A Light Weight Ambient Air Cooling Unit for Use in Hazardous Environments

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INTRODUCTION

Thermal stress to personnel as a result of working in a warm and contaminated environment is a critical problem in industry and the military. While performing under such stressful conditions an individual must wear a protective garment such as the military chemical defense ensemble (CDE) which features high thermal insulation and low moisture permeability. In the past years, various personal microclimate cooling systems have been developed and studied which remove stored heat, and therefore reduce body core and skin temperatures (1,2). Since man-mounted cooling units have the disadvantage of increased weight carriage and modest physiological cooling capacity, the concept of intermittent, microclimate cooling only during rest periods has been investigated **(3).** Use of either air or liquid, upper-body cooling during rest periods extended work times, lessened the associated physiological stress, and improved personal comfort when compared with uncooled control trials. However, even when cumulative heat storage was prevented, general physical fatigue was still more progressive than when no CDE was worn **(4).** In an attempt to further improve this concept, we conceived a strategy implementing continuous air cooling with the added wear of a ftltered air blower. With this approach, ambient air ventilation is added during work while conditioned air is delivered during rest periods. This paper describes the development and testing of this continuous cooling approach.

METHODS

<u>System Description</u>: In the current study, a prototype ambient air cooling unit was designed and fabricated at the USAF School of Aerospace Medicine. This unit is composed of a DC vacuum blower, battery set, air plenum, control panel, **3** Army C-2 filters, and supporting **frame.** This compact "beltpack" unit **(~ 3.8** Kg) provides **340** liters per **minute** (L/m) filtered ambient **air** through a U.S. Army developed air vest (5): **280** L/m to the body and 60 L/m to the face. The unit may be used independently or in conjunction with a chilled air cooling system.

<u>Human Testing</u>: The seven subjects used for **this series** of tests were military volunteers. The physical **task** employed for all test batteries in this study consisted of walking at **4.8 km/h** at **3-6 %** grade, which elicited approximately **40%** of each subject's VO_2 **max.** Subjects performed either intermittent or continuous exercise in a thermally controlled chamber under warm conditions **(32°C,** 40% RH) **until** reaching limits of T_{re}= 39.0°C, HR= **180** bpm, or volitional fatigue. For <u>intermittent</u> work, **three** experimental conditions were employed with each subject serving as his own control: **1) no** personal cooling during work or rest, (no cooling, NC), 2) conditioned air cooling during rest periods (intermittent cooling, IC), and **3)** conditioned **air** cooling during rest plus ambient air ventilation during work (continuous cooling, CC). Four cycles of **40** minutes work **(450** watts) and 20 minutes rest were attempted at each condition. The 510 **L/m** of **20°** C conditioned air **(85** L/m to the face**)** was delivered to subjects during rest periods in both the CC and IC trials. In a second set of experiments during <u>continuous</u> work, subjects walked on the treadmill with either: **1)** no personal cooling (NC), or 2) ambient air ventilation (AV) until reaching one of the **termination** criteria specified above.

<u>Data Analysis</u>: Preliminary statistical analysis applying a 3-way ANOVA was conducted using physiological data and ratings from Thermal Comfort and Rated Perceived Exertion including all conditions, and a second 3-way ANOVA was accomplished to specifically compare IC and CC using paired **data** from these conditions only. Rates of sweat production, and evaporation were analyzed using a 2-way ANOVA. Significance was accepted at the P= .05 level for all tests.

RESULTS

During the <u>intermittent</u> work scenario where subjects attempted four hours of work-rest cycles, all Seven subjects completed at least **80** minutes in the NC **trial.** Initial analysis of these data indicated that individuals receiving cooling performed significantly better both physiologically and perceptually than in the NC condition. Since four of the subjects completed at least **140** minutes work in IC and CC conditions, an additional statistical analysis was conducted up to this point for IC and CC only. This analysis indicated that the increase in rectal temperature and mean **skin** temperature observed over the first three work periods was significantly greater during IC **than** CC. Although there were no differences in heart rate during the work cycles, the average heart rate during rest cycles with CC was significantly lower than for IC. Sweat production rates (SP) were significantly lower for CC and IC than for NC, while the rate **for** CC was also lower than for IC. Additionally, the sweat evaporation rate for CC was higher than for IC and NC. Therefore, the percentage of sweat evaporated during the *CC* condition was ***also*** significantly greater than **for** IC **or** NC.

Use of ambient *air* ventilation (AV) during 50 minutes **of** continuous work, resulted in **significantly** less increase in heat storage. Mean skin temperatures were observed to be significantly higher in the no cooling (NC) scenario. AV *also* had a significant effect on lowering thermal comfort ratings (TC), which was evident even **at** the 10 minute **paint.** Sweat production rates (SP) were not different **for** AV and NC. However, there was a significant difference in sweat evaporation (SP) and percent **of** sweat evaporation.

DISCUSSION

All cooling scenarios (AV,IC,CC) decreased thermal strain **as** compared to no cooling trials. Significant differences between continuous cooling and intermittent cooling were observed in the following physiological measures: *skin* temperature, heat storage, and sweat evaporation efficiency. The 3.8 kg load experienced by subjects when carrying the ambient *air* cooling unit during work **periods** might have counteracted some of the expected physiological and psychological benefits from ambient air ventilation. However, since only four subjects completed at least 140 minutes of *intermittent* work, **limited data** were analyzed. These **data** may not be adequate to reflect truly significant physiological effects. It is necessary **that** additional subjects finish four work-rest cycles with continuous ***air*** cooling to more accurately evaluate **the full** effect of CC. Further reduction in weight of the ambient **air** cooling unit and **optimization** of work-rest cycle length would possibly **amplify** the efficacy of the application of ambient air ventilation. **Additionally,** the filtered ambient *air* gained heat from the motor and control panel, increasing inlet *air* temperame approximately 2-3° C. Therefore, **skin** temperahue and the resulting thermal perception may have also been **increased.** Another possible improvement may be to increase the *air* volume to 560 L/m to the body, 140 L/m to the face since most subjects commented that air flow to the face was marginal during work.

CONCLUSION

This beltpack, ambient **air** cooling system has been shown to reduce thermal stress during work when wearing the *military* CDE. Further improvements would support the main objective of ambient air ventilation which is to maximize the reduction of thermal stress for individuals working in a warm environment while wearing protective garments. The positive **air** pressure which **results** from the system may also decrease breathing resistance and increase protection from toxic substances. Consequently, mission effectiveness during a chemical warfare or industrial decontamination scenarios should be enhanced.

ACKNOWLEDGEMENT

We would like to note the critical technical suggestions provided by Dr. A.L. Allen, **USA** Natick RD&E center IPD/LSSD, regarding the choice **of** blower and battery hardware.

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