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MICROCLIMATE COOLING: WHERE WE'VE BEEN AND WHERE WE'RE GOING. MILITARY AND COMMERCIAL PERSPECTIVE

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INTRODUCTION

High heat exposures in the military operational and civilian industrial setting is common-placed. The impact of heat stress from extended exposure to these environments have been well documented. Since the early 1960s a common countermeasure to developing heat strain has been application of various means of individual cooling (microclimate cooling) (1-2). The effectiveness of such systems has had to depend on 1) provision of an adequate cooling sink to remove the combined heat load (ambient plus metabolic) over an extended temperature range, 2) contain sufficient power to operate over variable time periods, and 3) be universal as to operability (limited size and weight for stowage), to accommodate interface with vehicles, clothing, required job-task equipment, space restrictions, carrying capacity of the individual, etc.

METHODS

A literature review of microclimate cooling designs and human performance studies was conducted as a means to categorize current engineering approaches and physiological response range limitations. An additional survey of new "planning board" industrial/DoD designs was conducted to identify new engineering/application innovations.

RESULTS

Most designs of current microclimate cooling systems are active liquid and air or passive ice cooling systems. Liquid cooling generally consist of nylon bladders or tubing incorporated into a vest, cap, or total body fabric filled with either ice water, a propylene glycol mixture, or pressurized dichlorotetrafluoroethane (R114). Cooling capacity of these systems range from 0.4 l/min to 2.65 l/min with cooling rates between 107 and 244 watts. Air cooling systems have usually been a hose and manifold design incorporated within a fabric vest providing flow rates between 1.5 - 15 cfm of cooling. Studies have shown varied work endurance (2-12 hrs) in high environmental heat and work rate conditions (3-4). Passive microclimate cooling vests have proven to be most "operationally" feasible due to their simplicity and ruggedness (5). Cooling capacities of these passive systems have been reported to be high, however, the design is only suitable for short-term work due to a continued body heat storage. Table 1 (6) is provided as a representative summary of system designs and overall performance results.

TABLE 1

	Cooling Rate	Physiological Response
Liquid Cooling:		
ice & water at 2.65 l/min Chest nylon bladders, pump, battery	244 W	Responses are similar except for report of headaches with cap design. All were determined to be appropriate for only light to moderate work and limited suitability for sustained operations
Propylene glycol at .4l/min nylon chest/back/cap bladders	222 W	
Dichlorotetrafluroethane vest - 16 horizontal packets	108 W	
Full body undergarment ice & water, pump, battery	107 W	
Air cooling: Vest, chest, neck, back lightweight crush-resist hoses & manifold system mounted on an open-weaved fabric	10-15 cfm flow rate	Tolerance limits 2.5-4 time as long as without vests, moderate heat up to 5 hrs duration
Ice cooling: No external energy cotton canvas chest & back coverage	270 W/hr cooling capacity	Suitable for only short term work (2-4 hrs), does not prevent heat storage

Most of the "off-the shelf" systems have similar physiological and performance response. They do cool the body, retard heat strain, and have limited endurance enhancement. However, each have marked differences. Their prices range from $150 to $3000. Air-cooled systems rely on evaporative cooling, have relative weight, and are battery dependent. Liquid-cooled systems rely on conduction, are heavy, result in cutaneous vasoconstriction, and are also battery dependent. Ice-cooled systems are light weight and require no outside energy, but generally, are not as effective as air or liquid.

New cooling methods and technologies that address application to specific anatomical regions of the body and new structural designs are now being researched and reported for thermoelectric cooling, freon based vapor compression, phase transition microcapsules/crystals, and light weight/miniaturized compressors and power sources.
Two of the most intriguing of these new technologies are in the area of phase transition crystals and light weight power sources.

The traditional method for providing insulation in the apparel industry is to utilize trapped air spaces of the fabric or garment. Industry has now begun to depart from this traditional trapped air approach. Small spheres of microencapsulated phase change materials are added to the polymer solution just prior to man-made fiber extrusion. Thus, the thermal properties are contained inside each individual fiber filament. This new technology provides reduced weight and bulk when compared to standard insulative fabrics, is not affected by compression of trapped air, and is reported to significantly improve wearer comfort in harsh environmental conditions.

A proposed microclimate cooling system design with a Proton Exchange Membrane (PEM) and pressurized hydrogen/pressurized oxygen architecture (Fuel Cell) would provide a significant reduction in power requirement size and weight. Such an architecture is able to operate at high pressure with no gas compression hardware. Use of oxygen would allow the oxidant flow stream to be dead-ended resulting in a simplified stack cell structure. Pressure regulators, one each for the H_2 and O_2 supplies, would be the only components necessary in addition to the H_2 and O_2 tanks themselves and the fuel cell stack.

CONCLUSION
Although the development of adequate and efficient microclimate cooling systems that prevent heat injury and maintain performance is difficult and challenging, we have, by no means, exhausted the technologies that can be applied for effective solutions.

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