Designation: F2371 – 16 (Reapproved 2024)

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 uses a sweating manikin in an environmental chamber to measure the heat removal rate and cooling duration provided by a personal cooling garment worn with a base ensemble.[2]

1.1.1 The use of a sweating heated manikin is essential because of the potentially large amount of heat dissipation from the body 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 garments worn during the test and for the environmental conditions used.

1.2.1 It is feasible that this test method will yield unrealistically high cooling rates for ambient air circulation systems since the manikin's surface stays continuously saturated during the test and the relative humidity in the chamber is relatively low; consequently the convective and evaporative heat loss rates from the body to the environment are probably higher from the manikin than they would be from a human, particularly in environments with higher levels of humidity.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this 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:*[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

[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] 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 PCSs 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. Terminology

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

3.2 *Definitions:*

3.2.1 *personal cooling systems (PCS)*—garment technologies that are designed to be worn with protective clothing in warm/hot environments to remove heat from the body and prevent heat stress; types include ambient air systems which circulate air between the body surface and clothing, phase change materials which are worn close to the body and absorb heat, and refrigeration systems and ice bath systems that circulate chilled water in tubes in a vest worn next to the body (that is, a liquid cooling garment).

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) worn with a common base ensemble. Any base ensemble can be selected based on the intended end use of the PCS.

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 both dry and evaporative heat transfer.

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

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

4.2.2 Technical knowledge concerning the theory of heat transfer, temperature, air motion measurement, humidity, 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 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 significantly affect the results.

5.1.2 *Sweat Generation*—The manikin must have the ability to evaporate water from its surface. The 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.

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 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. 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 Surface (Skin) Temperature*—Measure the mean skin temperature with point sensors or distributed temperature sensors.

5.3.1 *Point Sensors*—The following are acceptable point sensors: thermocouples, resistance temperature devices (RTDs), 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. If point senors are used, 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 need to be area-weighted when calculating the mean surface (skin) temperature. Distributed sensors shall be less than 1 mm in diameter and firmly attached 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