Designation: F2371 – 05

Standard Test Method for Measuring the Heat Removal Rate of Personal Cooling Systems Using a Sweating Heated Manikin[1]

This standard is issued under the fixed designation F2371; 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

Personal Cooling Systems (PCS) are used when wearers could be exposed to conditions that render the body's thermoregulatory system inadequate to maintain body core temperature within a safe range. The use of PCS can reduce the possibility of heat stress related physiological disorders and can also provide increased comfort, which in turn could also result in higher productivity. Cooling needs vary greatly depending on the level of activity, the external temperature and humidity, as well as the personal protective equipment worn. The PCS should be selected that is best suited for the specific application. Sweating heated manikins provide a convenient tool to assess the effectiveness of PCS as they can provide objective and repeatable results. These instruments can be used to quantify, in a reproducible manner, the cooling rate and cooling duration provided by the PCS while eliminating the variables associated with human physiology. Sweating heated manikins can be used for direct comparisons of PCS.

1. Scope

1.1 This test method covers the measurement of heat removal rate from a sweating heated manikin as well as the duration of cooling provided by a cooling garment, in order to assess the effectiveness of PCS.[2]

1.1.1 This test method requires the use of a sweating heated manikin. The sweating capability is essential, to take into account the potentially large fraction of heat dissipation associated with evaporative cooling.

1.2 The experimental values obtained for the cooling rates and cooling duration apply only to the particular PCS and additional clothing ensemble (standard outer garment, outer garment integrated to the PCS, or any other outer garment, as appropriate) as tested, and for the specified environmental conditions.

1.3 The values stated in this standard shall be SI units.

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:*[3]

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

3. Terminology

3.1 *Definitions:*

3.2 *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 velocity 0.1 m/s, or roughly the insulation value of typical indoor clothing.

3.2.1 *Discussion*—Numerically, the clo is equal to 0.155 K·m^2/W.

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

3.4 *garment*, *n*—a single item of clothing (for example, shirt).

[1] This test method is under the jurisdiction of ASTM Committee F23 on Protective Clothing and is the direct responsibility of Subcommittee F23.60 on Human Factors.

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[2] The present standard does not attempt to determine the thermal insulation and evaporative resistance of garments worn with the PCS, or these same properties for the PCS's themselves. Test Methods F1291 and F2370 are available for these measurements.

[3] 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.

3.5 *thermal insulation*, *n*—the resistance to dry heat transfer by way of conduction, convection, and radiation.

3.6 *total heat loss*, *n*—the amount of heat transferred through a clothing system by the combined dry and evaporative heat exchanges under specified conditions expressed in watts per square metre.

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

4. Significance and Use

4.1 This test method can be used to quantify and compare the cooling provided by different Personal Cooling Systems (PCS's) worn with a standard outer garment or with any other specified one.

4.1.1 The test method is intended to allow garments based on various cooling technologies to be evaluated fairly and objectively, by taking into account convective and evaporative heat transfer.

4.1.2 A sweating thermal manikin accurately accounts for evaporative cooling, which represents the only active means of heat transfer occurring in humans. Utilizing a sweating thermal manikin will also permit the heat removal rate to be measured for all types of PCS.

4.2 The measurements of heat removal rates and duration of cooling provided by the PCS's depend on the apparatus and techniques used.

4.2.1 It is not practical in a test method of this scope to establish details sufficient to cover all contingencies.

4.2.2 Departures from the instructions in this test method will potentially lead to significantly different test results.

4.2.3 Technical knowledge concerning the theory of heat transfer, temperature, air motion measurement, evaporative cooling, and testing practices is needed to evaluate which departures from the instructions given in this test method are significant. Report any departures with the results.

5. Apparatus

5.1 *Manikin*—A standing sweating manikin having the form, shape, and size of an adult male or female shall be used. The manikin shall be heated to a uniform, constant, 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 significantly affect the results.

5.1.2 *Sweat Generation*—The manikin must have the ability to evaporate water from its surface. Some examples of a sweating system include a cotton body suit saturated with water or water fed capillary body suit worn over a thermal manikin. Other technologies exist that deliver water to the manikin's surface with a valve delivery system.

5.1.2.1 *Sweating Surface Area*—The surface area from which water is evaporated must include the chest, back, abdomen, buttocks, arms and legs. Ideally, the manikin's head, hands, and feet should be sweating also.

5.1.3 *Surface Temperature*—The manikin shall be constructed so as to maintain a constant uniform temperature over the nude body surface, with no local hot or cold spots. The 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. Repeat this procedure after repairs or alterations are completed that could affect temperature uniformity (for example, replacement of a heating element).

5.2 *Power-Measuring Instruments*—Record the time history of the power input to the manikin over the entire test period. 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*—Measure the mean skin temperature with point sensors or distributed temperature sensors.

5.3.1 *Point Sensors*—Point sensors may be thermocouples, resistance temperature devices (RTD's), thermistors, or equivalent sensors. They shall be no more than 2.0 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 pass through the interior of the manikin, or both. The sensors shall be distributed so that each one represents the same surface area or are area-weighted when calculating the mean skin temperature for the body. A minimum of 15 point sensors are required. At least one sensor shall be placed on the head, chest, back, abdomen, buttocks, and both the right and left upper arm, lower arm, hand, thigh, calf, and foot. These sensors must be placed in the same position for each test and the placement of the sensors shall be given in the report.

5.3.2 *Distributed Sensors*—If distributed sensors are used (for example, resistance wire), then the sensors must be distributed over the surface so that all areas are equally weighted. If several such sensors are used to measure the temperature of different parts of the body, then their respective temperatures should be area-weighted when calculating the mean skin temperature. Distributed sensors must be small in diameter (that is, less than 1.0 mm) and firmly bonded to the manikin surface at all points.

5.4 *Controlled Environmental Chamber*—The manikin shall be placed in a chamber at least 2 by 2 by 2 m in dimension that can provide uniform conditions, both spatially and temporally.

5.4.1 *Spatial Variations*—Spatial variations shall not exceed the following: air temperature ±1.0°C, relative humidity ±5 %, and air velocity ±50 % of the mean value. In addition, the mean radiant temperature shall not be more than 1.0°C different from the mean air temperature. The spatial uniformity shall be verified at least annually or after any significant modifications are made to the chamber. Spatial uniformity shall be verified by recording values for the conditions stated above at heights of 0.1, 0.6, 1.1, 1.4, and 1.7 m above the floor at the