Designation: F1291 – 10

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

This standard is issued under the fixed designation F1291; 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 insulation provided by a clothing ensemble is 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. 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 (see ASHRAE 55-1992 and ISO 7730). 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 the determination of the insulation value of clothing ensembles. It describes the measurement of the resistance to dry heat transfer from a heated manikin 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 ensembles 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. Within the text, the SI units are shown in parentheses. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other.

1.4 The evaporative resistance of a clothing ensemble can be measured in accordance with Test Method F2370.

1.5 *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 consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1518 Test Method for Thermal Resistance of Batting Systems Using a Hot Plate

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

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

2.2 *ASHRAE Standards:*[3]

ASHRAE 55-1992 Thermal Environmental Conditions for Human Occupancy

2.3 *ISO Standards:*[4]

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

[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.

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

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

ISO 9920 1995 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 a heavy business suit. 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 *thermal insulation, n*—the resistance to dry heat transfer by way of conduction, convection, and radiation.

3.1.3.1 *Discussion*—the following insulation values can be determined in this method using SI units:

R_a = thermal resistance (insulation) of the air layer on the surface of the nude manikin.
R_t = total thermal resistance (insulation) of the clothing and surface air layer around the manikin.
R_{cl} = intrinsic thermal resistance (insulation) of the clothing.

When the measurements are expressed in clo units, the symbol *I* is used instead of *R*.

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. 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 are determined by subtracting the air layer resistance around the clothed manikin from the total insulation value for the ensemble. Intrinsic clothing insulation values are used in several thermal comfort and clothing standards (see 2.2 and 2.3).

4. Significance and Use

4.1 This test method can be used to quantify and compare the insulation provided by different clothing systems. For example, variations in the design and fabric used in component 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 have the potential to 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. Report any departures with the results.

4.3 Report the insulation values in SI units or clo units as standard procedure. Conversion factors to other units are given in Test Method D1518.

5. Apparatus

5.1 *Manikin*[5]—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.

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 170 ± 10 cm. The manikin's dimensions shall 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 35°C. Local deviations from the mean skin temperature shall not exceed ±0.3°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 shall 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 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 shall be measured with point sensors or distributed temperature sensors.

5.3.1 *Point Sensors*—Point sensors shall be thermocouples, resistance temperature devices (RTD's), 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 surface. Lead wires shall be bonded to the surface or

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