EFFECT OF STEP RATE ON CLOTHING INSULATION – MEASUREMENT WITH A MOVEABLE THERMAL MANIKIN

Håkan O Nilsson, Désirée CE Gavhed, Ingvar Holmér,
Institute of Occupational Health, Dept. of Work Physiology
Solna, Sweden

INTRODUCTION

Assessment of the performance of clothing, when worn under realistic conditions, requires knowledge about the extent to which factors like body movements and wind affect the heat transfer process. Also, the value for clothing insulation required by most predictive thermal models (1, 2, 3) must be representative for the wear situation – values need to be "resultant values". Since most data available for clothing thermal insulation have been obtained in measurements with a standing, static thermal manikin under wind still conditions, some kind of correction is required to match the real performance of clothing (4, 5, 6, 7).

This paper reports results of measurements of thermal insulation with a moveable manikin.

METHOD

The thermal manikin is one in the TORE-series and has been described elsewhere (8). An external, pneumatically driven system applies a swinging movement to arms and legs. The action can be controlled so as to allow the manikin to perform realistic walking movements at different step rates. In the present study step rate was controlled at 0, 30 and 55 steps/min. This corresponds to standing and walking speeds of 0.3 and 0.55 m/s, respectively. Measurements were carried out in a climatic chamber at an air velocity of about 0.12 m/s. Repeatability with the applied procedure for measuring insulation was high; difference between values in double determinations was always lesser than 6 % of the average of the two.

Two examples of worker's outfit were tested. One comprised a light, two-layer ensemble for shop workers and the second was a heavy, three-layer cold protective clothing. Results are given as the percentage of the standard insulation value measured with the standing, static manikin under wind still conditions (9, 10). The standard insulation values were 0.67 (nude), 1.62 and 3.47 clo, respectively.

RESULTS AND DISCUSSION

Results are given for total insulation values. In other words, values presented are directly measured with the manikin and require no measurements of external air layer insulation and clothing area factor.

The figure shows the effect of step rate on total thermal insulation for the two ensembles and for the nude manikin. No value with the nude manikin at 30 steps/min. was obtained, but the value at 55 was close to the value for winter clothing.

Regression equations for reduction versus walking speed (m/s) were calculated as follows:

$$y = 100 - 36 \cdot x^{0.60}$$

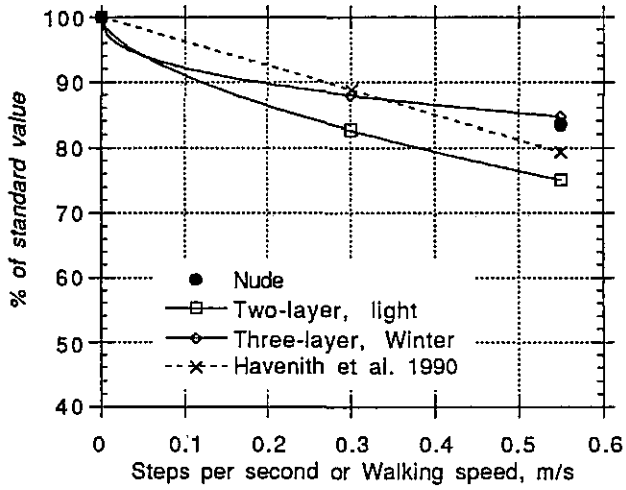
$$y = 100 - 19 \cdot x^{0.39}$$

The relative change, apparently, is greatest at the change from standing to slow movements. This is similar to the effect of external wind on insulation (see e.g. (11)

The step rate of 55 corresponds to a walking speed of 0.55 m/s (≈2 km/h), which is slower than the walking speeds used by others (5, 6, 7). Nevertheless, the results agree favorably with the results of Havenith et al. (6) in this range. On the other hand they predict a linear reduction with walking speed, which is not supported by our results. At a walking speed of 1.5 m/s (5.4 km/h) insulation would be less than 50% of standing value. The total resultant insulation of the winter ensemble measured with subjects walking at ≈1.4 m/s was 2.1 clo, which is a greater reduction (39 %) than predicted with the above equation. On the other hand significant moisture absorption contributed to the reduction in the experiments with subjects (7). If values are related to measurements on still-standing subjects the reduction was 21 %.

Despite the manikin movements being quite realistic, the rotation about the vertical body axis seen with normal walking is not very pronounced. This may yield lower resultant values and a slight underestimation of the pumping effect.

The reduction of insulation due to wind and walking increased with number of layers – the more layers the smaller be the reduction (except for the nude condition). In the figure it is clearly seen that the insulation of the winter ensemble was lesser than the light clothing. Apparently, the ventilation of an ensemble becomes less effective the more layers are put on. Also, the outer layer of the winter clothing is likely to be more wind proof than the light two-layer clothing.



CONCLUSIONS

Clothing insulation is greatly affected by body movements. Insulation appears to reduce as a power function of step rate (walking speed). The effect is more pronounced with light clothing than with multi-layer winter clothing. The moveable manikin seems to produce reproduceable insulation values, the relevance of which require validation

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