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Standard Test Method for Measuring the Thermal Insulation of Clothing Items Using Heated Manikin Body Forms[1]

This standard is issued under the fixed designation F3426; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

The type of clothing worn by people directly affects the heat exchange between the human body and the environment. The heat transfer is both sensible (conduction, convection, and radiation) and latent (evaporation). The thermal resistance (insulation) and evaporative resistance provided by a clothing ensemble are measured on full-body, life-size manikins according to Test Methods F1291 and F2370, respectively. These standards also discuss measuring the local total resistance values of garments by using only a few body parts (zones) covered by the clothing. However, more detailed data can be obtained from a body part manikin with several zones than from a full-body manikin where only one or two zones are used to take measurements. This detailed information about extremities is important, as they are often vulnerable to thermal injury. The resistance values measured are dependent upon the designs and materials used in the component garments, the amount of body surface area covered by clothing, distribution of the fabric layers over the body, looseness or tightness of fit, and the increased surface area for heat loss. Insulation measurements made on fabrics alone do not take these factors into account.

1. Scope

1.1 This test method covers the determination of the insulation value of clothing items that cover only the head (Option 1), a hand (Option 2), or a foot (Option 3). It describes the measurement of the resistance to dry heat transfer from a heated manikin form to a relatively calm, cool environment.

1.1.1 This is a static test that provides a baseline clothing measurement on a stationary head manikin form (Option 1), hand manikin form (Option 2), or foot manikin form (Option 3).

1.1.2 The effects of body form position, movement, and contact with other surfaces are not addressed in this test method.

1.2 The insulation values obtained apply only to the particular clothing item evaluated and for the specified environmental conditions of each test, particularly with respect to air movement.

1.3 The values stated in either clo or SI units are to be regarded separately as standard. Each system shall be used independently of the other. The thermal resistance units, clo or SI, shall be identified clearly and consistency of units shall be maintained throughout reporting process.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F1291 Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin

F2370 Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin

[1] This test method 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.

2.2 *ASHRAE Standard:*[3]

ASHRAE 55 Thermal Environmental Conditions for Human Occupancy

2.3 *ISO Standard:*[4]

ISO 9920 Ergonomics of the Thermal Environment—Estimation of the Thermal Insulation and Evaporation Resistance of a Clothing Ensemble

3. Terminology

3.1 *Definitions:*

3.1.1 *clo, n*—unit of thermal resistance defined as the insulation required to 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, or roughly the insulation value of typical indoor clothing.

3.1.1.1 *Discussion*—Numerically, one clo is equal to 0.155 °C·m^2/W.

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

3.1.3 *clothing item, n*—a garment or product worn as part of the clothing ensemble or separately.

3.1.3.1 *Discussion*—This standard only addresses clothing items worn on the head, a hand, or a foot. However, this is not limited to a single item. For example, some handwear systems consist of multiple gloves, mittens, or both, and may be evaluated using this test method.

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

3.1.4.1 *Discussion*—The following insulation values can be determined in this method:

R_a = thermal resistance (insulation) of the air layer on the surface of the nude manikin body form,

R_t = total thermal resistance (insulation) of the clothing item and surface air layer around the manikin body form, and

R_{cl} = intrinsic thermal resistance (insulation) of the clothing item.

R_a, R_t, and R_{cl} are typically used for SI units while I_a, I_t, and I_{cl} are typically used with clo units.

4. Significance and Use

4.1 This test method can be used to quantify and compare the insulation provided by different clothing items as long as each test is conducted using the same experimental procedures and test conditions. For example, variations in the design and fabric used in gloves can be evaluated. The effects of layering, closures, and fit can be measured for clothing items.

4.2 The measurement of the insulation provided by clothing is complex and dependent upon the apparatus and techniques used. It is not practical in a test method of this scope to establish details sufficient to cover all contingencies. Departures from the instructions in this test method have the potential to lead to significantly different test results. Technical knowledge concerning the theory of heat transfer, temperature, humidity and air motion measurement, and testing practices is needed to evaluate which departures from the instructions given in this test method are significant. Standardization of the method reduces, but does not eliminate, the need for such technical knowledge. Report any departures with the results.

4.3 Report the insulation values in SI units or clo units as standard procedure.

5. Apparatus

5.1 *Manikin Body Forms:*

5.1.1 *Option 1 – Head Manikin:*

5.1.1.1 *Manikin*—Use a manikin head form that is the size and shape of an adult human and heated to a constant, average surface temperature.

5.1.1.2 *Size and Shape*—The manikin head shall be constructed to simulate the head of a human being; that is, it shall consist of a head, chin, and nose. Ear protrusions are not required. Total surface area shall be 0.134 m^2 ± 15 %.

5.1.1.3 *Manikin Zones*—Construct the manikin head form with no less than four independent temperature-controlled zones. At a minimum the top of the head, the back of the head, the eye/forehead area, and the mouth area shall be independent zones.

5.1.1.4 *Guard Zone*—Construct the manikin head form with a guard zone butting up against the terminus of the head/neck (where the head form would connect to the rest of a body if it were a full-body manikin). Heat this zone to the same constant temperature as all other zones to prevent unwanted heat loss from the manikin head form into the apparatus or environment. This zone shall not be included as one of the four required manikin zones.

5.1.2 *Option 2 – Hand Manikin:*

5.1.2.1 *Manikin*—Use a hand manikin form that is the size and shape of an adult human's left or right hand and heated to a constant, average surface temperature.

5.1.2.2 *Size and Shape*—The hand manikin shall be constructed to simulate the hand and wrist/forearm of an adult human being; that is, it shall consist of a wrist/forearm, palm and back of hand, four finger digits, and a thumb digit with fingers extended to allow gloves to be worn. Total surface area of form shall be 0.069 m^2 ± 15 %.

NOTE 1—Based on the specified manikin dimensions, use appropriately sized glove specimens approximately size 8 to 10 (medium to large).

5.1.2.3 *Manikin Zones*—Construct the manikin hand form with no less than four independent temperature-controlled zones. At a minimum the palm, the fingers, the back of the hand, and the wrist shall be independent zones.

5.1.2.4 *Guard Zone*—Construct the manikin hand form with a guard zone butting up against the terminus of the wrist/forearm (where the hand form would connect to the rest of a body if it were a full-body manikin). Heat this zone to the same constant temperature as all other zones to prevent unwanted heat loss from the manikin hand form into the apparatus or

[3] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329, http://www.ashrae.org.

[4] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

environment. This zone shall not be included as one of the four required manikin zones.

5.1.3 *Option 3 – Foot Manikin:*

5.1.3.1 *Manikin*—Use a foot manikin form that is the size and shape of an adult human's left or right foot and heated to a constant, average surface temperature.

5.1.3.2 *Size and Shape*—The foot manikin shall be constructed to simulate the foot and ankle/lower leg of an adult human being; that is, it shall consist of an ankle/lower leg and an approximate foot form. The foot must have an overall shape that is representative of a human foot; however, it is not necessary for the manikin to have individual toe digits. Total surface area of the foot form shall be 0.096 m^2 ± 15 %.

NOTE 2—Based on the specified manikin dimensions, use appropriately sized shoe specimens approximately size US 9M to US 10.5M (EU 43 to 44).

5.1.3.3 *Manikin Zones*—Construct the manikin foot form with no less than four independent temperature-controlled zones. At a minimum the bottom of the foot, the toes, the top of the foot, and the ankle/leg area shall be independent zones.

5.1.3.4 *Guard Zone*—Construct the manikin foot form with a guard zone butting up against the terminus of the lower leg (where the foot form would connect to the rest of a body if it were a full-body manikin). Heat this zone to the same constant temperature as all other zones to prevent unwanted heat loss from the manikin hand form into the apparatus or environment. This zone shall not be included as one of the four required manikin zones.

5.2 *Surface Temperature*—The manikin body form shall be constructed so as to maintain a uniform temperature distribution over the nude body surface, with no local hot or cold spots. The mean surface (skin) temperature of the manikin body form shall be 35 °C. Local deviations from the mean skin temperature shall not exceed ±0.3 °C. Temperature uniformity of the nude manikin body form shall be evaluated at least once annually or after repairs or alterations are completed that could affect temperature uniformity, for example, replacement of a heating element. Due to variation in manikin body part forms, consulting with the manikin manufacturer for an appropriate method is recommended.

5.3 *Power Measuring Instruments*—Power to the manikin form shall be measured so as to give an average over the period of a test. If time proportioning or phase proportioning is used for power control, then devices that are capable of averaging over the control cycle are required. Integrating devices (watt-hour meters) are preferred over instantaneous devices (watt meters). Overall accuracy of the power monitoring equipment must be within ±2 % of the reading for the average power for the test period. Since there are a variety of devices and techniques used for power measurement, no specified calibration procedures shall be given. However, an appropriate power calibration procedure is to be developed and documented.

5.4 *Equipment for Measuring the Manikin's Surface (Skin) Temperature*—The mean surface temperature shall be measured with point sensors or distributed temperature sensors.

5.4.1 *Point Sensors*—Point sensors shall be thermocouples, resistance temperature devices (RTDs), thermistors, or equivalent sensors. They shall be no more than 2 mm thick and shall be well bonded, both mechanically and thermally, to the manikin's body form surface. Lead wires shall be bonded to the surface or pass through the interior of the manikin, or both. Each sensor temperature shall be area-weighted when calculating the mean surface temperature for the body form. If point sensors are used, apply at least one point sensor in each zone of the manikin body form.

5.4.2 *Distributed Sensors*—If distributed sensors are used (for example, resistance wire), then the sensors must be distributed over the surface so that all areas are equally weighted. If several such sensors are used to measure the temperature of different zones of the manikin, then their respective temperatures shall be area-weighted when calculating the mean surface temperature. Distributed sensors shall be less than 1 mm in diameter and firmly attached to the manikin surface at all points.

5.5 *Controlled Environmental Chamber*—The manikin shall be placed in a chamber that can provide uniform conditions, both spatially and temporally.

5.5.1 *Spatial Variations*—Spatial variations shall not exceed the following: air temperature ±1.0 °C, relative humidity ±5 %, and air velocity ±50 % of the mean value. In addition, the mean radiant temperature shall not be more than 1.0 °C different from the mean air temperature. The spatial uniformity shall be verified at least annually or after any significant modifications are made to the chamber. Spatial uniformity shall be verified by recording values for the conditions stated above at two distinct heights. Take the measurements, at the two locations occupied by the manikin form, 50 mm ± 10 mm below the top of the manikin form and 50 mm ± 10 mm above the bottom of the manikin form.

5.5.2 *Temporal Variations*—Temporal variations shall not exceed the following: air temperature ±0.5 °C, mean radiant temperature ±0.5 °C, relative humidity ±5 %, air velocity ±25 % of the mean value for data averaged over 5 min (see 5.5.5).

5.5.3 *Relative Humidity Measuring Equipment*—Any humidity sensing device with an accuracy of ±5 % relative humidity and a repeatability of ±3 % is acceptable (for example, wet bulb/dry bulb, dew point hygrometer). Only one location needs to be monitored during a test to ensure that the temporal uniformity requirements are met.

5.5.4 *Air Temperature Sensors*—Shielded air temperature sensors shall be used. Any sensor with an overall accuracy of ±0.15 °C is acceptable (for example, RTD, thermocouple, thermistor). The sensor shall have a time constant not exceeding 1 min. The sensor(s) shall be 0.2 m ± 0.05 m in front of the manikin's closest undressed point. If a single sensor is used, it shall be vertically aligned with the center of the manikin. If multiple sensors are used, they shall be spaced at equal intervals apart from one another and their readings averaged.

5.5.5 *Air Velocity Indicator*—An omnidirectional anemometer with ±0.05 m⁄s accuracy shall be used. Measurements shall be averaged for at least 1 min at each location. If it is demonstrated that velocity does not vary temporally by more than ±0.05 m⁄s, then it is not necessary to monitor air velocity during a test. However, the value of the mean air velocity must

be reported. If air velocity is monitored, then measurement location requirements are the same as for temperature.

6. Sampling, Test Specimens, and Test Units

6.1 *Sampling*—It is desirable to test three identical clothing items to reflect sample variability. However, if only one clothing item is available (that is often the case with prototype products), take replicate measurements on the single clothing item.

6.2 *Specimen Size and Fit*—Select the size of clothing item that will fit the manikin form appropriately (that is, the way the manufacturer designed it to be worn during its intended end use). For example, some gloves (surgical) are designed to fit the hand relatively tightly. Others are designed to fit loosely to accommodate stiffer materials. In a stationary manikin test, large air layers in the clothing items will contribute to a higher insulation value than small air layers. Therefore, clothing items that do not have the appropriate fit on the body forms (that is, are too tight or too loose) will cause errors in measurement.

6.2.1 When manikin body part forms are used to compare materials used in certain clothing items, those clothing items must be made from the same pattern so that design and fit variables are held constant.

6.2.2 When manikin body part forms are used to compare a variety of clothing items, test the same size clothing item of a given type as indicated by the size label in the clothing item (for example, large). However, if it is determined that the fit of a clothing item is inappropriate, use another size and state the difference in the report.

6.3 *Specimen Preparation*—Clothing items shall be tested in the as-received condition or after dry cleaning or laundering in accordance with the manufacturer's instructions. The cleaning procedures and number of cleanings shall be stated in the report.

6.4 *Conditioning*—Allow the clothing items to come to equilibrium with the test atmosphere in the test chamber by conditioning them for at least 12 h prior to testing.

7. Procedure

7.1 *Environmental Test Conditions*—The test conditions given below shall be standard for all tests.

7.1.1 *Air Temperature*—The air temperature shall be at least 12 °C lower than the manikin's mean temperature (that is, $T_a \leq$ 23 °C) during a test. When ensemble elements with high insulation values are tested (for example, winter boots), the air temperature shall be lowered so that a minimum heat flux of 20 W/m^2 from the manikin's segments is maintained.

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

7.1.3 *Relative Humidity*—Select a level between 30 % and 70 % relative humidity ±5 %, preferably 50 %. The relative humidity has no significant effect on measurements of insulation under steady-state conditions.

7.1.4 If it is necessary to test the clothing item in different environmental conditions (air temperature, air velocity, or relative humidity), the conditions must be clearly defined and reported.

7.2 *Mean Surface (Skin) Temperature of Manikin*—The manikin's surface temperature shall be maintained at 35 °C ± 0.5 °C for all tests. The mean surface temperature shall not be allowed to drift more than ±0.2 °C during a 30-min test.

7.3 *Manikin Posturing*—The manikin shall be set in a fixed location and remain stationary throughout the test.

7.3.1 For Option 1, the manikin head shall be upright with nose facing windward and the back of the neck leeward.

7.3.2 For Option 2, the hand manikin shall be set upright (fingers skyward) with palm facing windward and back of hand leeward.

7.3.3 For Option 3, the manikin shall be set upright (foot above the floor) with toes facing windward and heel leeward.

7.4 Dress the manikin body form in the clothing items to be tested. Record a description of the clothing item and the dressing procedures. Take a photograph of the clothing item on the manikin body form for the report.

7.4.1 For Option 1, dress the manikin head with headgear as it would be worn in use.

7.4.2 For Option 2, dress the manikin hand with the handwear as it would be worn in use. Ensure that the material between the interspace between fingers is pushed down as far as possible. If handwear includes any straps or lacings, ensure they are tightened consistently between clothing items.

7.4.2.1 In some cases, handwear requires alterations (cutting) to get them to fit on to the hand form. If this is required, it is necessary to make every attempt to put the handwear back together after it placed on the hand form. This information must also be identified in the report.

7.4.3 For Option 3, dress the manikin foot with footwear as it would be worn in use. If footwear includes any straps or lacings, ensure they are tightened consistently between clothing items.

7.4.3.1 In some cases, footwear requires alterations (cutting) to get them to fit properly on the foot form. If this is required, it is necessary to make every attempt to put the footwear back together after it placed on the foot form. This information must also be identified in the report.

7.4.3.2 For this testing standard, ensure that there is at least 10 mm air space between the bottom of the footwear and nearest surface.

7.5 Bring the dressed manikin body form to 35 °C ± 0.5 °C and allow the system to reach steady state (that is, the mean surface temperature of the manikin and the power input remain constant ±3 %).

7.5.1 After the clothing item reaches equilibrium conditions, record the manikin's surface temperatures, the air temperature, and the heater wattage (power) every 1 min. The average of these measurements taken over a period of 30 min will be sufficient to determine the insulation value. Heater wattage (power) shall be measured every 1 min or continuously over the test period also.

7.6 *Replication of Tests*—Conduct three independent replications of the clothing item. If only one clothing item is available for testing, remove it from the manikin form and then put it back on the manikin body form between each replication