INTERNATIONAL

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Standard Test Method for Measuring the Cooling Energy Provided by Wicking Liquid Moisture and Evaporating It from Clothing Materials Using a Sweating Hot Plate[1]

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INTRODUCTION

Clothing is often made of materials that are designed to enhance the pickup and distribution of liquids (wicking) to promote the evaporation of sweat. Higher amounts of evaporation should lead to more cooling of the body during active work and less of a chilling effect after active work has stopped. This is important to individuals wearing PPE or athletic wear to enhance comfort and prevent overheating while working. Therefore, it is important to isolate and quantify the amount of cooling provided by a clothing material's ability to distribute and evaporate liquid away from a heated surface. Just as important, it's also important to isolate and quantify the amount of cooling provided and the amount of time it takes to remove all the liquid after it is no longer being delivered to the surface.

1. Scope

1.1 This test method covers the measurement of the cooling energy released back to the wearer's skin by a clothing material's ability to move and evaporate controlled dosages of water under controlled ambient conditions using a sweating hot plate.

1.1.1 This test method establishes procedures for measuring the cooling energy during a simulated "sweating" phase and in a drying phase. Calculations are also provided to determine the drying time and how efficient the clothing material is at assisting in the evaporation of liquid water by comparing it to the maximum amount of energy that can be lost.

1.2 This test method does not address all properties that affect a clothing material's ability to lose heat from the body. Consider measuring properties such as air permeability, insulation, and evaporative resistance.

1.3 The values in SI units shall be regarded as standard. No other units of measurement are included in the 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]

F1494 Terminology Relating to Protective Clothing

F1868 Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate

3. Terminology

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

4. Significance and Use

4.1 A clothing material's ability to assist in the evaporation of liquid sweat by managing liquid moisture is of considerable importance when trying to maximize cooling and comfort benefits to the wearer while active. Understanding how much energy is released back to the skin is critical in determining their suitability for use in fabricating protective clothing systems or athletic wear.

[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.

4.1.1 The cooling energy released back to the wearer can be significantly affected by environmental conditions. Extreme care must be taken when using standard results measured under standard testing conditions to determine a material's suitability for use in conditions outside the testing conditions.

4.2 This test method accounts for a clothing material's ability to assist in evaporating liquid water during a sweating phase, as well as its ability to dry after the cessation of sweating.

4.2.1 A large amount of cooling energy released from clothing materials during active work (sweating) is often seen as a positive, as it would assist in keeping the body cooler.

4.2.2 A large amount of cooling energy released from clothing materials after active work (no sweating) is often seen as a negative, as it known to cause a chilling effect to the wearer.

4.2.3 The longer it takes for a clothing material to dry after becoming wet is perceived as a negative, as it increases the potential for chilling the wearer.

4.3 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, the cooling provided from liquid evaporation 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. Consider measuring other clothing material properties such as thermal resistance and evaporative resistance when evaluating a clothing material.

4.3.1 The thermal resistance and evaporative resistance of clothing materials are measured with a standard sweating hot plate in an environmental chamber in accordance with Test Method F1868.

5. Apparatus

5.1 *Guarded Sweating Hot Plate*—The guarded sweating hot plate shall be composed of a test plate surrounded entirely by a heated guard section. Below the surface of the plate shall be a cooling plate providing cooling to both the guard and testing plate.

5.1.1 *Test Plate*—The test plate shall be 20.3 cm by 20.3 cm (8 in. by 8 in.) and electrically heated to maintain a constant temperature in the range of human skin temperature (33 °C to 36 °C). The test plate shall also have nine sweating pores arranged in a three-by-three array for water delivery.

5.1.2 *Guard Section*—The guard section of the guarded sweating hot plate shall be at least 5.1 cm (2 in.) and surround the test plate completely. It shall be electrically heated and designed to maintain a constant temperature in the range of human skin temperature (33 °C to 36 °C).

5.1.3 *Cooling Plate*—Underneath the test plate and guard, a cooling plate must be present. This cooling plate must have sufficient cooling power to keep it at least 0.5 °C cooler than the test plate above.

5.2 *Water Delivery System*—A water delivery system must supply a constant and consistent flow to each of the nine sweat pores embedded in the test plate. The water delivery system shall have a delivery rate accuracy of ±0.1 mL⁄h for each pore.

5.2.1 The tubing connecting the water delivery system and the sweating pores shall be sufficiently long enough to have the air within in the chamber heat the water to 35 °C prior to entering the test plate.

5.3 *Temperature Control*—Separate, independent temperature control is required for the three sections of the hot plate (test plate, guard section, and cooling plate). Temperature control of the test plate and guard is 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 cooling plate can provide cooling with liquid heat exchanger. The test plate, guard, and cooling plate sections shall be controlled to measure the temperature to within ±0.1 °C.

5.4 *Heat Flux Measuring Instrument*—Heat lost or gained from the surface of the test plate shall be measured to provide an accurate average over the period of the test. Overall accuracy of the measuring device must be within ±2 % of the reading for the average power for the test period.

5.5 *Temperature Sensors*—Temperature sensors shall be thermistors, thermocouples, resistance temperature devices (RTDs), or equivalent sensors. The test plate, guard section, and cooling plate shall each contain one or more temperature sensors that are mounted flush with each plate surface and in such a manner that they measure the surface temperature within ±0.1 °C.

5.6 *Controlled Atmosphere Chamber*—The hot plate shall be housed in an environmental chamber that can be maintained at selected a temperature of 35 °C. The test chamber wall temperature shall be ±0.5 °C of the air in the chamber. The relative humidity shall be maintained as specified in the individual procedure section.

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

5.7.1 *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 ±4 %.

5.7.2 *Air Temperature Sensors*—Shielded air temperature sensors shall be used. Any sensor with an overall accuracy of ±0.1 °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.

5.7.3 *Air Velocity Indicator*—Air velocity shall be measured with an accuracy of ±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 one position perpendicular to the airflow, at the center of the plate.

5.7.3.1 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 distance from the plate or test specimen to the anemometer sensing element (wire)—not to the bottom of the sensing element housing.

5.7.3.2 At a minimum, annually verify that air velocity spatial variation does not exceed ±10 % of the mean value. Measurements of 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.

5.7.3.3 The additional two anemometers needed for spatial variation must meet the same requirements as defined in 5.7.3 and shall be permitted to be external anemometers or integral anemometers to the system.

5.7.4 *Air Temperature Variations*—Air temperature variations during testing shall not exceed ±0.1 °C.

5.7.5 *Relative Humidity Variations*—Relative humidity variations during testing shall not exceed ±4 %.

5.7.6 *Air Velocity Variations*—Air velocity variations shall not exceed ±10 % of the mean value for data averaged over 5 min.

6. Materials

6.1 *Water*—For measuring the cooling power of clothing materials, distilled, de-ionized, or reverse osmosis-treated water shall be used to wet the test plate surface.

7. Sampling and Preparation of Test Specimens

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

7.1.1 As wicking patterns are not always perfect circles, it is recommended to test specimen fabric in the warp, weft, and bias direction.

7.2 *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.

7.2.1 If any heat or moisture is applied to the fabric (for example, ironing or steaming) to remove wrinkles, this process shall be reported.

7.3 *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.

8. Procedure

8.1 *Test Conditions:*

8.1.1 *Temperature of the Test Plate and Guard Section*—Maintain the temperature of these sections at 35 ± 0.5 °C without fluctuating more than ±0.2 °C during a test.

8.1.2 *Temperature of the Cooling Plate*—Maintain the temperature of this section at 34.5 ± 0.5 °C.

8.1.3 *Water Supply*—Prior to testing, verify that water is available at each pore on the surface of plate.

8.1.4 *Isothermal Conditions*—The air temperature is the same as the test plate temperature, so no dry heat exchange is occurring between the plate and the environment.

8.1.4.1 *Air Temperature*—Maintain the air temperature of the air flowing over the plate at 35 ± 0.5 °C without fluctuating more than ±0.1 °C during a test.

8.1.4.2 *Air Velocity*—Maintain the air velocity at 2 m/s without fluctuating more than ±0.1 m/s over the duration of the test measurement.

8.1.4.3 *Relative Humidity*—The relative humidity shall be 40 ± 4 % during a test.

8.2 *Procedures:*

8.2.1 Place conditioned fabric on the test plate and guard and adjust the height such that the wind anemometer is 15 mm above the fabric surface.

8.2.1.1 Make sure the back or skin side of the fabric is in contact with the plate and that the face side is exposed to the environment.

8.2.2 Once the environment, test plate, guard, and cooling plate are within tolerance and are stable, start testing.

8.2.2.1 Data shall be recorded at least ten times per minute throughout the test.

8.2.3 *Initialization Phase:*

8.2.3.1 Measure heat flux at the surface of the plate for 10 min.

8.2.4 *Sweating Phase:*

8.2.4.1 Turn on the water delivery system and measure the heat flux at the surface of the plate for 30 min.

8.2.4.2 Deliver water to the test plate at a rate of 2.2 mL/h per pore.

8.2.5 *Drying Phase:*

8.2.5.1 Turn off the water delivery system and continue measuring the heat flux at the surface of the test plate until fabric is dry.

8.2.5.2 The fabric is considered dry when the heat flux value at the surface is within 5 % of the average heat flux value found during the baseline phase.

8.3 *Calculations*—Calculate the total energy absorbed during sweating, total energy absorbed during drying, drying time, cooling efficiency, and the chilling potential of the clothing material.

8.3.1 Calculate the total energy measured during sweating using Eq 1.

$$E_s = \int_{t_1}^{t_2} (H_L - H_i) \times A \times 10^{-3} dt \qquad (1)$$

where:

E_s = sweating cooling energy E_s (kJ) is the total amount of energy absorbed during the sweating phase,
t_1 = the start time of the sweating phase (min),
t_2 = the end of the sweating phase, that is, the start of the drying phase (min),
H_L = heat flux measurement at the surface of the hot plate (W/m^2),
H_i = average heat flux value from initialization phase (8.2.3) (W/m^2), and