CONVECTION IN CLOTHING AIR LAYERS

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INTRODUCTION

It has been known since decades that physical activities affect the insulation value of a garment. In the middle of the forties Belding et al. (1) found that the heat loss from a man wearing an arctic uniform could increase 100% due to rapid walking. Since then several researchers have made similar observations. Changes of enclosed and surrounding air layers, were found to be related to the rate of activity. The concepts pumping or bellow effect were coined to illustrate the mechanism behind these phenomena. Nevertheless, most garment characteristics are obtained at rest. Hence, discussions on the dynamic processes involving dry and evaporative heat transfer are relatively rare. If the convection in an air layer is increased the consequence on e.g. the insulation value depends on the relative magnitudes of the radiation and convection heat transfer components. Considering the vapour resistance the convection will be of major importance for the mass transfer. Hence, the ratio between the heat and the vapour resistance, the permeation index, will be affected differently depending on the location and the magnitude of the convection. Moreover the design of the ensemble including the choice of material, thickness, number of layers, fitting etc. will be of significance for the effects of the changes in the enclosed air gaps. The purpose of the present study was to investigate, on humans and cylinders, the mechanisms behind the convection in enclosures and to measure the convection heat transfer coefficients occurring between garment layers and at the outer surface of an ensemble.

METHODS

A technique based on the cooling rate of a periodically heated thermistor was developed to measure the local air temperature as well as the air velocity in the enclosure. These variables were correlated with the convective heat transfer coefficients *(h,)* measured with heat flux sensors (2) when a combat uniform, jacket and trousers, was worn. The activities, standing still and walking, were conducted in a wind tunnel. When standing still the external wind speed was 0, 1,4 or 1,9 m/s. The walking and the wind speeds were combined as 1,4/0, 1,9/0, 1,4/1,4 and 1,9/1,9 m/s, respectively.

RESULTS AND DISCUSSION

The convective heat transfer coefficient of a naked body when standing still in an external wind, v (m/s), $h_c=8{,}8\cdot v^{0{,}53}$ is similar to that of a vertical cylinder in cross wind (3). From this result it might be expected that the clothed body should obey roughly the same correlation equation. However, $h_c=10{,}2\cdot v^{0{,}64}$ was derived which differ both in respect of the velocity coefficient and -exponent. As the garments made the characteristic diameter greater a smaller velocity coefficient than for the nude whole body would be expected. Comparing the corresponding equations for a bare and a covered cylinder the same relations were obtained after correction for the different diameters. So, reasonably the deviations should not be related to the changed structure of the surface. The local h_c-values of the clothed subject, at the lower leg, thigh etc., differed considerable from those of the nude body. Moreover, h_c did not correlate with the characteristic diameter. Probably, the difference in *h,* between the nude and the clothed body was due to increased impact of the adjacent parts and changed geometry caused by the loose fabric layers. The greatest h_c-value was obtained for the geometry exposing the largest part of the the circumference to the wind. Walking changed the relationship. Approximately the same h_c-value was obtained for the clothed surface as for the nude one. This result is in accordance with insulation measurements found in the literature (e.g. 4, 5). The convection coefficient was weakly correlated with the diameter, probably because of the induced turbulence from the swinging limbs and the effect of the adjacent parts. Consequently, these results indicates that irrespective of material and fitting the same relation between velocity and convection coefficient can be used for the outer surface of the whole body when walking in still air or in wind. The mass transfer is closely related to the heat convection, especially at forced turbulent air flow. Therefore the whole body h_c-value is likely to be a good predictor of the evaporation rate and the permeability index at the outer surface. The internal air speed was measured at various parts of the body during walking. The velocity was found to be important for the changes in intrinsic insulation value though the air layer width also contributed to the variations. The internal wind speed increased more than proportional to the walking velocity for most parts except at the leg where the intrinsic wind speed was roughly linearly related to the transportation speed. As the convection coefficients and the wind speeds were measured at the same sites correlation equations could be derived. The intrinsic air layer h_c-value was similar to that occurring in a duct with laminar air flow where the temperature and the velocity profiles are not developed. For the loose fitting one-layer ensemble (combat uniform) $h_c=14{,}5 \cdot v_i^{0{,}34}$ v_i=intrinsic air speed (m/s), was obtained where v_i ranged from 0,1 m/s up to 1m/s depending on walking velocity and measuring site. However, the intrinsic h_c-value at standing still as well as during walking is also dependant on the air gap width. So, a tight fitting ensemble will impose a greater h_c-value than a loose fitting one for the same air speed. This result is in line with the findings that garment design affects the insulation value (e.g. 6). The conclusion is that using the knowledge of the convection in enclosures and at the outer surface, intrinsic and total heat as well as vapour resistances could be predicted for different ensemble design during various activity rates.

REFERENCES

1. BELDING H. S., RUSSELL H. D., DARLING R. C. and FOLK G. E. 1947, Analysis of factors concerned in maintaining energy balance for dressed men in extreme cold; effects of activity on the protective value and comfort of an arctic uniform. ***American Journal of Physiology,*** 149, 223-239.

2. DANIELSSON, U. 1990, Convective heat transfer measured directly with a heat flux sensor, ***Journal of Applied Physiology,*** 68, 1275-1281.

3. DANIELSSON, U. 1990, Activity and wind induced convective heat transfer coefficients in man. ***Climate & Buildings,*** Royal Institute of Technology, Stockholm.

4. NIELSEN, R., and B. W. OLESEN. 1984, Effect of body posture, activity and wind on the thermal insulation of clothing. Measurements on human subjects. ***Proceedings of the 1984 International Conference on Occupational Ergonomics,*** 11-14.

5. HAVENITH, G., R. HEAUS, and W. A. LOTENS. 1990, Resultant clothing insulation: a function of body movement, posture, wind clothing fit and ensemble thickness. ***Ergonomics,*** 33, 67-84.

6. McCULLOUGH, E. A., B. W. JONES, and P. J. ZBIKOWSKI. 1983, The effect of garment design on the insulation values of clothing. ***ASHRAE Transactions*** 89, 327-352.