Designation: F 1291 – 99

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

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INTRODUCTION

The type of clothing worn by people directly affects the heat exchange between the human body and the environment. The insulation provided by a clothing ensemble is dependent upon the designs and fabrics 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. Measurements of the resistance to dry heat loss provided by clothing can be used to determine the thermal comfort or stress of people in cold to comfortable environments. However, the moisture permeability of clothing is more important in environmental conditions where heat balance can only be achieved by the evaporation of sweat.

1. Scope

1.1 This test method covers determination of the insulation value of a single garment or a clothing ensemble. It describes measurement of the resistance to dry heat transfer from a constant skin temperature manikin (with a human skin temperature pattern) to a relatively calm, cool environment.

1.1.1 This is a static test that provides a baseline clothing measurement on a standing manikin.

1.1.2 The effects of body position and movement are not addressed in this test method.

1.2 The insulation values obtained apply only to the particular garments, as tested, and for the specified thermal and environmental conditions of each test, particularly with respect to air movement, are not addressed in this test method.

1.2.1 The insulation values obtained apply only to the particular ensembles evaluated and for the specified thermal and environmental conditions of each test, particularly with respect to air movement past the manikin.

1.3 The values stated in either clo or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the test method.

2. Referenced Documents

2.1 *ASTM Standards:*

D 123 Terminology Relating to Textiles[2]

D 1518 Test Method for Thermal Transmittance of Textile Material[2]

2.2 *ASHRAE Standards:*

ASHRAE 55-1981 Thermal Environmental Conditions for Human Occupancy[3]

Handbook of Fundamentals, Chapter 8 on Physiological Principles, Comfort and Health[3]

2.3 *ISO Standards:*

ISO 7730 1994 Moderate Thermal Environments—Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort[4]

ISO 9920 1995 Ergonomics of the Thermal Environment—Estimation of the Thermal Insulation and Evaporation Resistance of a Clothing Ensemble[4]

3. Terminology

3.1 *Definitions:*

[1] This test method is under the jurisdiction of ASTM Committee F-23 on Protective Clothing and is the direct responsibility of Subcommittee F23.60 on Human Factors.

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[2] *Annual Book of ASTM Standards*, Vol 07.01.

[3] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1791 Tullie Circle, N.E. Atlanta, GA 30329.

[4] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

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 *total clo, n*—clo plus the thermal resistance from the air boundary layer, (clo$_t$).

3.1.1.2 *Discussion*—Numerically, one clo is equal to 0.155 K 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 *garment*, *n*—a single item of clothing (for example, shirt).

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

3.1.5 *total insulation* (I_T), *n*—the total resistance to dry heat loss from the manikin, that includes the resistance provided by the clothing and the air layer around the clothed manikin.

3.1.5.1 *Discussion*—Total insulation (I_T) values are measured directly with a manikin. They can be used to compare different clothing ensembles as long as each test is conducted using the same experimental procedures and test conditions. Intrinsic clothing insulation values (I_{cl}) are determined by subtracting the air layer resistance around the clothed manikin from the I_T value for the ensemble. Intrinsic clothing insulation (I_{cl}) values are used in several thermal comfort and clothing standards (see 2.2 and 2.3). Information on determining I_{cl} from measured I_T values is given in ISO Standard 9920 and ASHRAE Transactions.[5]

4. Significance and Use

4.1 This test method can be used to quantify and compare the insulation provided by different garments and clothing systems. For example, variations in the design and fabric used in garments can be evaluated. The effects of garment layering, closure, and fit can be measured for clothing ensembles. The insulation values for ensembles can be used in models that predict the physiological responses of people in different environmental conditions.

4.2 The measurement of the insulation provided by clothing is complex and dependent on 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 may lead to significantly different test results. Technical knowledge concerning the theory of heat transfer, temperature, 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. Any departures should be reported with the results.

4.3 The insulation values should be reported in clo units and SI units as standard procedure. Conversion factors to other units are given in Test Method D 1518.

5. Apparatus

5.1 *Manikin*[6]—A standing manikin shall be used that is formed in the shape and size of an adult male or female and heated to a constant, average skin temperature, with a skin temperature distribution similar to that of a human being.

5.1.1 *Size and Shape*—The manikin shall be constructed to simulate the body of a human being; that is, it shall consist of a head, chest/back, abdomen/buttocks, arms, hands (preferably with fingers extended to allow gloves to be worn), legs, and feet. Total surface area shall be 1.8 ± 0.3 m^2, and height shall be 180 ± 10 cm. The manikin's dimensions should correspond to those required for standard sizes of garments because deviations in fit will affect the results.

5.1.2 *Surface Temperature*—The manikin shall be constructed so as to maintain a constant temperature distribution over the nude body surface, with no local hot or cold spots. The mean skin temperature of the manikin shall be between 32 and 35°C (89.6 and 95°F). It is recommended that the average temperature of the hands and feet be lower in studies of clothing for cold or comfortable conditions. Local deviations from the mean skin temperature shall not exceed ± 3°C. Temperature uniformity of the nude manikin shall be evaluated at least once annually using an infrared thermal imaging system or equivalent method. This procedure should also be repeated after repairs or alterations are completed that could affect temperature uniformity, for example, replacement of a heating element.

5.2 *Power-Measuring Instruments*—Power to the manikin shall be measured so as to give an accurate 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.

5.3 *Equipment for Measuring the Manikin's Skin Temperature*—The mean skin temperature may be measured with point sensors or distributed temperature sensors.

5.3.1 *Point Sensors*—Point sensors may be thermocouples, resistance temperature devices (RTD's), thermistors, or equivalent sensors. They shall be no more than 3 mm thick and shall be well bonded, both mechanically and thermally, to the manikin's surface. Lead wires shall be bonded to the surface or pass through the interior of the manikin, or both. The sensors shall be distributed so that each one represents the same surface area or each sensor temperature should be area-weighted when calculating the mean skin temperature for the body. A minimum of 15 point sensors are required. It is recommended that

[5] McCullough, E. A., Jones, B. W., and Huck, J., *ASHRAE Transactions*, Vol 91, Part 2, 1985, pp. 29–47.

[6] Information on laboratories with heated manikins can be obtained from the Institute for Environmental Research, Kansas State University, Manhattan, KS 66506.

a sensor be placed on the head, chest, back, abdomen, buttocks, and both the right and left upper arm, lower arm, hand, thigh, calf, and foot.

5.3.2 *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 parts of the body, then their respective temperatures should be area-weighted when calculating the mean skin temperature. Distributed sensors must be small in diameter (that is, less than 1 mm) and firmly bonded to the manikin surface at all points.

5.4 *Controlled Environmental Chamber*— The manikin shall be placed in a chamber at least 2 by 2 m in dimension that can provide uniform conditions, both spatially and temporally.

5.4.1 *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 heights of 0.1, 0.6, 1.1, 1.4, and 1.7 m above the floor at the location occupied by the manikin. Sensing devices specified below shall be used when measuring the environmental conditions.

5.4.2 *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 ± 20 % of the mean value for data averaged over 5 min. (see 5.4.5.).

5.4.3 *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.

5.4.4 *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 0.5 m in front of the manikin. If a single sensor is used it shall be 1.0 m above the floor. If multiple sensors are used, they shall be spaced at equal height intervals and their readings averaged.

5.4.5 *Air Velocity Indicator*—An omni-directional 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. The value of the mean air velocity must be reported, however. If air velocity is monitored, then measurement location requirements are the same as for temperature.

6. Sampling, Test Specimens, and Test Units

6.1 It is desirable to test three identical garments or sets of garments to reflect sample variability. However, if only one is available (that is often the case with prototype garments), replicate measurements can be made on one garment or ensemble.

7. Preparation of Test Garments

7.1 Select the size of garments that fit the manikin properly; otherwise, alter the garments to achieve the fit needed.

7.2 Garments may be tested in the as-received condition or after dry cleaning or laundering in accordance with the manufacturer's instructions.

7.2.1 Dry cleaning or laundering may affect the results of the test. If garments are tested after cleaning, the specific care method and number of times repeated should be reported.

7.3 *Control Ensemble*—Assemble and retain a "control" ensemble for use in verifying that the manikin system is functioning correctly. The garments recommended for use in this control ensemble are:

7.3.1 *Trousers*—65 % polyester, 35 % cotton; durable press, 2 by 1 twill weave; 279.7 g/m^2 (8.25 oz/yd^2); two front pockets, and 2 hip pockets.

7.3.2 *Long-Sleeve Shirt*—65 % polyester, 35 % cotton; durable press, poplin weave; 144 g/m^2 (4.25 oz/yd^2); 2 front pockets.

7.3.3 *Men's Underwear Briefs*—100 % cotton jersey knit; jockey style that fits snugly at the waist and legs.

7.3.4 *Men's Calf Length Socks*—80 % cotton, 20 % nylon with spandex in top; jersey and rib knit.

7.3.5 *Men's Tennis or Athletic Shoes*— Fabric/soft leather and soft sole.

7.3.6 *Men's Belt*—Leather or vinyl, 25 mm (1 in. wide).

7.3.7 The insulation provided by this ensemble should be measured at least every 60 days. It is recommended that the control ensemble be measured at the beginning of each series of tests. The control ensemble should be tested in a standard set of environmental conditions (such as, air temperature, 20°C; relative humidity, 50 %; air velocity, 0.15 m/s).

8. Procedure

8.1 *Environmental Test Conditions*— The test conditions given below shall be standard for all tests. Other conditions are specified under Option 1 and Option 2.

8.1.1 *Air Velocity*—An air speed appropriate for the intended end-use of the clothing should be selected. A low air velocity less than or equal to 0.15 m/s (that is, natural convection) will produce the best interlaboratory agreement.

8.1.2 *Relative Humidity*—Select a level between 30 and 70 % relative humidity ±5 %, preferably 50 %.

8.2 *Mean Skin Temperature of Manikin*— Select an average temperature between 32 and 35°C and maintain it within± 0.3°C for all tests conducted in a series. The mean skin temperature shall not be allowed to drift more than ± 0.1°C during a 30 min test.

8.3 *Options*—Select one of the following procedures.

8.3.1 *Option 1*—Select one air temperature for the chamber that is at least 10°C below the manikin's mean skin temperature and use that temperature for a series of tests. The power that it takes to keep the manikin heated to a constant, higher temperature will vary with the amount of insulation provided by the clothing being tested.

8.3.2 *Option 2*—Select a watt level that corresponds to the sensible heat lost from a standing human being the size of the manikin. A person produces about 60 W/m^2 of heat when standing, relaxed. Assuming that 25 % of this heat is lost through insensible perspiration and respiration, 44 W/m^2 is left to be lost through the skin (see 2.2). Consequently, a manikin with a surface area of 1.8 m^2 would be operating at a 79 W level. Adjust the air temperature in the chamber until the proper watt level is achieved± 10 W.

8.3.2.1 Option 2 is a more time-consuming procedure than Option 1 and depends upon the speed with which the chamber can change conditions.

8.4 Dress the standing manikin in the garment(s) to be tested. Record a description of the garment(s) and the dressing procedures. (Is the shirt tail tucked in? Are any buttons left unfastened?) Position the manikin so that it is standing with its arms hanging straight at its sides.

8.4.1 Bring the dressed manikin to the selected skin temperature and allow the system to reach steady-state (that is, the mean skin temperature of the manikin and the power input remain constant ± 3 %).

8.4.2 After the ensemble reaches equilibrium conditions, record the manikin's skin temperatures and the air temperature at least every 10 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 5 min or continuously over the test period.

8.5 *Replication of Tests*—Three independent replications of the clothing test shall be conducted. If only one garment or set of garments is being tested, they should be removed and put back on the manikin for another test. In this way, normal variations in dressing and instrumentation will be taken into account.

8.6 *Nude Test*—Measure the insulation provided by the air layer surrounding the nude manikin by conducting a test in a standard set of environmental conditions (such as, air temperature, 20°C; relative humidity, 50 %; air velocity, 0.15 m/s). The insulation provided by the air layer should be measured at least once every 60 days. It is recommended that the nude manikin be tested at the beginning of each series of clothing tests.

9. Calculations

9.1 Calculate the total thermal insulation of the clothing system, including the air layer resistance (I_T), using Eq 1:

$$I_T = \frac{K(T_s - T_a)A_s}{P} \quad (1)$$

where:

I_T = total thermal insulation, W/m^2 (clo),
K = unit constant (6.45 clo),
T_s = mean skin temperature of manikin, °C,
T_a = air temperature, °C,
A_s = surface area of manikin, m^2, and
P = power supplied to the manikin, *W*.

9.1.1 Calculate the clo values to one or two significant digits, depending on the intended use of the data.

9.2 Calculate the average total thermal insulation for set of data.

10. Report

10.1 State that the specimens were tested as directed in (F 1291).

10.2 Report the following information:

10.2.1 Describe the garments(s) used and the type of sampling used.

10.2.2 Report the total insulation values for each sample set.

10.2.3 Specify the environmental test conditions and procedure option used.

10.2.4 Explain any departures from the specified apparatus or procedure.

11. Precision and Bias

11.1 *Precision*—In comparing three independent observations of the thermal insulation value (I_T), the variation should not exceed ± 4 % of the average of the three measurements when the measurements are taken by the same well-trained operator using the same testing equipment. Otherwise, additional replications must be conducted until this criterion is met.

11.2 *Bias*—The procedure in Test Method F 1291 for determining total thermal insulation has no bias because the value can be defined only in terms of a test method.

12. Keywords

12.1 protective clothing; thermal insulation