SUSTAINABILITY
SURVIVABILITY SUPPORTABILITY

TECHNICAL REPORT
NATICK/TR-93/042

AD__________

COMMERCIAL THERMOELECTRIC COOLING SYSTEMS FOR MILITARY APPLICATIONS

By
Mark W. Wolfson
Roger Masadi

October 1993

FINAL REPORT
February 1991

Approved for Public Release; Distribution Unlimited

UNITED STATES ARMY NATICK
RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
NATICK, MASSACHUSETTS 01760-5000

INDIVIDUAL PROTECTION DIRECTORATE

DISCLAIMERS

The findings contained in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

DESTRUCTION NOTICE

For Classified Documents:

Follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

For Unclassified/Limited Distribution Documents:

Destroy by any method that prevents disclosure of contents or reconstruction of the document.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1993	FINAL February 1991

4. TITLE AND SUBTITLE
Commercial Thermoelectric Cooling Systems for Military Applications

5. FUNDING NUMBERS
AG 33081CM110D00

6. AUTHOR(S)
Wolfson, Mark W. and Masadi, Roger

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Natick RD&E Center
Attn: SATNC-ICAS
Natick, MA 01760

8. PERFORMING ORGANIZATION REPORT NUMBER
NATICK/TR-93/042

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This research examines current thermoelectric cooling (TEC) systems for possible microclimate cooling applications. TEC systems offer simplicity, but have some drawbacks. Although TEC systems have few moving parts, the power required for operation and the weight of the systems limit their usefulness in dismounted, untethered modes of operation. Unlike phase change material (PCM) cooling systems, TEC's can provide uninterrupted cooling for extended periods of time. TEC's operate on electricity and so do not suffer from the logistical difficulties of resupplying frozen PCM's to the field. In comparison to vapor–compression (VC) cooling systems, TEC's are heavier and significantly less energy efficient.

For tethered modes with a large source of power, the simple TEC systems offer a great deal. TEC's lose their advantage if power is limited and/or the complete system, including the power source, must be carried by an individula.

14. SUBJECT TERMS
Thermoelectric Cooling, Microclimate Cooling, Peltier Cooling, Cooling System, MCC(Microclimate Cooling), Hot Environment, Military Applications, Heat

15. NUMBER OF PAGES
15

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Table of Contents

List of Tables

PREFACE

The purpose of this research was to give direction to and recommend future efforts for Microclimate Cooling (MCC) possibilities. The research was conducted in February 1991 by the Special Projects Section of the Individual Protection Directorate (IPD), U.S. Army Natick Research, Development and Engineering Center, Natick, MA.

ACKNOWLEDGMENTS

The authors of this report would like to thank the U. S. Navy Clothing and Textiles Research Facility for supporting the chamber studies, and Brad Laprise of IPD for his technical assistance.

COMMERCIAL THERMOELECTRIC COOLING SYSTEMS FOR MILITARY APPLICATIONS

INTRODUCTION

BACKGROUND:

This document examines current commercial thermoelectric cooling (TEC) systems for use in military applications. A soldier, when wearing combat clothing, armor, and NBC gear, becomes extremely sensitive to elevated ambient temperatures. Heat stress has become an important factor when creating work/rest cycles and predicting heat stress related casualties. When an individual is functioning in a hot environment, the body cannot efficiently reject heat to the environment due to the various layers of protective clothing. This heat is stored, and the individual's core temperature begins to rise. As the core temperature rises, heat-related stress and injuries may result.

The best way to reduce the risk of heat casualties in a hot environment is to help the body reject heat. The microclimate cooling (MCC) systems can remove a significant amount of heat from a soldier, thus increasing mission duration and enhancing mission performance. Many different technologies have been considered for this purpose. The three most common are phase change materials (PCM) systems, thermoelectric cooling (TEC) systems, and vapor compression (VC) systems.

PHASE CHANGE MATERIAL SYSTEMS: These systems typically use ice, paraffin, or other types of phase change materials. They are very simple and, in many cases, require no maintenance. They don't, however, provide cooling for an extended period of time. There are problems with recharging PCM's and supplying them to the soldiers in a battlefield environment. The frozen PCM's are usually in a vest against the skin or are used to chill water that is pumped to a vest which, in turn, absorbs the heat from the user.

THERMOELECTRIC COOLING SYSTEMS: These systems are electronic devices. They have very few moving parts, but require a significant amount of electric power to operate. An electric current is passed through a series of semiconductors. One side of the semiconductor gets hot while the other side becomes cold--the Peltier effect. By passing the cooling media over the cold side, and the ambient media over the hot side, cooling is achieved. Again, the cooling media is usually pumped through a liquid vest which absorbs heat from the user. Other TEC systems, not discussed here, cool air instead of liquid and then supply the conditioned air to the soldier through an air vest, providing evaporative and convective cooling.

VAPOR COMPRESSION COOLING SYSTEMS: These systems are very efficient and compact, but they tend to be more complicated than the others. Refrigerant vapor is compressed. The resulting high temperature, high pressure gas is passed through a condenser which rejects heat to the environment, causing the refrigerant to condense into a liquid. This liquid is passed through an expansion device, producing a sudden drop in temperature. The cold liquid then flows through the evaporator, removing heat from the cooling media. In this process, the refrigerant boils as the heat is absorbed. The vapor then returns to the compressor. The coefficient of performance (cooling power / power input) for a vapor compression system can exceed 2.0. Not included here is the air cycle vapor compression cooling system common in some vehicle applications, such as the M1A1 tank.

These are the most common systems in use today. The choice of one system over another depends on the application and available resources.

TESTING

METHODS:

In order to evaluate the different thermoelectric cooling systems, tests were performed in climatic chambers on a thermal manikin. The use of a thermal manikin removed the subjectivity that would result from the use of individual test subjects. In all tests, the thermal manikin wore the MCC system under the Battle Dress Overgarment (BDO). The ambient temperature was 35°C (95°F) and the relative humidity was 0% to 5% with a wind speed of 2 mph. The thermal manikin skin temperature was maintained at 35°C (95°F) during the test.

As the cooling system removed heat from the manikin, power was applied to keep the skin at a constant temperature. This power is related to the amount of heat extracted by the cooling system. The manikin is also divided into separate regions so that the cooling of different body surfaces can be monitored and recorded.

Once the cooling systems were operating at steady state, measurements were taken every minute for an hour. Then the results were averaged using Simpson's 1/3 Approximation and tabulated.

It should also be stated that the TEC systems are not set up in a backpack configuration and are primarily for vehicle-mounted applications.

DISCUSSION OF RESULTS

The data recorded for the different units is summarized in Table 1 and Table 2. The information is displayed in this format to facilitate comparison of the different systems.

The first three columns show the name of the cooling unit, the number of individuals supported by the cooling unit, and the garment used to deliver the cooling. The results are ordered according to their coefficient of performance (COP). The COP is a way of measuring the efficiency of a system. For this test, the COP represents the observed cooling divided by the amount of energy required to operate the system.

The most efficient unit starts the list, while the least efficient unit ends the list. It is also interesting to note that these tests seem to indicate that the full Exotemp Cooling Garment is best suited for the removal of heat. A cooling garment that is more effective at removing heat will increase the COP of the cooling system.

The next two columns represent the cooling per person (Q/Per) and the total cooling (Q) delivered, both in Watts. To just consider the total cooling delivered by each system would not be accurate because the MRI system is designed to be mounted on an airframe and cool 2 crewmen. The consideration of the weight is presented similarly in the next two columns, weight per person, and total weight.

The last two columns show the basis for rating the systems. The COP is very important if the supply of power is limited. A higher COP means that the system can deliver more cooling for a given energy capacity.

Another important factor is the cooling per pound. This number represents the amount of cooling received by the user divided by the weight of the system. For applications where weight is important, the cooling per pound (Q/lb) should be taken into consideration. A higher Q/lb indicates that a system can deliver more cooling for a given weight. It is necessary to note that the weight presented here does not include the weight of the power source.

Table 1. Results of Testing

Cooling Unit	#	Cooling Garment	Q/Per (Watts)	Q (Watts)	W/Per (lbs)	W (lbs)	COP	Q/lb (W/lb)
MRI	2	XSPH	199	398	14	28	.38	14.2
Marlow	1	XSPH	177	177	16	16	.34	11.1
Marlow	1	MLLV	162	162	16	16	.31	10.1
Carlson	1	LSSI	57	57	14	14	.31	4.1
MRI	2	MLLV	159	318	14	28	.30	11.4
MRI	2	XS	135	270	14	28	.26	9.6
KT	1	MLLV	120	120	17	17	.24	7.1

DEFINITION OF VARIABLES

Cooling Unit ----	The commercial unit supplying the cooling
# ---------------	The number of people the system is designed to cool
Cooling Garment -	The cooling garment worn
LSSI ---------	Life Support Systems Incorporated Vest
MLLV ---------	ML Lifeguard Vest
XSPH ---------	Exotemp with shirt, pants and hood
XS -----------	Exotemp shirt
Q/Per -----------	Cooling per person (Watts)
Q ---------------	Total cooling supplied by unit
W/Per -----------	Weight of system per person cooled (lbs)
W ---------------	Total weight of system (lbs)
COP -------------	Coefficient of performance (Cooling delivered / power required)
Q/lb ------------	Cooling delivered per weight of cooling system (Watts/lb)

COOLING UNITS

MRI -------------	Midwest Research Institute model: MRI 2-Man Liquid
Marlow ----------	Model: 1-Man Liquid
Carlson ---------	Model: 312
KT --------------	Koslow Technology Model: KT M10

note: MRI, Marlow, Carlson and KT are registered trademarks.

Table 2. Power Requirements

Cooling Unit	Cooling Garment	Volts	Amps	Power (Watts)	Q (Watts)	COP
MRI	XSPH	28	37.5	1050	396	.38
Marlow	XSPH	28	18.5	518	177	.34
Marlow	MLLV	28	18.5	518	162	.31
Carlson	LSSI	12	15.1	181	57	.31
MRI	MLLV	28	37.5	1050	318	.30
MRI	XS	28	37.5	1050	269	.26
KT	Tabbard	24	21.0	504	120	.24

DEFINITION OF TERMS

Volts ----------- The voltage supplied to the cooling unit
Amps ------------ The current required
Power ----------- The power needed to operate the cooling system (Watts)
Q --------------- Cooling rate supplied by the system (Watts)
COP ------------- Coefficient of performance (Cooling Rate/Power)

The MRI system with the complete Exotemp cooling garment had the highest COP and the highest Q/lb. The drawback of this system for man-portable applications is that it provides cooling for two individuals. The unit weighs 28 pounds and can supply 398 Watts of cooling. If only one individual requires cooling, the Marlow system with the full Exotemp cooling garment appears to be the best choice. This setup weighs 16 pounds and provides 177 Watts of cooling. The third entry is the Marlow system with the ML Lifeguard Vest. The next entry in the list is the Carlson system. It should be noted that although the Carlson system has the same COP as the Marlow system with the MLLV, the Carlson system has the lowest cooling per pound. The 14 pound unit only supplied 57 Watts of cooling. The table continues to present other systems and configurations.

CONCLUSIONS

The thermoelectric cooling units show some definite promise for use in MCC applications, but still need refinements. The coefficients of performance need to be increased and the weights need to be reduced. Current vapor compression systems have COP's greater than 2.1, and can supply in excess of 32.6 Watts of cooling per pound of system weight. Phase change systems have varying weights and low to no power consumption. For specialized use, thermoelectrics offer a great deal, but they are not practical for the dismounted soldier. TEC systems would need to be tethered to a power source. The batteries required to power a TEC system would drastically increase the weight of the whole system, prohibiting use in a dismounted, untethered mode.

For example, if the Marlow system were to be used with BA-5590 Lithium battery technology, the weight of the system would increase by 20 pounds. The cooling system would now weigh more than 36 pounds and need to be resupplied with 20 pounds of batteries every 3 to 4 hours.

An increase in the thermoelectric's COP and/or an increase in power source technology would bring Peltier cooling systems within the boundaries for man portable applications. Until this occurs, tethered operation and fixed mounting on vehicles and airframes will remain the most common forms of use.

This document reports research undertaken at the U.S. Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-93/042 in the series of reports approved for publication.