTAL SYMPTOMS QUESTIONNAIRE

We are interested in how warm or cool, comfortable or uncomfortable you feel during your work shift. Circle each item separately to indicate whether you DO or DO NOT have the symptom at any time during your work shift. Please read each item carefully.

For example, if you felt moderately lightheaded during your workshift, circle the mark as shown below.

|-------------|-------------|-------------|-------------|
not at all slightly moderately very extremely

1. I feel lightheaded.

|-------------|-------------|-------------|-------------|
not at all slightly moderately very extremely

2. I have a headache.

|-------------|-------------|-------------|-------------|
not at all slightly moderately very extremely

3. I feel dizzy.

|-------------|-------------|-------------|-------------|
not at all slightly moderately very extremely

4. My coordination is off.

|-------------|-------------|-------------|-------------|
not at all slightly moderately very extremely

5. I'm short of breath.

|-------------|-------------|-------------|-------------|
not at all slightly moderately very extremely

6. My heart is beating fast.

|-------------|-------------|-------------|-------------|
not at all slightly moderately very extremely

7. I have chest tightness.

|-------------|-------------|-------------|-------------|
not at all slightly moderately very extremely

8. My hands are shaking or trembling.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

9. My muscles feel tight or stiff.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

10. Parts of my body ache.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

11. I feel sick to my stomach (nauseous)

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

12. I feel warm.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

13. I am sweating.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

14. I feel chilly.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

15. My skin is burning or itching.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

16. My vision is blurred.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

17. My mouth is dry.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

18. I'm thirsty.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

19. I feel tired.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

20. My concentration is off.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

21. I feel irritable.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

22. I feel tense.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

23. I feel alert.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

24. I feel relaxed.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

25. I feel good.

|-------------|--------------|------------|------------|
not at all slightly moderately very extremely

Do you have any comments that you would like to add about the cooling vests?

Please answer the following questions as best you can. We are interested in how YOU feel about the cooling vests on such matters as their fit, comfort, and usefulness. There are no right or wrong answers; we simply want your opinion, but please try to be as accurate as possible.

FIT

A.) How heavy does the vest seem to you?

|-------------|--------------|------------|------------|

not at all heavy	slightly heavy	moderately heavy	very heavy	extremely heavy

B.) How bulky does the vest seem?

|-------------|--------------|------------|------------|

not at all bulky	slightly bulky	moderately bulky	very bulky	extremely bulky

C.) How tight does the vest feel?

|-------------|--------------|------------|------------|

not at all tight	slightly tight	moderately tight	very tight	extremely tight

D.) If the vest included a headpiece, was wearing it difficult?

|-----------|-----------|-----------|----------|----------|

vest did not have a headpiece	not at all difficult	slightly difficult	moderately difficult	very difficult	extremely difficult

E.) Did the vest provide consistent cooling, or did it change from warm to cool often?

|-------------|--------------|------------|------------|

not at all consistent	slightly consistent	moderately consistent	very consistent	extremely consistent

DEXTERITY

Please give your impression of your ability to move about while you are wearing the cooling vest.

A.) If your vest had a hose attached to it, did the hose restrict your movement?

|-----------|-----------|-----------|----------|----------|

vest did not have a hose	not at all restricting	slightly	moderately restricting	very	extremely restricting

B.) Did you think that this vest would hinder you from moving into tight spaces (for example, crawl spaces or hatches)?

|-------------|-------------|------------|------------|

not at all restricting	slightly restricting	moderately restricting	very restricting	extremely restricting

C.) Did the vest cause you to have any difficulty in reaching or bending?

|-------------|-------------|------------|------------|

not at all difficult	slightly difficult	moderately difficult	very difficult	extremely difficult

Please answer the next set of questions in terms of how well you could perform your job while wearing the cooling vest compared to how well you could perform if you were not wearing it.

A.) Speed at performing your job. I feel like I could work:

|------------------|-------------|------------|--------------|

the same or faster WITHOUT the vest	slightly faster with the vest	moderately faster with the vest	much faster with the vest	very much faster with the vest

B.) Skill at performing your job. I feel like I could perform:

|------------------|-------------|------------|--------------|

the same or better WITHOUT the vest	slightly better with the vest	moderately better with the vest	much better with the vest	very much better with the vest

C.) Length of time that you could perform your job. I feel like I could keep working:

|------------------|-------------|------------|--------------|

the same or longer WITHOUT the vest	slightly longer with the vest	moderately longer with the vest	much longer with the vest	very much longer with the vest

D.) Comfort at performing your job. I feel:

|------------------|-------------|------------|--------------|

the same or more comfort WITHOUT wearing the vest	slightly more comfort with the vest	moderately more comfort with the vest	much more comfort with the vest	very much more comfort with the vest

E.) Preference for wearing the vest. I:

|------------------|-------------|------------|--------------|

prefer NOT wearing the vest	slightly prefer wearing the vest	moderately prefer the vest	much prefer the vest	very much prefer the vest

After you have participated in two conditions, please rank order your preference for the cooling vests and/or your normal clothing. Use numbers 1 and 2 (with 1 being the best) to represent your rank.

Note: the instructor will identify the suits in the columns shown below, and will explain the ranking procedure.

	Condition	
ITEM	A:	B:
Which vest fits better?		
Which vest cools the best?		
Which vest is the lightest?		
Which vest is the least bulky?		
Which vest is least restrictive?		
Which vest makes you feel the best?		
Which vest lets you perform the best?		

After you have participated in 3 sessions, please rank order them, using the numbers 1, 2, and 3 (with 1 being the best). Follow the same procedure as you did when you ranked two conditions.

	Condition		
ITEM	A:	B:	C:
Which vest fits better?			
Which vest cools the best?			
Which vest is the lightest?			
Which vest is the least bulky?			
Which vest is least restrictive?			
Which vest makes you feel the best?			
Which vest lets you perform the best?			

After you have participated in 4 conditions, please rank order them, using the numbers 1, 2, 3, and 4 (with 1 being the best). Follow the same procedure as you did when you ranked three conditions.

	Condition			
ITEM	A:	B:	C:	C:
Which vest fits better?				
Which vest cools the best?				
Which vest is the lightest?				
Which vest is the least bulky?				
Which vest is least restrictive?				
Which vest makes you feel the best?				
Which vest lets you perform the best?				