Designation: F2370 – 10

StandardTest Method for Measuring the Evaporative Resistance of Clothing Using a Sweating 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 heat transfer is both sensible (conduction, convection, and radiation) and latent (evaporation). The evaporative resistance of a clothing ensemble is dependent upon the designs and materials used in the component garments, the amount of body surface area covered by the clothing, the distribution of the layers over the body, looseness or tightness of fit, and the increased surface area for heat loss. Evaporative resistance measurements made on fabrics alone do not take these factors into account. Measurements of the resistance to evaporative heat loss provided by clothing can be used with thermal resistance values (Test Method F1291) to determine the comfort or stress of people in different environments.

1. Scope

1.1 This test method covers the determination of the evaporative resistance of clothing ensembles. It describes the measurement of the resistance to evaporative heat transfer from a heated sweating thermal manikin to a relatively calm 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 evaporative resistance values obtained apply only to the particular ensembles evaluated and for the specified environmental conditions of each test, particularly with respect to air movement and sweating simulations.

1.3 Evaporative resistance values reported 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 establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

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

2.2 *ISO Standards:*[3]

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

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

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

3.1.2 *clothing area factor (f_{cl}) , n*—the ratio of the surface area of the clothed body to the surface area of the nude body.

3.1.3 *evaporative resistance, n*—the resistance to evaporative heat transfer from the body to the environment.

3.1.3.1 *Discussion*—The evaporative resistance values can be used to compare different clothing ensembles as long as each test is conducted using the same experimental procedures and test conditions. The following evaporative resistance

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

values can be determined in this method:

R_{ea} = evaporative resistance of the air layer on the surface of the nude manikin's sweating surface measured under isothermal conditions.

R_{et} = total evaporative resistance of the clothing and surface air layer around the manikin measured under isothermal conditions.

R_{ecl} = intrinsic evaporative resistance of the clothing measured under isothermal conditions.

AR_{ea} = apparent evaporative resistance of the air layer on the surface of the nude manikin's sweating surface measured under non-isothermal conditions.

AR_{et} = apparent total evaporative resistance of the clothing and surface air layer around the manikin measured under non-isothermal conditions.

AR_{ecl} = apparent intrinsic evaporative resistance of the clothing measured under non-isothermal conditions.

3.1.4 *total thermal resistance (R_t)* —the total resistance to dry heat loss from the manikin that includes the resistance provided by the ensemble and the air layer around the clothed manikin.

4. Significance and Use

4.1 This test method can be used to quantify and compare the evaporative resistance provided by different clothing systems. The evaporative resistance values for ensembles measured under isothermal conditions can be used in models that predict the physiological responses of people in different environmental conditions.

4.2 The measurement of the evaporative resistance 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, moisture 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.

5. Apparatus[4]

5.1 *Manikin*—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 surface 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 *Sweat Generation*—The manikin must have the ability to evaporate water from its surface. Sweating system can be a water-fed capillary body suit worn over a thermal manikin. Sweating can also be simulated by supplying water to and maintaining it at the inner surface of a waterproof, but moisture-permeable fabric skin. Other technologies exist that deliver water to the manikin's surface with a valve delivery system.

5.1.2.1 *Sweating Surface Area*—The entire surface of the manikin shall be heated and sweating including the head, chest, back, abdomen, buttocks, arms, hands, legs, and feet.

5.1.3 *Surface Temperature*—The manikin 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 shall be 35°C. Local deviations from the mean surface temperature shall not exceed ±0.5°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 *Methods of Measuring Evaporative Resistance*—The evaporative resistance of a clothing system shall be measured by measuring the power consumption of the manikin (Option 1 in 8.6) or by measuring the evaporation rate of the liquid exiting the garment (Option 2 in 8.6).

5.2.1 *Power-Measuring Instruments*—If power consumption method (Option 1) is used to calculate evaporative resistance, the 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.

5.2.2 *Equipment for Measuring Evaporative Water Loss*—If the rate of evaporation method (Option 2) is used to calculate evaporative heat loss, the mass loss due to evaporation shall be measured by a set of balances to give an accurate average over the period of a test. One balance shall be used to measure the amount of water being fed to the manikin while the other measures the weight change of the manikin. Both balances shall be calibrated yearly and have a resolution to the nearest gram.

5.2.2.1 *Measuring Water Dripping from the Manikin*—A pan large enough to retain all water drippings from the manikin during steady-state measurements, must be utilized if the rate of evaporation method (Option 2) is used to calculate the evaporative resistance of a clothing system. The captured water shall be measured at the end of the test with a calibrated balance having a resolution to the nearest gram. Water loss

[4] Information on laboratories with sweating manikins can be obtained from the Textile Protection and Comfort Center, North Carolina State University, Raleigh, NC 27695 or from the Institute for Environmental Research, Kansas State University, Manhattan, KS 66506.