LOCALIZED TEMPERATURES AND WATER VAPOR PRESSURES WITHIN THE CLOTHING OF WORKING MAN IN THE COLD

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INTRODUCTION

The thermal phenomenons and the interactions between avenues of heat exchange taking place within the clothing of sweating man have been simulated **with** introduction of water on a hot plate covered with layers of fabrics (**Woodcock** 1962; Mecheels 1970; Famworth and **Dolhan** 1985). However, few actual measurements of temperatures and humidities **within the** clothing of man have **been** reported (Vokaç et **al.** 1976; Fujitsuka and Ohara 1977).

The purpose of this study was to determine the variation of localized skin temperatures, clothing surface temperatures and water vapor pressures within a prototype clothing system when worn during alternating work/rest cycles in a cold environment. The effects of different fiber type and knit structure in the innermost layer of the clothing system **on** the **various** temperatures and water vapor pressures inside the clothing ensemble were **also** investigated.

METHODS

A two-layer prototype clothing system comprised of 100% polypropylene underwear (1-by-1 rib knit), a **uniform**, socks, **shoes** and gloves was tested ***on*** **eight** subjects ($T_a = T_r = 5°C$; $T_{dp} = -4°C$; $v_a = \mathbf{0.3}\ m \cdot s^{-1}$; $I_{cl} = \mathbf{0.25}\ m^2 \cdot K \cdot W^{-1}$). In addition, measurements were done **with** Eve different fiber type materials (cotton, wool, polypropylene, and ***two*** polyesters **with** different **finish)** and Eve different knit structures (1-by-1 rib knit, fleece, interlock, fishnet, and double-layered interlock) in the underwear. The 2-hour experiment comprised a twice repeated bout of 40-min cycle exercise ($W = \mathbf{56}\ W \cdot m^{-2}$; $M = \mathbf{313}\ W \cdot m^{-2}$) followed by 20 min of rest ($M = 65\ W \cdot m^{-2}$). Esophageal, ***skin***, **clothing** and ambient temperatures, **as** well **as** dew-point temperatures near **the skin**, in the clothing and in the environment were monitored. **In** addition, evaporation of sweat and sweat accumulated in the various clothing parts were determined.

RESULTS & DISCUSSION

In the prototype clothing system with polypropylene underwear, the temperatures and water vapor pressures in all clothing layers varied significantly **with** the **human** thermoregulatory responses (**skin** temperature, sweating) to alternating work/rest **cycles.** There were large differences at **the** various body sites in temperatures and vapor pressures observed. The different patterns of change in temperature and water vapor pressure in separate body areas indicated a different importance locally of influencing factors **as** the pumping effect, the intrusion of wind in the micro-environment, and **the** transfer between **insensible** and sensible heat exchange.

During **the** Erst exercise period clothing temperatures changed more than **skin** temperatures. On **the** exercising lower part of the body clothing temperatures decreased, whereas they increased on the less moving upper part of the body. The water vapor pressures at **the** upper back, at the chest and at the **thigh** all increased significantly **with** 2-3 kPa near **the** *skin* and with 1-2 kPa in the outer clothing compartment during the bout of exercise. Thus, water vapor pressures changed more near **the** *skin* during exercise **than** in the outer clothing compartment although most sweat/water accumulated in **the** outer clothing layer.

During rest mean *skin* temperature., mean underwear temperature and almost all local temperatures decreased significantly ($p < 0.05$). However, **on** the legs *skin* temperatures did not decrease, and the temperatures **on** underwear and BDU **on the legs** actually increased. This is the result of an abrupt decrease in convective heat loss **with** cessation of bicycling. **On** torso, *arms* and **hands skin** temperatures decreased with 1-2°C. **All** water vapor pressures near the *skin* decreased ($p < 0.05$) to **values** of 1.5 or 2.2 kPa. ***Also***, the water vapor pressures in **the** outer clothing compartment decreased (< 0.05) during the course of the rest period, where sweating came to an end, and clothing began to *dry* **out.**

A repeated bout of exercise and rest, respectively, did not result in much lower temperatures; however, mean underwear temperature was significantly lower after the **second** bout of exercise compared to the value at the end of the Erst bout. Locally, the **skin** temperature **on the** upper arm and the forearm were lower

(<0.05) compared to at d e end of the first bout of exercise and rest. At d e end of d e second rest period, hand temperature was also lower. Clothing temperatures in all layers at the chest were lower after the second exercise. At the end of d e second rest period hardly any of d e dothing temperatures were lower compared to at d e end of d e first rest period No differences in end-values of d e water vapor pressures in the two compartments were found between exercise 1 and exercise 2, and between rest 1 and rest 2.

The fiber type material of the underwear had little influence on de vapor pressures near d e skin and within d e clothing. Skin temperatures were not influenced by the fiber type of the underwear material (Nielsen and Endrusick, 1988). However, surface temperatures on the underwear, and temperatures observed inside and outside the jacket were significantly influenced by the fiber type material of d e underwear. Generally, the clothing surfaces were warmest with one of the polyesters (Thermax), and coldest with wool as the underwear fiber type material.

Underwear knit structure influenced the vapor pressures near the skin more than it influenced d e vapor pressures within d e clothing. However, for d e temperatures in d e system the influence of underwear knit structure was significant both at the skin (Nielsen and Endrusick, 1990), and at d e surface of the undernear. The heavy fleece construction resulted in the warmest thermoregulatory responses, but on its outwards surface the lowest underwear temperatures were measured This can probably be ascribed to a greater thickness than of the other constructions. The warmest clothing temperatures were recorded over the I-by-1 rib knit construction.

CONCLUSIONS

In conclusion, the present study showed that d e thermoregulatory responses to alternating work/rest cycles can be quantified in all clothing layers. When sweating occurs with various underwear fiber type materials it creates even more important temperature differences within d e clothing than on d e skin surface.

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