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COOLING EFFECT OF A PCM VEST ON A THERMAL MANIKIN AND ON HUMANS EXPOSED TO HEAT

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INTRODUCTION

In hot environmental exposures, combined with physical work, such as fire fighting, military exercises and actions, and sports activities, the human body suffers heat stress, resulting in reduced working endurance, performance, comfort and an increased risk of heat illness. Cooling vests are designed as to prevent heat strain, increase work performance, and possibly create thermal comfort. Some of them apply phase change materials (PCM; e.g., ice, gel, salt) in a vest. The cooling effect of an ice vest has been studied (Yoshimi et al 1998; Smolander et al 2004; Myhre and Muir 2005, Hunter et al 2006). Microcapsules of PCMs in clothing have been reported to provide a small, temporal heating/cooling effect during environmental transients between warm and cold chambers (Shim et al 2001). However, the cooling effect of salt vest has not been reported. The objectives of this study were to investigate physical, physiological and subjective cooling effects of a salt vest on a thermal manikin, and on human subjects.

METHODS

Cooling vest: TST cooling vest made of polyester containing 21 flat pieces of PCM elements (salt mixture) with melting temperature (T_m) at 28°C. Before and after the test, the vest was kept horizontally at 20°C for solidifying and re-use. The total weight of the vest was two kilograms.

Clothing: Clothing and equipment worn by the subjects during the test in the climatic chamber was Swedish RB90 fire fighting ensemble including cotton T-shirt, briefs, TST cooling vest, underwear, outer wear, socks, safety boots, and gloves. The vest was dressed between T-shirt and RB90 underwear. The clothing was dressed the same way on manikin except for that no safety boots and equipment (pulse belt and watch, skin and rectal temperature sensors, helmet, mask, self-contained breathing apparatus) were used on manikin. Total weight (with vest) was 22 kg.

Manikin test: Thermal manikin Tore with 17 individually controlled zones was used. Manikin surface temperature was kept at 38°C. Climatic chamber temperature was kept the same, so that there was no heat loss from the manikin to environment. Heat losses and manikin surface temperatures were recorded at 10 s intervals. As the vest covered only torso part of the manikin, therefore these torso zones (chest, abdomen, upper and lower back) were included in calculations.

Subject test: Two healthy male fire fighters volunteered to participate in the study. A written consent had been obtained before they participated in the tests. Their ages were 27 and 40 years old, heights 1.78 m (both subjects), weights 76.0 and 68.9 kg. Both subjects came to the lab twice and performed two tests (with and without vest) on two different days. The procedure followed the study by Holmér et al (2006). Rectal temperature (T_{rec}) sensor (YSI-401) was inserted by the subject at a depth of 10 cm. Skin temperature (T_{sk}) sensors (thermistors ACC-001) were taped on forehead

and left side chest, scapula, forearm, thigh and calf. The subject cycled on a cycle ergometer at 50 W for 20 min at 20°C. T_{rec} and T_{sk} were recorded by Labview program. Whole body thermal sensation was recorded. After cycling, the subject entered the climatic chamber ($T_a=55^\circ\text{C}$, $RH=30\%$, and $V_a=0.4\text{m/s}$, $P_a=4\ 725$), and walked on a level treadmill (5km/h). VO_2 was measured. The activity was terminated based on one of the following criteria: 1) subjects felt that the condition was intolerable and were unable to continue, 2) T_{rec} reached 39°C .

RESULTS AND DISCUSSION

Heat loss on manikin: The vest had a stronger cooling effect during the first hour (Figure 1). The duration of the effect was about seven hours. Effects of cooling devices depend not only on the melting temperature, but also on manikin surface temperature, as reported by other researchers (Jetté et al 2004). In reality (e.g. fire fighting), skin temperatures higher than 34°C often occur. Average cooling rate during the first hour was $32.8\ \text{W/m}^2$ on the torso, and $11.5\ \text{W/m}^2$ on the whole manikin. The torso surface area was 31.9% of the whole manikin ($1.774\ \text{m}^2$).

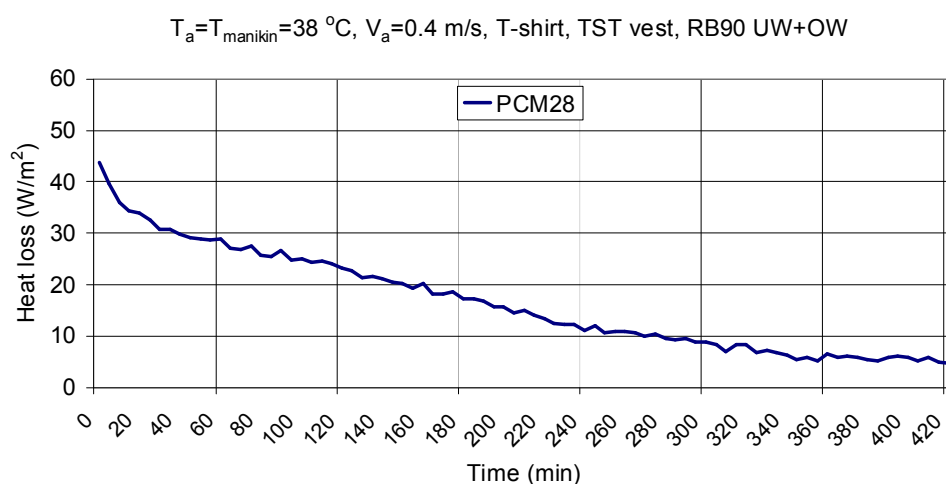


Figure 1. Heat loss from torso on manikin at 38°C (isotherm)

Metabolic rate: The mean metabolic rate ($309\ \text{W/m}^2$) for two subjects with cooling vest (2 kg), all clothes and equipment (20 kg) was 10% higher than that ($281\ \text{W/m}^2$) without cooling vest. Even though the metabolic rate was increased by 10% while wearing the vest, heat strain was decreased, as evidenced by the skin, body and core temperature alleviations as below.

Local cooling effect (chest skin): For one subject, the chest temperature with the cooling vest was about $3\text{-}4^\circ\text{C}$ lower than that without the vest (Figure 2, bold lines). The chest temperature reached 39.5°C in the end of the test without the vest, whilst it was only 36.5°C when wearing the vest. For the other subject, the local cooling effect on the chest was even better, in particular, in the end of the test. The chest temperature with the vest (34.2°C) was about 5.8°C lower than that without the vest (40.0°C). This was dependent on the placement of the temperature sensor (i.e. precisely under the PCM or in-between two pieces of PCMs). Without the vest, the chest temperatures of

the two subjects increased linearly and sharply with time. Other studies have shown that an ice vest can decrease local skin temperature by 8~10°C and, possibly causing discomfort (Yoshimi et al 1998; Smolander et al 2004; Myhre and Muir 2005).

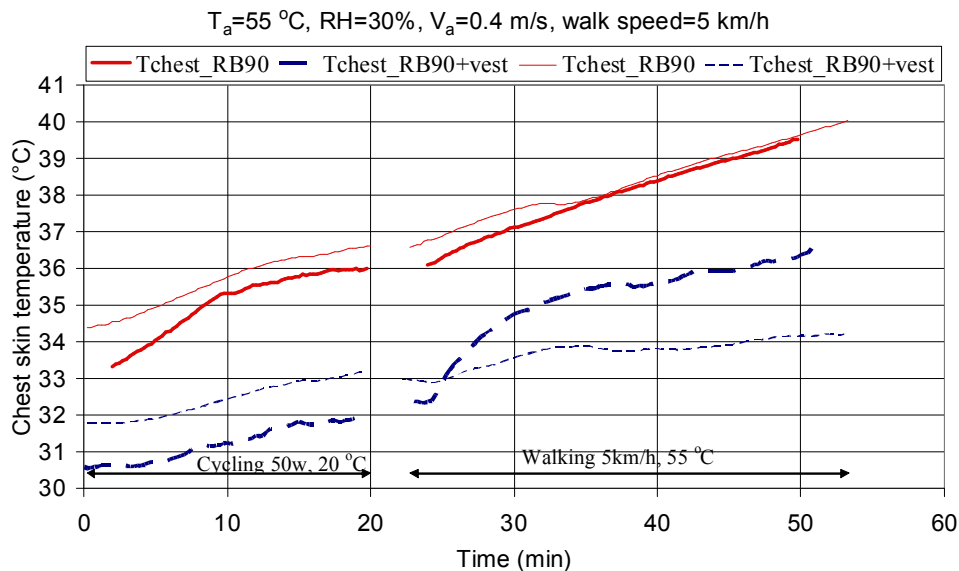


Figure 2. The cooling effect of the vest on chest (two subjects)

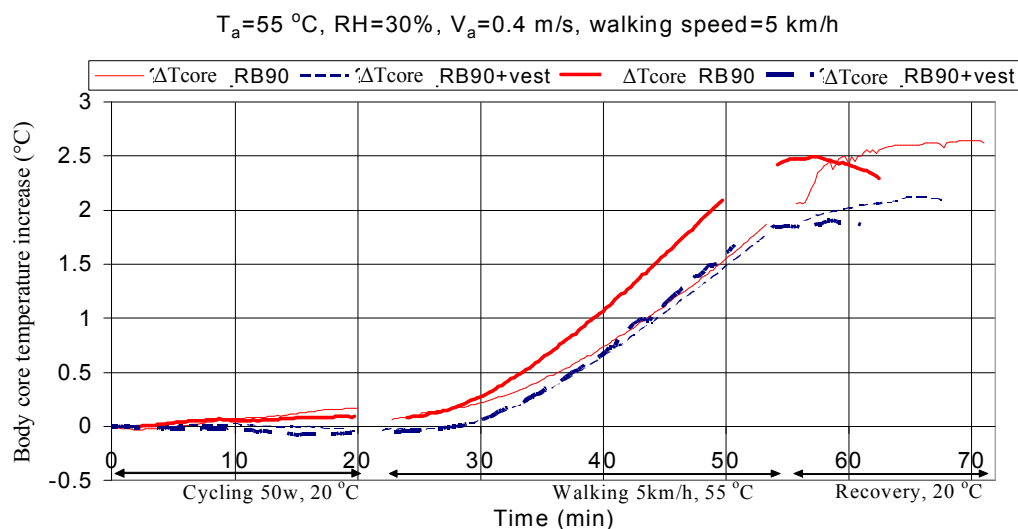


Figure 3. The cooling effect of the vest on rectal temperature (two subjects)

Mean skin and mean body temperatures: The mean T_{sk} and mean T_b were about 1.0°C and 0.5°C lower respectively with the vest at the end of heat exposure.

Core temperature T_{rec} increase and recovery after test: For one subject, T_{rec} increased 2.1°C by the end of heat exposure without the vest, whilst with the vest it increased only 1.7°C. During recovery at room temperature, T_{rec} was still increasing for a few minutes. The peak increase reached 2.5°C (including heat exposure and recovery), and then gradually dropped. This phenomenon was reported by Holmér et al. (2006). Therefore, the absolute peak rectal temperature could reach about 39.5-40°C after the exposure. With the vest, the peak increase was only about 1.9°C during recovery (Figure 3). Thermal strain and illness risk are thus reduced. A similar result was found for the second subject during recovery. These results are in agreement with other

studies using an ice vest in cross-country racing (Hunter et al. 2006), and frozen gel by Pimental et al. (1992). Mean whole body thermal sensation with the vest was somewhat less during the heat exposure. However, there has also been a recent study showing that a cooling vest incorporating a water-based PCM (mainly sodium sulphate additives, $T_m=28^\circ\text{C}$) had no significant cooling effects on core and skin temperatures during and after fire fighting (Carter et al. 2007), which was carried out in a lower temperature environment (less heat stress).

CONCLUSIONS

The cooling vest has an effect in reducing heat strain as evidenced by both thermal manikin and subject tested in very hot conditions.

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