



# Standard Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate<sup>1</sup>

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## INTRODUCTION

Clothing is often made of materials that impede the flow of heat and moisture from the skin to the environment. Consequently, people may suffer from heat stress or cold stress when wearing clothing in different environmental conditions. Therefore, it is important to quantify the thermal resistance and evaporative resistance of clothing materials and to consider these properties when selecting materials for different clothing applications.

### 1. Scope

1.1 This test method covers the measurement of the thermal resistance and the evaporative resistance, under steady-state conditions, of fabrics, films, coatings, foams, and leathers, including multi-layer assemblies, for use in clothing systems.

1.2 The range of this measurement technique for intrinsic thermal resistance is from 0.002 to 0.5 K·m<sup>2</sup>/W and for intrinsic evaporative resistance is from 0.0 to 1.0 kPa·m<sup>2</sup>/W.

1.3 The values in SI units shall be regarded as standard.

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 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:*<sup>2</sup>

[C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus](#)

[D 1518 Test Method for Thermal Transmittance of Textile Materials](#)

[E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods](#)

[E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method](#)

[F 1291 Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin](#)

[F 1494 Terminology Relating to Protective Clothing](#)

[F 2370 Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin](#)

2.2 *Other Standards:*

[ISO 11092 Textiles—Physiological Effects—Measurement of Thermal and Water-Vapour Resistance Under Steady-State Conditions \(Sweating Guarded-Hotplate Test\)](#)<sup>3</sup>

### 3. Terminology

3.1 *Definitions:*

3.1.1 *clo, n*—a unit of thermal resistance (insulation) equal to 0.155 K·m<sup>2</sup>/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<sup>2</sup>) comfortable in an environment at 21°C, air movement 0.1 m/s.

3.1.2 *evaporative resistance, n*—The resistance to the flow of moisture vapor from a saturated surface (high vapor pressure) to an environment with a lower vapor pressure.

3.1.2.1 *Discussion*—The evaporative resistance in units of kPa·m<sup>2</sup>/W can be calculated for several different cases.

$R_{ef}^A$  = apparent total evaporative resistance of the fabric test specimen only, when evaluated non-isothermally. The term apparent is used as a modifier for total evaporative resistance to reflect the fact that condensation may occur within the specimen.

$R_{et}^A$  = apparent total evaporative resistance of the fabric test specimen, liquid barrier, and surface air layer when evaluated non-isothermally. The term *apparent* is used as a modifier for

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

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

total evaporative resistance to reflect the fact that condensation may occur within the specimen.

$R_{ebp}$  = evaporative resistance of the air layer on the surface of the liquid barrier without a fabric test specimen (that is, bare plate). This property reflects the instrument constant and the resistance of the liquid barrier, and in conjunction with  $R_{er}$ , is used in the calculation of  $R_{ef}$ .

$R_{ef}$  = intrinsic evaporative resistance of the fabric test specimen only. In the calculation of this value, the assumption is made that the boundary layers of the bare plate and the boundary layers of the fabric are equal.

$R_{et}$  = total evaporative resistance of the fabric test specimen, the liquid barrier, and the surface air layer.

3.1.3 *permeability index* ( $i_m$ ),  $n$ —the efficiency of evaporative heat transport in a clothing system.

3.1.3.1 *Discussion*—An  $i_m$  of zero indicates that the clothing system allows no evaporative heat transfer. An  $i_m$  of one indicates that the clothing system achieves the theoretical maximum evaporative heat transfer allowed by its insulation. The permeability index is calculated one of two ways.

$i_m$  = permeability index calculated using the total thermal resistance and the total evaporative resistance of a material. The U.S. military uses this value in their databases on fabrics and clothing systems.

$i_{mf}$  = permeability index calculated using the intrinsic thermal resistance and the intrinsic evaporative resistance of a material. ISO 11092 uses this value.

3.1.4 *thermal resistance*,  $n$ —the resistance to the flow of heat from a heated surface to a cooler environment.

3.1.4.1 *Discussion*—Thermal resistance in units of  $K \cdot m^2/W$  can be calculated for several different cases.

$I_t$  = total insulation value of the test specimen and the air layer, expressed in clo units.

$I_f$  = intrinsic thermal resistance of the fabric test specimen only, expressed in clo units.

$R_{cbp}$  = thermal resistance of the air layer on the surface of the plate without a fabric test specimen (that is, bare plate). This property reflects the instrument constant and is used to standardize the plate, and in conjunction with  $R_{er}$ , is used in the calculation of  $R_{cf}$ .

$R_{cf}$  = intrinsic thermal resistance of the fabric test specimen only. In the calculation of this value, the assumption is made that the boundary layers of the bare plate and the boundary layers of the fabric test specimen are equal.

$R_{ct}$  = total thermal resistance of the test specimen and the air layer.

3.1.5 *total heat loss*,  $n$ —the amount of heat transferred through a material or a composite by the combined dry and evaporative heat exchanges under specified conditions expressed in watts per square meter.

3.1.5.1 *Discussion*—This single criterion for comparing fabric assemblies was developed as a special case by the National Fire Protection Assoc. The specific conditions used by NFPA are a 35°C fully sweating hot plate surface in a 25°C, 65 % RH environment.

3.2 For definitions of other terms related to protective clothing used in this test method, refer to Terminology [F 1494](#).

## 4. Significance and Use

4.1 The thermal resistance and evaporative resistance provided by fabrics, films, coatings, foams, and leathers, including multi-layer assemblies, is of considerable importance in determining their suitability for use in fabricating protective clothing systems.

4.2 The thermal interchange between people and their environment is, however, an extremely complicated subject that involves many factors in addition to the steady-state resistance values of fabrics, films, coatings, foams, and leathers, including multi-layer assemblies. Therefore, thermal resistance values and evaporative resistance values measured on a hot plate may or may not indicate relative merit of a particular material or system for a given clothing application. While a possible indicator of clothing performance, measurements produced by the testing of fabrics have no proven correlation to the performance of clothing systems worn by people. Clothing weight, drape, tightness of fit, and so forth, can minimize or even neutralize the apparent differences between fabrics or fabric assemblies measured by this test method.

4.3 The thermal resistance and evaporative resistance of clothing systems can be measured with a heated manikin in an environmental chamber in accordance with Test Methods [F 1291](#) and [F 2370](#).

## 5. Interferences

5.1 Departures from the instructions of this test method may lead to significantly different test results. Technical knowledge concerning the theory of heat flow, temperature measurement, and testing practices is needed to evaluate which departures from the instructions are significant. Standardization of the method reduces, but does not eliminate the need for such technical knowledge. Report any departures from the instructions of Test Method F 1868 with the results.

## 6. Apparatus

6.1 *Hot Plate*—The guarded flat plate shall be composed of a test plate, guard section, and bottom plate, each electrically maintained at a constant temperature in the range of human skin temperature (33 to 36°C). The guard section shall be designed to prevent lateral loss of heat from the test plate. The guard section shall be wide enough to minimize heat loss and moisture transport through the edges of the test specimen under the conditions of the test. The bottom plate shall prevent downward loss of heat from the test plate and guard section. A system for feeding water to the surface of the test plate and guard section is also needed for testing Parts B and C. See Test Methods [D 1518](#), [C 177](#), and [ISO 11092](#) for additional information on hot plates.

6.2 *Temperature Control*—Separate independent temperature control is required for the three sections of the hot plate (test plate, guard section, and bottom plate). Temperature control may be achieved by independent adjustments to the voltage or current, or both, supplied to the heaters using solid state power supplies, solid-state relays (proportional time on), adjustable transformers, variable impedances, or intermittent heating cycles. The test plate, guard, and bottom plate sections shall be controlled to measure the same temperature to within  $\pm 0.1^\circ\text{C}$  of each other.

6.3 *Power Measuring Instruments*—Power to the hot plate test section shall be measured to provide an accurate average over the period of the test. If time proportioning or phase proportioning is used for the power control, then devices that are capable of averaging over the control cycle are required. Integrating devices (watt-hour transducers) are preferred over instantaneous devices (watt meters). Overall accuracy of the power monitoring equipment must be within  $\pm 2\%$  of the reading for the average power for the test period.

6.4 *Temperature Sensors*—Temperature sensors shall be thermistors, thermocouples, resistance temperature devices (RTDs), or equivalent sensors. The test plate, guard section, and bottom plate shall each contain one or more temperature sensors that are mounted flush with the hot plate surface and in such a manner that they measure the surface temperature within  $\pm 0.1^\circ\text{C}$ .

6.5 *Controlled Atmosphere Chamber*—The hot plate shall be housed in an environmental chamber that can be maintained at selected temperatures between 20 and  $35^\circ\text{C}$ . The test chamber wall temperature shall be  $\pm 0.5^\circ\text{C}$  of the air in the chamber. The relative humidity shall be maintained as specified in the individual procedure section.

6.6 *Measuring Environmental Parameters*—The air temperature, relative humidity, and air velocity shall be measured as follows:

6.6.1 *Relative Humidity Measuring Equipment*—Either a wet-and-dry bulb psychrometer, a dew point hygrometer, or other electronic humidity measuring device shall be used to measure the relative humidity and calculate the dew point temperature inside the chamber. The relative humidity sensing devices shall have an overall accuracy of at least  $\pm 4\%$ .

6.6.2 *Air Temperature Sensors*—Shielded air temperature sensors shall be used. Any sensor with an overall accuracy of  $\pm 0.1^\circ\text{C}$  is acceptable. The sensor shall have a time constant not exceeding 1 min. The sensor(s) is suspended with the measuring point exposed to air inside the chamber at a point in the air stream such that the air temperature sensor is not influenced by the plate temperature.

6.6.3 *Air Velocity Indicator*—Air velocity shall be measured with an accuracy of  $\pm 0.1$  m/s using a hot wire anemometer. Air velocity is measured at a point 15 mm (nominal) from the plate surface or from the top of the test specimen surface to the bottom of the anemometer sensing element. The air velocity shall be measured at three positions located along a horizontal line perpendicular to the airflow, including a point at the center of the plate and at points at the centers of the guard section on both sides of the plate. Spatial variations in air velocity shall not exceed  $\pm 10\%$  of the mean value.

NOTE 1—The air velocity is to be measured 15 mm above the plate surface for bare plate measurements. The air velocity is to be measured 15 mm above the test specimen surface when testing fabric or systems. The 15 mm distance is to be the distance from the plate or test specimen to the anemometer sensing element (wire)—not to the bottom of the sensing element housing.

6.6.4 *Air Temperature Variations*—Air temperature variations during testing shall not exceed  $\pm 0.1^\circ\text{C}$

6.6.5 *Relative Humidity Variations*—Relative humidity variations during testing shall not exceed  $\pm 4\%$ .

6.6.6 *Air Velocity Variations*—Air velocity variations shall not exceed  $\pm 10\%$  of the mean value for data averaged over 5 min.

## 7. Materials

7.1 *Water*—For the evaporative resistance measurements in Parts B and C distilled, de-ionized, or reverse osmosis-treated water shall be used to wet the test plate surface.

7.2 *Liquid Barrier*—For the evaporative resistance measurements in Parts B and C, a liquid barrier shall be used to cover the test plate so that water does not contact the test specimen. The permeability index of the liquid barrier shall be greater than 0.7, where  $i_m = .060 (R_{cbp}/R_{ebp})$ . Examples include untreated cellophane film and microporous polytetrafluoroethylene film.

7.3 *Calibration Fabrics*<sup>4</sup>—A calibration fabric is required for the calibration in Part C. The calibration fabric is 7.5 oz/lyd<sup>2</sup>, plain weave, yellow color with a fiber blend of 93 % meta-aramid, 5 % para-aramid, and 2 % anti-static with a durable water-repellent finish. Sources for the calibration fabric are given in Footnote 8.

## 8. Sampling and Preparation of Test Specimens

8.1 *Sampling*—Test three specimens from each laboratory sampling unit.

8.2 *Specimen Preparation*—Use test specimens large enough to cover the surface of the hot plate test section and the guard section *completely*. Remove any undesirable wrinkles from the test specimens. Possible techniques for removing wrinkles include smoothing, free-hanging, pressing, steaming, ironing, and so forth.

8.3 *Conditioning*—Allow the test specimens to come into equilibrium with the atmosphere of the testing chamber by conditioning them in the chamber for a least 4 h.

## 9. Procedure Part A—Thermal Resistance ( $R_{ct}$ and $R_{ct}$ ; $I_t$ and $I_p$ )

### 9.1 Test Conditions:

9.1.1 *Temperature of the Test Plate, Guard Section, and Bottom Plate*—Maintain the temperature of these sections at  $35 \pm 0.5^\circ\text{C}$  and without fluctuating more than  $\pm 0.1^\circ\text{C}$  during a test.

9.1.2 *Air Temperature*—Maintain the air temperature of the air flowing over the plate between 4 and  $25^\circ\text{C}$  without fluctuating more than  $\pm 0.1^\circ\text{C}$  during a test.

9.1.2.1 Select an air temperature that will generate a power level in the middle range of the instrument while maintaining the plate temperature at  $35^\circ\text{C}$ . Thicker materials will need to be tested at lower temperatures.

9.1.3 *Relative Humidity*—Maintain the relative humidity of the air flowing over the plate between 20 and 80 % without fluctuating more than  $\pm 4\%$  during a test.

<sup>4</sup> Information on laboratories with sweating hot plates, liquid barriers, and calibration fabrics can be obtained from The Center for Research on Textile Protection and Comfort, NCSU, Raleigh, NC 27695 and The Institute for Environmental Research, KSU, Manhattan, KS 66506.