Designation: F1868 – 23

Standard Test Method for Thermal Resistance, Evaporative Resistance, and Total Heat Loss Measurements of Clothing Materials Using a Sweating Hot Plate[1]

This standard is issued under the fixed designation F1868; 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

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, evaporative resistance, and total heat loss 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, evaporative resistance, and total heat loss 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 $K \cdot m^2/W$ and for intrinsic evaporative resistance is from 0.0 to 1.0 $kPa \cdot m^2/W$. The total heat loss range is from 0.0 to 1300 W/m^2.

1.3 The values in SI units shall be regarded as standard. Other units of measurement are provided in this standard but are not 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 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]

C177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus

D1518 Test Method for Thermal Resistance of Batting Systems Using a Hot Plate (Withdrawn 2023)[3]

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

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

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

F1494 Terminology Relating to Protective Clothing

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

F3426 Test Method for Measuring the Thermal Insulation of Clothing Items Using Heated Manikin Body Forms

2.2 *Other Standards:*

ISO 11092 Textiles – Physiological Effects – Measurement of Thermal and Water-Vapour Resistance Under Steady-State Conditions (Sweating Guarded-Hotplate Test)[4]

3. Terminology

3.1 *Definitions:*

[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] The last approved version of this historical standard is referenced on www.astm.org.

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

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 person (producing heat at the rate of 58 W/m^2) comfortable in an environment at 21 °C, air movement 0.1 m/s. When clo was developed, typical indoor clothing consisted of a three-piece suit and light underclothes.

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^2/W can be calculated for several different cases.

R_{ef}^{A} = apparent intrinsic evaporative resistance of the fabric test specimen only, when evaluated non-isothermally. The term *apparent* is used as a modifier for intrinsic evaporative resistance to reflect the fact that the properties of the specimen may be altered in the testing condition and 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 total evaporative resistance to reflect the fact that the properties of the specimen may be altered in the testing condition and 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_{et}, 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; however, a value of one is not approached in practice. 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.

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·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_{ct}, 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 Association. The specific conditions used by NFPA simulate skin at 35 °C fully sweating in a 25 °C, 65 % RH environment, with a 2 m/s wind flowing parallel to the surface of the skin.

3.2 For definitions of other terms related to protective clothing used in this test method, refer to Terminology F1494.

4. Significance and Use

4.1 The thermal resistance, evaporative resistance, and total heat loss 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.

4.1.1 The thermal resistance, evaporative resistance, and total heat loss can be significantly affected by environmental conditions. Extreme care must be taken when using results measured under standard testing conditions to determine a material's suitability for use in conditions outside the testing conditions.

4.2 The thermal interchange between people and their environment is an extremely complicated subject that involves many factors in addition to the steady-state resistance values of fabrics, films, coatings, foams, and leathers, including multilayer assemblies. Therefore, thermal resistance values, evaporative resistance values, and total heat loss 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 and items can be measured with a heated sweating manikin in an environmental chamber in accordance with Test Methods F1291, F2370, and F3426.

5. Interferences

5.1 Departures from the instructions of this test method lead to different testing results. Technical knowledge concerning the