A DATA BASE FOR DETERMINING THE EFFECT OF WALKING ON CLOTHING INSULATION

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INTRODUCTION

Previous studies have created large data bases of clothing insulation values for a number of different ensembles and developed insulation prediction equations based on the physical properties of the clothing (McCullough *et al.* 1985). Some standards (ASHRAE Standard 55-1991, ISO 7730) also provide comfort indices using clothing insulation values measured on a standing manikin. However, the insulation value is actually lower during movement, and several investigators have tried to quantify this effect (Olesen *et al.* 1982, Vogt *et al.* 1983, Nielsen *et al.* 1985, Havenith *et al.* 1990). Due to the diversity of tasks and experimental conditions used, it is difficult to integrate the findings of those studies. Further, these studies dealt only with a few ensembles worn on subjects or manikins, and the results were mainly limited to protective or work clothing.

The purpose of this study was 1) to provide a balanced data base for determining the effect of body motion on the insulation value of indoor clothing ensembles, and 2) to develop equations from the physical properties of the garments and their component fabrics for predicting the change in the insulation due to body motion. Since the clothing ensembles were intended to be worn in an indoor climate with relatively still air, wind effects were not studied.

METHODS

Different types of indoor clothing ensembles were selected so as to include garments worn by men and/or women, variations in the amount of body surface area covered, the number of fabric layers on different parts of the body, the looseness or tightness of fit, the type of garments worn (i.e., coverall, pajamas, lab coat, sweat suit, etc.), the range of the insulation values, seasonal differences, and the thickness and air permeability of the component fabrics. Clothing designed to protect people from hazards (e.g., chemicals) and/or extreme environments was not included. As a result, 24 different types of indoor conventional clothing ensembles were selected for study. Two samples of each garment were purchased—one for testing on the manikin and one to cut into specimens for textile testing.

To determine the insulation value of the clothing ensembles, manikin tests were conducted in an environmental chamber according to ASTM F 1291-90 (ASTM 1991). The air temperature in the chamber was 22 ± .5°C, the air velocity was less than 0.15 m/s, and relative humidity was 50 ± 3%. The mean skin temperature of the manikin was maintained at 33.2 ± .5°C. To determine the maximum change in clothing insulation during body motion, a walking activity which made all four limbs move was used. The difference in the insulation value between walking at 90 steps/min. and not walking at all (i.e., standing) was compared. In addition, four different walking speeds--30 steps/min. (1.23 km/h); 50 steps/min. (2.06 km/h); 70 steps/min. (2.88 km/h); 90 steps/min. (3.70 km/h)--were used with three representative ensembles to evaluate the effect of walking speed on the insulation value.

For an empirical prediction of the change in the insulation value of indoor clothing due to walking, selected physical characteristics of textiles and clothing that could affect the insulation value of clothing were measured. **Textile variables** measured according to ASTM standards (ASTM 1991) included fabric thickness (THICK, mm), weight (WEIGHT, g/m^2), air permeability (AIRPERM, $cm^3/cm^2 \cdot s$), stiffness (STIFF, mg·cm), and insulation value (FABRICIN, $m^2 \cdot {}^\circ C/W$). The outer most layer of each ensemble was area weighted and used for the prediction. **Clothing variables** included the amount of body surface area covered by the clothing (TOTBSAC, %), ensemble weight without shoes (ENWEIGHT, g), the area of the garment openings (OPENINGS, cm^2), and air volume enclosed in the clothing ensemble (AIRVOL, cm^3). To determine clothing coverage, the percent of each body segment covered by clothing was estimated and multiplied by the percent of total body surface area represented by the segment. The total amount of surface area covered by clothing was found by adding these percentages for all segments. Air volume was determined by measuring clothing circumferences at different locations on the body. The thickness of the air and fabric layers between the manikin and the outer most garment layer was determined by subtracting the nude body radius from the outer most clothing radius. Data from 10 cylinders representing the head, chest, back, upper arm, lower arm, hand, abdomen/buttocks, thigh, calf, and foot were summed to determine the volume. The area of the most common garment openings--neck, arm, waist, bottom hemline--were determined by measuring the circumference of the most outer layer and the nude body (unless the inner layer of clothing fit tightly).

ANALYSIS AND RESULTS

Linear regression analyses and stepwise multiple regression analyses were conducted to predict the change in the insulation value due to walking from selected textile and clothing characteristics. Equations were developed for predicting the absolute change and percentage change in total insulation (I_T) and intrinsic clothing insulation (I_{cl}). The relationship of walking speed to the change in insulation for three ensembles was analyzed by regression also. The R^2 values and mean square error terms were compared to evaluate the predictability of the equations.

The results indicated that the stationary manikin insulation value explained 65% of the variance in the change insulation due to walking: Absolute change in I_{cl} = 0.394 x ICLSTAND + 0.002. The area weighted thickness and insulation value of the outer most layer of clothing each explained about half of the change in ensemble insulation. The stepwise regression developed models with the textile characteristics that explained up to 76% of the variance: Percent change in I_{cl} = (-593 x FABRICIN) + (0.0639 x AIRPERM) + (-0.0404 x STIFF) + (0.0722 x WEIGHT) + 45.170. The volume of air (and fiber) contained in an ensemble explained 83% of the variance in insulation due to walking: Absolute change in I_{cl} = 0.000004714 x AIRVOL + 0.0736. When the clothing variables were used in a stepwise regression, they explained 90% of the variance: Absolute change in I_{cl}: (0.00000245 x AIRVOL) + (0.0001620 x OPENINGS) + (0.00357 x TOTBSAC) - 0.194. Some combinations of textile and clothing variables explained up to 94% of the change in I_{cl} due to walking. When the effect of walking speed and the standing insulation value were combined, these variables accounted for 94% of the variance in clothing insulation: Absolute change in I_{cl} = (0.504 x ICLSTAND) + (0.00281 x WALKSPEED) - 0.240.

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