INSULATION VALUES FOR COLD WEATHER CLOTHING UNDER STATIC AND DYNAMIC CONDITIONS

Elizabeth A. McCullough and Chil Soon Kim

Institute for Environmental Research, Kansas State University,
Manhattan, KS 66506 USA

INTRODUCTION

Insulation values for indoor clothing that were measured with a stationary, standing manikin are available in the literature [1] and in ISO and ASHRAE standards [2,3]. Little data are available, however, for clothing ensembles designed for use in cold environments. In addition, the reduction in insulation during movement (i.e., dynamic or resultant insulation) has not been documented for a wide range of cold weather clothing [4]. Equations for predicting the decrease in insulation due to movement that were developed from a large data base of indoor clothing [5] are not valid for cold weather clothing because the outdoor garments have more fabric layers, thicker layers, and more body coverage.

The purpose of this study was 1) to develop a large, representative data base of static (standing) and dynamic (walking) clothing insulation values for different types of clothing designed for use in cold environments, 2) to determine the change in insulation due to walking, and 3) to develop regression equations for predicting static insulation and dynamic insulation from selected clothing variables. In addition, static insulation mas used to predict dynamic insulation directly.

MATERIALS AND METHODS

Thirty different clothing ensembles designed for use in cold environments were selected for study. These included ski wear, hunting gear, work clothing, functional garments, and "everyday" outdoor clothing for men and women. Some ensembles were tested with all of their closures secured; others were tested with selected zippers, drawstrings, etc. open to maximize pumping.

The number of garment layers were counted and their thicknesses were measured for four parts of the body: torso (i.e., chest and back), arms, thighs, and calves. Each garment was counted as one layer if it covered more than 80% of the body part. Garment layers were counted--not individual fabric layers. However, detachable coat and pant liners were counted as separate garment layers. Thickness (mm) was measured with a compressometer according to ASTM D 1777 [6] under a 7.6 cm diameter presser foot and very light pressure (0.117 kPa). The thicknesses of garments constructed with fiberfil or down were measured with a pendulum vernier height gauge under no pressure.

The insulation values for the clothing ensembles were measured with a thermal manikin in an environmental chamber according to ASTM F 1291 [6]. The air temperature was 14 C and the air velocity <0.15 m/s. The manikin had 18 body segments with independent measurement and control. Its surface area was 1.82 m^2, and its mean skin temperature was controlled at 33.2 C. When the standing manikin reached steady-state conditions, a stationary test was conducted for **30** minutes. After approximately 10 minutes of walking at 90 steps per minute, a 10 minute dynamic test was conducted.

Thus, total insulation (I,) was measured under both static and dynamic conditions. Intrinsic clothing insulation (I_{cl}) was determined by subtracting I, / f_{cl} from I, for each ensemble. The clothing area factor (f_{cl}) for each ensemble was estimated [1,2], and the resistance of the air layer around the nude manikin (I_a) was measured while he was standing (0.68 clo) and walking (0.49 clo). The percent change in insulation was obtained by dividing the absolute change in insulation by the static insulation value and multiplying by 100.

Step-wise multiple regression analyses were conducted to predict the static insulation value and dynamic insulation value from the number and thickness of garment layers on different parts of the body. Linear regression analyses were also used to predict the dynamic insulation value from the static insulation value. These regression equations are applicable to ensembles with static intrinsic clothing insulation values (I_{cl}) ranging from 1 to 4 clo and with ensemble weights without footwear ranging from about 1 to 4 kg.

RESULTS

According to this study, the total static insulation values for cold weather clothing ensembles ranged from 1.51 clo to 4.12 clo, and the intrinsic static insulation values ranged from 1.10 clo to 3.67 clo.

Dynamic insulation values for cold weather clothing were lower than the static insulation values due to an increase in convective heat transfer within the clothing systems during movement. The total dynamic insulation values ranged from 0.85 clo to 3.54 clo, whereas the intrinsic dynamic insulation ranged from 0.53 clo to 3.21 clo.

The decrease in total insulation due to walking at 90 steps/min varied from 14 to 46 %. The decrease in intrinsic insulation due to walking at 90 steps/min varied from 12 to 51%. In summary, cold weather clothing ensembles provided higher levels of static and dynamic insulation than indoor clothing ensembles [5]. However, the pumping effect or change in insulation due to walking was lower on average for cold weather clothing--probably because of fewer and smaller garment openings.

The number and thickness of garment layers on the arms and calves were good predictors of static insulation (R^2 = **0.87** for I_{cl}) and dynamic insulation (R^2 = **0.90** for I_{cl}). The arms and calves were better predictors than the chest and thighs because the number of layers varied more on these parts (e.g., exposed calves and covered thighs in a women's ensemble). Thus, people who are unable to use a thermal manikin can estimate the static insulation value by ICL-STATIC (clo) = **0.0198 x** Arm Thickness (mm) + **0.0149** x Calf Thickness (mm) + **0.191 x** Number of Garment Lagers on Arm + **0.242 x** Number of Garment Layers on Calf + **0.556** and dynamic insulation by ICL-DYNAMIC **(clo) = 0.0170 x** Arm Thickness (mm) + **0.0187 x** Calf Thickness (mm) + **0.101 x** Number of Garment Layers on Arm + **0.212 x** Number of Garment Layers on Calf + **0.317.** The regression equation for predicting dynamic insulation values from standing insulation values was excellent because it accounted for **95%** of the variance in dynamic insulation. Thus, people who do not have access to a movable manikin can estimate dynamic insulation values using the following equations: IT-DYNAMIC (clo) = **0.893 x** IT-STATIC (clo) - **0.393** or ICL-DYNAMIC (CLO) = **0.883 x** ICL-STATIC **(clo) - 0.290.**

Therefore, both the standing and dynamic insulation provided by cold weather clothing ensembles can be estimated with confidence from the number and thickness of garment layers on the arms and calves. No manikin **is** needed.

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