HEAT STRAIN WHILE WORKING INDOORS UNDER HIGH RELATIVE HUMIDITY AND TEMPERATURE WITH COOLING VESTS

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Abstract: Climate change increase summer air temperatures also in Northern regions, that may lead to elevated indoor temperatures as well. This study aimed to find how much high relative humidity (RH) in hot indoor working conditions effects on heat strain and if it can be mitigated by cooling vest. A 75-min test protocol simulating light work with six test subjects was performed at an ambient temperature of 30°C and RH of 40 and 75%. During the tests was measured heart rate, core and skin temperatures, moisture accumulations, and thermal and moisture sensations were recorded. Fan and hybrid cooling vests were studied. The results showed that skin temperatures, heart rate and sweating increased when RH was higher. The fan-integrated vest was more effective to remove moisture from the clothing and the hybrid vest (fan and phase change material packages) to decrease the skin temperature. Breaks should be taken in cooler recovery room.

Keywords: Phase change material, fan cooling vest, hybrid cooling vest, relative humidity, heat strain.

1. INTRODUCTION

Climate change causes increase in air temperature and extend periods of heatwaves (IPCC, 2022). The ambient temperature above 28°C is the criterium for hot work in Finnish occupations. However, high relative humidity (RH) at hot work environment increases heat stress by decreasing sweat evaporation, which is not considered in the criterium. In indoor workplaces temperature can increase during heatwaves, adding heat stress on top of those ambient factors from the production process (Narocki, 2022). Correspondingly, Rissanen et al. (2022) found a cumulative increment in indoor temperatures during the heat waves in Finland especially in workplaces where heat radiative machines are required, such as in laundries. Heat strain of the workers was shown to be generally moderate. Heat problems in summertime are recognized at indoor workplaces in Finland (Kaisto et al., 2022). It has been shown that thermal comfort can be improved by personal cooling with phase change materials (PCM), air-cooled, evaporative cooling, liquid-cooled and hybrid cooling garments (Golbabaei et al., 2022).
The purpose of this study was to demonstrate how much elevated RH in hot working conditions effects on workers' heat strain and if it can be mitigated by cooling vests.

2. MATERIALS AND METHODS

2.1. Cooling vests and clothing

The study was performed with subjects wearing a vest with two fans at lower back (fans OFF = "No Cooling" and fans ON = "Fan Cooling") and a hybrid cooling vest ("Hybrid Cooling") with the two fans at lower back and packages of PCM on the upper back.
Clothing worn during the study was: T-shirt (cotton), thin working trousers (cotton), socks and running shoes.

2.2. Test subjects

Six volunteer test subjects (5 females, 1 male) participated in the study. Their age was on average 38.2 years (SD±15.3 years) and body mass index (BMI) was on average 23.8 (SD±4.9).

2.3. Ambient conditions

To create realistic working scenario into laboratory conditions, air temperature (T_a) and RH data was collected in real conditions at a laundry located in Southern Finland during summer 2023. The T_a varied from 23 to 30°C at the worksites when outdoor temperature was 25°C or above. RH varied at the same time from 39 to 82% at different work sites. Ambient conditions to laboratory study were selected based on these measurements: T_a was 30°C, the wind speed of 0.5 m/s, and RH was 40 and 75%, the WGBT was 26.0 and 29.4 °C, respectively.

2.4. Thermo-physiological measurements and experimental protocol

Skin temperatures (T_{sk}) from nine sites, core temperature (T_c), and heart rate were measured. Thermal sensation, thermal comfort and skin moisture sensation were asked from the test subjects in every 10 min. Moisture accumulations were measured by weighing the garments separately before and after the measurement. The subjects performed a 75-min trial consisted of rest (standing, 5 min), light work (walking in treadmill at a 1-degree angle 4km/h, 40 min), rest (standing, 10 min), and light work (walking in treadmill at a 1-degree angle 4km/h, 20 min).

3. RESULTS AND DISCUSSION

The results showed that elevated RH from 40 to 75% at T_a of 30°C increased the mean T_{sk} approx. by 0.5°C, average heart rate by 3.4% during working periods, and sweating was increased based on approx. 3.5 times higher moisture accumulations in the clothing (T-shirt and trousers). The T_c was approx. 0.16°C higher at RH 40%. However, the T_c rose 0.1°C more during the working periods at RH 75%. At the end of the tests thermal sensation was “hot” at RH 75% and “very warm” at RH 40%.

The mean T_{sk} was lower when cooling vests were used. When RH was 40% at the end of test protocol the mean T_{sk} were 33.0, 32.5, and 32.4°C with No Cooling, Fan Cooling and Hybrid Cooling, respectively. Correspondingly, when RH was 75% the mean T_{sk} were 33.8, 33.2 and 32.9°C with No Cooling, Fan Cooling and Hybrid Cooling, respectively. The largest variation between the local T_{sk} was found on shoulder blade where also the PCM packages in Hybrid Cooling vest were located. Thermal sensations were slightly cooler when cooling vests were used. However, no differences were found in thermal sensations between the cooling vests.

The moisture accumulations in the T-shirt were the lowest when the Fan Cooling vest was worn (Figure 1). The integrated fans increased the air movement under the vest and thus increased moisture evaporation. In the Hybrid Cooling vest air movement is partly restricted due to the weight of the PCM packages located on the shoulder blade area. The skin moisture sensations were “wet” at RH 75% with No Cooling and “moist” at the end of the other test protocols.

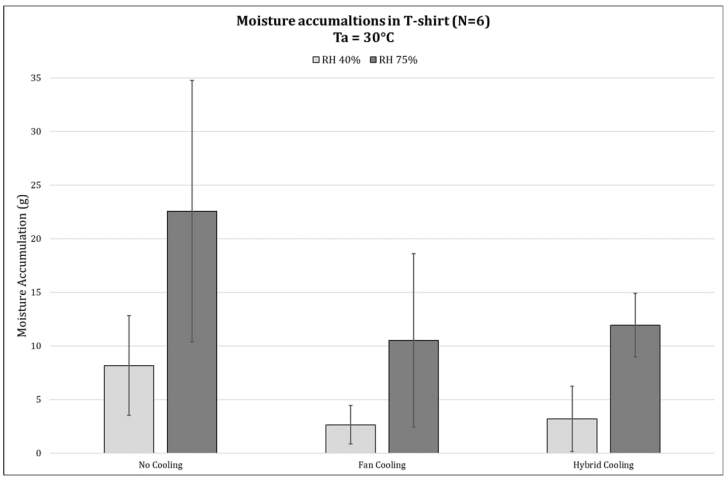

Figure 1. Moisture accumulations in the T-shirt (N=6) with different type of cooling vests at ambient conditions: T_a 30°C, RH 40 and 75% and wind 0.5m/s.

4. CONCLUSION

High relative humidity in hot environment increased heat strain of the test subjects. This is important to consider especially at workplaces where heat radiative machines are used, and moisture is evaporated from the process, such as in laundries. The fan integrated cooling vest was more effective to remove moisture from the clothing and the hybrid vest (Fans - PCM) to decrease the skin temperature. Breaks should be taken in cooler recovery room to provide sufficient recovery from the heat strain.

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