CONDENSATION IN CLOTHING

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INTRODUCTION

Normally, the heat production of man performing physical exercise is balanced by changing the local blood flow and the sweat rate. Hence, the skin temperature and vapour pressure will change in order to maintain core temperature within proper limits. Clothing will reduce the dissipation of heat and water vapour, not only by acting as a diffusion barrier to heat and mass transfer but also by absorbing liquid water and water vapour in the fibres. These latter two processes liberate heat, differential heat of sorption, at various degrees depending on the material and condensation rate, respectively. If heat is produced in the fabric due to changed regain or if water vapour condensates, the temperature of the fabric raises, thereby decreasing the temperature difference between skin and clothing (1). This would reduce the dry heat transfer from the skin whereas the heat loss outwards from the fabric would increase. On the other hand, if the relative humidity around the fibre is reduced, the changed regain will consume heat. This will happen also when the condensate evaporates. Then the temperature in the material will fall, increasing the heat transfer from the skin to the inside of the garments whereas the loss from the outer side to the ambient air will be reduced. An analogy happens at condensation which limits the evaporation from the skin to the surrounding air giving a lower weight loss rate than at the moment when the condensation decreases. All these mechanisms can occur at the same time at various sites of the garment. These processes have been described relatively sparsely, mostly by measuring the material temperature when changing between climatic chambers having different relative humidities (2). Effects on the heat transfer from humans clothed with permeable (3) or impermeable ensembles has also been demonstrated (4). The aim of this presentation is to demonstrate some effects of sorption on heat transfer and temperature in clothed subjects.

METHODS

Different types of CW-protective garments and combat uniforms have been used and the subjects have exercised at various metabolic rates and ambient temperatures. Dry heat transfer and temperature were measured using heat flux sensors and thermocouples attached to the skin and in some cases to the outer surface of the ensemble. A continous measure of the evaporation was obtained by weighing the subject during the exercise.

RESULTS AND DISCUSSION

Figure 1 shows typical results from a subject wearing an one-layer (jacket and trousers) CW-protective garment during cycle ergometer exercise at a metabolic rate of 600W. A series of events started with changed heat flux and temperatures at the time of the onset of exercise. After about 5 minutes of exercise there was a marked reduction of the heat flux from the skin. Approximately one minute later (minute 7) evaporation increased rapidly. At minute 8 the heat flux from the outer side of the ensemble rose and at minute 9 the temperature sensors at the garment surface displayed increased values. At this moment the heat flux from the skin decreased rapidly and the skin temperature started to rise. At minute 15 the heat flux and the temperature at the outer side of the ensemble suddenly levelled off at the same time as the evaporation rate increased. A few minutes later (minute 17) the heat flux from the skin raised at the same time as the elevation of the skin temperature ceased. These series of events can, reasonably, only be a result of heat generation in the garments. The only known processes available are liberation of heat of condensation and heat of wetting and these observations fits very well with what is expected if water vapour is condensated on and absorbed by the fabric. As the used garments were composed of materials with rather low heat of wetting (5) presumably the main part of the heat liberated originated from condensation.

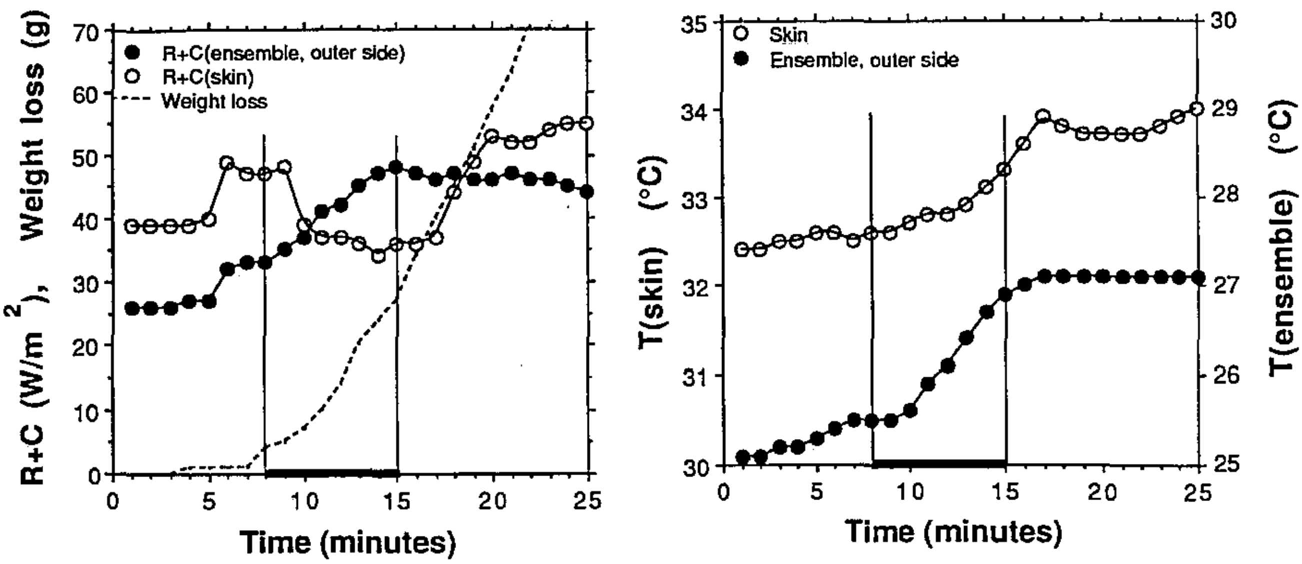

Figure 1. Changes in dry heat loss (R+C), skin- and garment temperature and whole body weight loss due to activity and liberation of heat in the garments when wearing a CW-protective ensemble at 21 °C. The subject is sitting still on the cycle ergometer until minute 5 at which time he starts to work.

The course of events was similar irrespective of subject, air temperature or garment design, but the duration and the magnitude of the changes were affected. However, the relative importance of sweat rate, garment temperature, material etc. have not yet been established.

CONCLUSIONS

During exercise in permeable garments there are distinct changes in dry heat loss, evaporation rate and temperatures indicating that condensation of water vapour occurs in the garment.

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