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Standard Practice for Determining the Temperature Ratings for Cold Weather Protective Clothing[1]

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INTRODUCTION

Manufacturers of cold weather protective clothing want consumers to be thermally comfortable when wearing their products. Therefore, they want to indicate the amount of warmth (that is, insulation) their products will provide to consumers at the point of sale. This is often expressed as a temperature rating on product labels and in product descriptions in catalogs. A temperature rating is commonly understood to mean the lowest air temperature at which the average adult person will have an acceptable level of thermal comfort when wearing the product. Although it is not always stated on labels or in catalogs, manufacturers are assuming that consumers will wear the appropriate amount of clothing with the cold weather garments.

Heated manikins can be used to measure the thermal resistance (insulation) and evaporative resistance of clothing ensembles in accordance with F 1291 and F 2370, respectively. The thermal insulation value of a cold weather protective ensemble can be used in heat loss models to estimate the thermal comfort of people in cold environments. This approach has already been used for sleeping bags (see EN 13537).

1. Scope

1.1 This standard practice covers the determination of the temperature rating of cold weather protective clothing ensembles. It involves measuring the insulation value of a clothing ensemble with a heated manikin in accordance with F 1291 and using a heat loss model to predict the lowest environmental temperature for comfort.

1.2 The predictive model used in this standard estimates the evaporative heat loss from a person wearing cold weather clothing as opposed to measuring the evaporative resistance on a sweating manikin. If a person is active and gets overheated in a cold environment, he/she can adjust the garments in order to dissipate excess heat.

1.3 The temperature ratings estimated by this standard practice are guidelines for thermal comfort that are designed to protect people from hypothermia when wearing cold weather protective garments. However, localized cooling, discomfort, and even frostbite could still occur at extremely low temperatures because clothing insulation is not evenly distributed over the body surface. In addition, some body parts (for example, ears, fingers, toes) have a high surface area relative to their mass, and consequently lose heat at a faster rate than other parts of the body.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F 1291 Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin

F 2370 Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin

2.2 *Other Standards:*[3]

EN 13537 Requirements for Sleeping Bags

ANSI/ASHRAE 55-2004 Thermal Environmental Conditions for Human Occupancy

[1] This practice is under the jurisdiction of ASTM Committee F23 on Personal Protective Clothing and Equipment and is the direct responsibility of Subcommittee F23.60 on Human Factors.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3. Terminology

3.1 *Definitions:*

3.1.1 *clo*, *n*—a unit of thermal resistance (insulation) equal to 0.155 K-m^2/W.

3.1.1.1 *Discussion*—The value of the clo was selected as roughly the insulation value of typical indoor clothing, which should keep a resting man (producing heat at the rate of 58 W/m^2) comfortable in an environment at 21°C, air movement 0.1 m/s.

3.1.2 *clothing ensemble*, *n*—a group of garments worn together on the body at the same time.

3.1.3 *temperature rating*, *n*—the lowest environmental temperature at which a person can remain thermally neutral while wearing a particular clothing ensemble.

3.1.4 *thermal comfort*, *n*—that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation (see ANSI/ASHRAE 55-2004).

3.1.5 *thermal insulation*, *n*—the resistance to dry heat transfer by way of conduction, convection, and radiation.

3.1.5.1 *Discussion*—the following insulation values can be determined with a thermal manikin using clo units:

I_a = thermal resistance (insulation) of the air layer on the surface of the nude manikin.
I_t = total thermal resistance (insulation) of the clothing and surface air layer around the manikin.
I_{cl} = intrinsic thermal resistance (insulation) of the clothing.

Total insulation values are measured directly with a manikin. Intrinsic clothing insulation values are determined by subtracting the air layer resistance around the clothed manikin from the total insulation value for the ensemble.

4. Significance and Use

4.1 This practice can be used to measure the insulation provided by different cold weather clothing systems using a heated manikin (see F 1291) and to predict the temperature rating for comfort using whole body heat loss models.

4.1.1 The temperature rating is for an ensemble—not an individual garment. However, manufacturers want to label cold weather garments with a temperature rating to help consumers select the product that will best meet their needs. Therefore, the standard is limited to garments that cover a substantial amount of body surface area such as jackets, coats, and insulated pants, coveralls, or snow suits. The temperature ratings of head wear, footwear, and hand wear cannot be determined with this practice.

4.1.2 The temperature predictions determined by this standard practice are for adults only. The physiology of children is significantly different from that of adults, so a modified heat loss model would need to be used to predict the comfort of children wearing outdoor clothing.

4.1.3 The temperature ratings determined by this standard practice and listed on garment labels are only guidelines for comfort and will be affected by the garments consumers wear with them, their activity level during wear, and individual differences in the physiological characteristics of people (for example, gender, age, body mass, etc.).

5. Calibration of Manikin

5.1 *Manikin*—Use a thermal manikin as described in F 1291.

5.2 *Calibration*—Calibrate the manikin using the procedures in F 1291.

5.2.1 The intrinsic clothing insulation value of the F 1291 calibration ensemble (I_{cl}) should be 0.79 clo, ±10 % before proceeding with this method.

6. Base Ensembles

6.1 Cold weather garments are worn with other garments as part of an ensemble. Therefore, they need to be tested that way on the manikin in order to determine the temperature for comfort. All cold weather jackets, coveralls, and jacket/pant sets (where the garments are designed to be worn together) shall be tested with a lightweight base ensemble that represents the minimum amount of clothing that a reasonable person might wear with the cold weather clothing (Base Ensemble #1). Cold weather pants shall be tested with a base jacket added to the base ensemble (Base Ensemble #2). The size of the garments shall be selected based on the measurements of the manikin.

6.2 The garments used in Base Ensemble #1 are:

6.2.1 *Shirt*—Long-sleeve mock turtle neck shirt, interlock knit, 100 % cotton, 214 g/m^2 (6.3 oz/yd^2); worn with shirttail over jeans.

6.2.2 *Jeans*—Denim 5-pocket jeans, 100 % cotton 397 g/m^2 (11.7 oz/yd^2).

6.2.3 *Men's Underwear Briefs*—Jersey knit briefs, 100 % cotton, 180 g/m^2 (5.3 oz/yd^2); jockey style that fits snugly at the waist and legs (from F 1291).

6.2.4 *Men's Socks*—Basic knit sock that covers foot and extends up the calf no more than 25.4 cm (10 in.) from the bottom of the heel. Socks must be composed of at least 75 % cotton and shall weigh 65 ± 10 g each (from F 1291).

6.2.5 *Athletic Shoes*—Fabric/soft leather and soft sole.

6.2.6 *Gloves or Mittens*—Insulated knitted fleece gloves or mittens, 100% polyester, all layers 454 g/m^2 (13.4 oz/yd^2); cuffs worn under jacket sleeves.

6.2.7 *Hat*—Knitted fleece hat, 100 % polyester 129 g/m^2 (3.8 oz/yd^2); worn pulled down to eye brows.

6.2.8 The intrinsic clothing insulation value (I_{cl}) of Base Ensemble #1 should be 0.80 clo, ±10 %.

6.2.8.1 The insulation value of the cold weather ensembles would be higher (and the predicted temperature ratings lower) if a thicker base ensemble was used. However, many people will not wear more clothing with the cold weather garments, and some people might not wear gloves, or a hat, or both. Consequently, this standard practice is specifying a lightweight base ensemble only. Other garments such as thermal underwear could be substituted for the knit shirt and jeans as long as the intrinsic insulation value is 0.80 clo, ±10 % and the head, hands, and feet are covered in the same way.

6.3 The garments used in Base Ensemble #2 are:

6.3.1 All of the garments in Base Ensemble #1.

6.3.2 A quilted fiberfill jacket, 100 % nylon shell and lining, 100 % polyester fiberfill insulation, all layers 339 g/m^2 (10.0 oz/yd^2). The stow-away hood shall not be placed on the head during the test; it should stay stowed in the collar.

6.3.3 The intrinsic clothing insulation value (I_{cl}) of Base Ensemble #2 should be 1.35 clo, ±10 %.

7. Sampling and Test Specimens

7.1 *Sampling*—It is acceptable to test one sample (that is, specimen) of each garment type. However, there may be variability in garments made of fiberfill or down insulations, so it is recommended to test two or three specimens and average their insulation values prior to modeling.

7.2 *Specimen Size and Fit*—Select the size of garments that will fit the manikin appropriately (that is, the way the manufacturer designed them to be worn on the human body during their intended end use).

8. Manikin Procedure

8.1 *Environmental Test Conditions*—The test conditions given below shall be standard for all tests unless otherwise stated.

8.1.1 *Air Temperature*—The air temperature shall be 5 to 20°C during a test. The air temperature shall be selected within that range so that a minimum heat flux of 20 W/m^2 from the manikin's segments is maintained and a skin temperature of 35°C on each segment is maintained. A temperature at the high end of the range will be needed for the nude test and the base ensemble test. An air temperature at the low end of the range will be needed for heavy cold weather ensembles.

8.1.2 *Air Velocity*—The air velocity shall be 0.4 ± 0.1 m/s during a test.

8.1.3 *Relative Humidity*—The relative humidity of the environment has little effect on measurements of insulation under steady-state conditions; therefore, it does not need to be controlled at a specific level. Relative humidity does have to be monitored to make sure that it does not change more than 4 % during a test.

8.2 *Mean Skin Temperature of Manikin*—The mean skin temperature shall be maintained at 35 ± 0.2°C during a 30 min test.

8.3 *Nude Test*—Measure the insulation (I_a) provided by the air layer surrounding the nude manikin by conducting a test using the same environmental conditions and procedures given for the cold weather ensemble tests (see 8.5).

8.4 *Base Ensemble Test*—Measure the total insulation (I_t) provided by Base Ensemble #1 (and Base Ensemble #2 if cold weather pants will be evaluated) by conducting a test using the same environmental conditions and procedures given for the cold weather ensemble tests (see 8.5).

8.5 *Cold Weather Ensemble Test*—Dress the standing manikin in Base Ensemble #1 or #2 and the cold weather garment (such as a jacket, coverall, or pants) or garments (such as a work jacket and pants set) to be tested. Garments with a hood should be tested with the hood drawn up over the hat and tightened around the face. Position the manikin so that it is hanging vertically a few inches off the floor with its arms at its sides.

8.5.1 Conduct the test in accordance with procedures given in F 1291.

8.5.2 *Replication of Tests*—Conduct three replications of the test, with at least 15 minutes in between test periods. If more than one sample is available of each garment type, test each separately one time.

9. Insulation Calculations

9.1 The parallel method of calculating the total thermal resistance (insulation) shall be used, where the area-weighted temperatures of all body segments are summed and averaged, the power levels to all body segments are summed, and the areas are summed before the total resistance is calculated. Calculate the total thermal insulation of the clothing system (I_t) to the nearest 0.01 clo, using Eq 1: (6.45 is a units constant)

$$I_t = (T_s - T_a)\, A \cdot 6.45 / H \quad (1)$$

where:

I_t = total thermal resistance (insulation) of the clothing ensemble and surface air layer (clo),
A = area of the manikin's surface (m^2),
T_s = temperature at the manikin surface (°C),
T_a = temperature in the air flowing over the clothing (°C), and
H = power required to heat manikin (W).

9.2 Determine the average total insulation value (I_t) of the ensemble by averaging the values from the three replications of the test.

9.3 Determine the average intrinsic insulation value of the clothing alone (I_{cl}) to the nearest 0.01 clo, using the mean I_t value and Eq 2:

$$I_{cl} = I_t - (I_a/f_{cl}) \quad (2)$$

where:

I_{cl} = intrinsic clothing insulation (clo),
I_t = total thermal resistance (insulation) of the clothing ensemble and surface air layer (clo),
I_a = thermal resistance of the air layer on the surface of the nude manikin (clo), and
f_{cl} = clothing area factor (dimensionless).

9.3.1 Use the value of 1.25 for the f_{cl} of Base Ensemble #1.

9.3.2 Use the value of 1.30 for the f_{cl} of Base Ensemble #2.

9.3.3 Use the value of 1.35 for the f_{cl} of cold weather clothing ensembles. The f_{cl} value for each ensemble can be estimated using a photographic method, but it is very time consuming. Therefore, an average value for cold weather clothing ensembles is used here.

9.4 Calculate the standardized total insulation value ($I_{t,s}$) of the cold weather clothing ensembles to the nearest 0.01 clo, using a standard air layer resistance of 0.5 clo in Eq 3:

$$I_{t,s} = I_{cl} + (I_{a,s} / f_{cl}) \quad (3)$$

where:

I_{cl} = intrinsic clothing insulation (clo),
$I_{t,s}$ = standardized total thermal resistance (insulation) of the clothing ensemble and surface air layer (clo),
$I_{a,s}$ = standard thermal resistance of the air layer on the surface of the nude manikin, 0.5 clo, and
f_{cl} = clothing area factor (dimensionless).