Standard Test Method for Thermal Resistance of Batting Systems Using a Hot Plate[1]

INTRODUCTION

This standard replaces D1518-85, Thermal Transmittance of Textile Materials. This standard provides a method for measuring the thermal resistance (insulation) provided by battings and batting/fabric systems under still air conditions or an air flow condition. Other hot plate standards F1868 and ISO 11092 provide a method for measuring the thermal resistance and evaporative resistance of fabrics and fabric systems. The method for measuring fabric insulation in these standards is comparable to Option 2: Air Velocity Condition in D1518. These standards can be used to compare the thermal properties of textile materials. Manikin standards F1291 and F2370 can be used to measure and compare the thermal resistance and evaporative resistance of clothing systems, respectively. Manikin standard F1720 can be used to measure the insulation provided by sleeping bag systems.

1. Scope

1.1 This test method covers the measurement of the thermal resistance, under steady-state conditions, of battings and batting/fabric systems, and other materials within the limits specified in 1.2. It measures the heat transfer from a warm, dry, constant-temperature, horizontal flat-plate up through a layer of the test material to a cool atmosphere and calculates the resistance of the material. The measurements are made under still air conditions (Option #1) or with a horizontal air flow over the specimen (Option #2).

1.2 For practical purposes, this test method is limited to determinations on specimens of battings and layered batting/fabric assemblies having an intrinsic thermal resistance from 0.1 to 1.5 $K \cdot m^2/W$ and thicknesses not in excess of 50 mm.

1.3 This test method also provides a method for determining the bulk density of the material, the insulation per unit thickness, and the insulation per unit weight.

1.4 The values stated in SI units are to be regarded as standard.

1.5 *This standard does not purport to address the safety concerns associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D123 Terminology Relating to Textiles
D3776 Test Methods for Mass Per Unit Area (Weight) of Fabric
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
F1720 Test Method for Measuring Thermal Insulation of Sleeping Bags Using a Heated Manikin
F1868 Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate
F2370 Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin

2.2 *ISO Standards:*[3]

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

[1] This test method is under the jurisdiction of ASTM Committee D13 on Textiles and is the direct responsibility of Subcommittee D13.51 on Conditioning and, Chemical and Thermal Properties.

Current edition approved July 1, 2014. Published August 2014. Originally published as D1518 – 57 T. Last previous edition approved in 2011 as D1518 – 11a. DOI: 10.1520/D1518-14.

[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.

ISO 9073-2 Textile—Test Methods for Nonwovens—Part 2: Determination of Thickness

3. Terminology

3.1 The following terms are relevant to this standard: bulk density, clo, thermal resistance, thermal insulation.

3.2 For terminology relating to thermal resistance and insulation see Terminology F1494.

3.3 For terminology relating to textiles see Terminology D123.

4. Significance and Use

4.1 The thermal resistance of a batting or batting/fabric system is of considerable importance in determining its suitability for use in fabricating cold weather protective clothing, sleeping bags, and bedding systems. The thermal interchange between man and his environment is, however, an extremely complicated subject which involves many factors in addition to the insulation values of fabrics and battings. Therefore, measured thermal insulation values can only indicate relative merit of a particular material.

5. Interferences

5.1 Departures from the instructions of this test method may lead to significantly different test results. Technical knowledge concerning the theory of heat transfer, temperature measurement, and testing practices is needed to evaluate which departures from the instructions are significant. Standardization of the method reduces, but does not eliminate the need for such technical knowledge. Report any departures from the instructions of Test Method D1518 with the results.

6. Apparatus (Fig. 1and Fig. 2)

NOTE 1—The illustrations and captions (including dimensions) shown in Fig. 1and Fig. 2 are provided as informational guidance only and are not to be taken as prescriptive design criteria or construction drawings. The information is given as guidance for possible design concepts only. The final design of equipment, including dimensions of component parts, selection of electrical components and selection of sensors, shall be in conformance with the specifications set forth in the body of this standard.

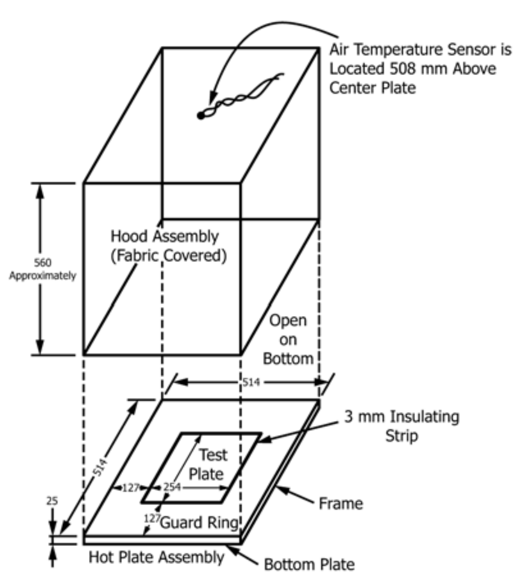

FIG. 1 Hot Plate with Guard Ring and Hood (No Air Velocity Method) Dimensions in mm

6.1 *Hot Plate*—A guarded flat plate composed of a test plate, guard ring, and bottom plate as follows, each electrically maintained at a constant temperature in the range of human skin temperature (33 to 38°C).

6.1.1 *Test Plate*—The test plate portion of the hot plate shall be at least 254 mm (10.0 in.) square and shall be placed at the center of the upper surface of the hot-plate assembly. It shall be made of aluminum or copper with a dull black coating to approximate the emissivity of human skin. The heating element shall be uniformly distributed over the entire area of the test plate, mounted within 3 mm (0.1 in.) of the upper plate surface and well-thermally coupled to it.

6.1.2 *Guard Ring*—The guard ring bordering the test plate shall be at least 127 mm (5.0 in.) in width and shall be of the same thickness, composition, and type of construction as the test plate. It shall be coplanar with the test plate, and shall be separated from it by means of a strip of cork or other suitable insulating material approximately 3-mm (0.1-in.) wide. The guard ring shall be designed to prevent lateral loss of heat from the test plate.

6.1.3 *Bottom Plate*—The bottom plate shall be in a plane parallel to the test plate and guard ring, and at a distance of at least 25 mm (1.0 in.) but not in excess of 75 mm (3.0 in.) beneath them. It shall be separated from the test plate and guard ring and the air pocket formed thereby, or by other means of causing air entrapment. The dimensions offered as suggested design specifications are shown in Fig. 2. The purpose of the bottom plate is to prevent a downward loss of heat from the test plate and guard ring.

6.2 *Temperature Control*—Separate independent temperature control is required for the three sections of the hot plate (test plate, guard section, and bottom plate). Temperature control may be 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 test plate, guard, and bottom plate sections shall be controlled to measure the same temperature to within ±0.1°C of each other.

6.3 *Power-Measuring Instruments*—Power to the hot plate test section shall be measured to provide an accurate average over the period of the test. If time proportioning or phase proportioning is used for the power control, then devices that are capable of averaging over the control cycle are required. Integrating devices (watt-hour transducers) 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.

6.4 *Temperature Sensors*—Temperature sensors shall be thermistors, thermocouples, resistance temperature devices (RTDs), or equivalent sensors. The test plate, guard section, and bottom plate shall each contain one or more temperature sensors that are mounted flush with the hot plate surface or within 3 mm of the hot plate surface in such a manner that they measure the surface temperature within ±0.1°C.

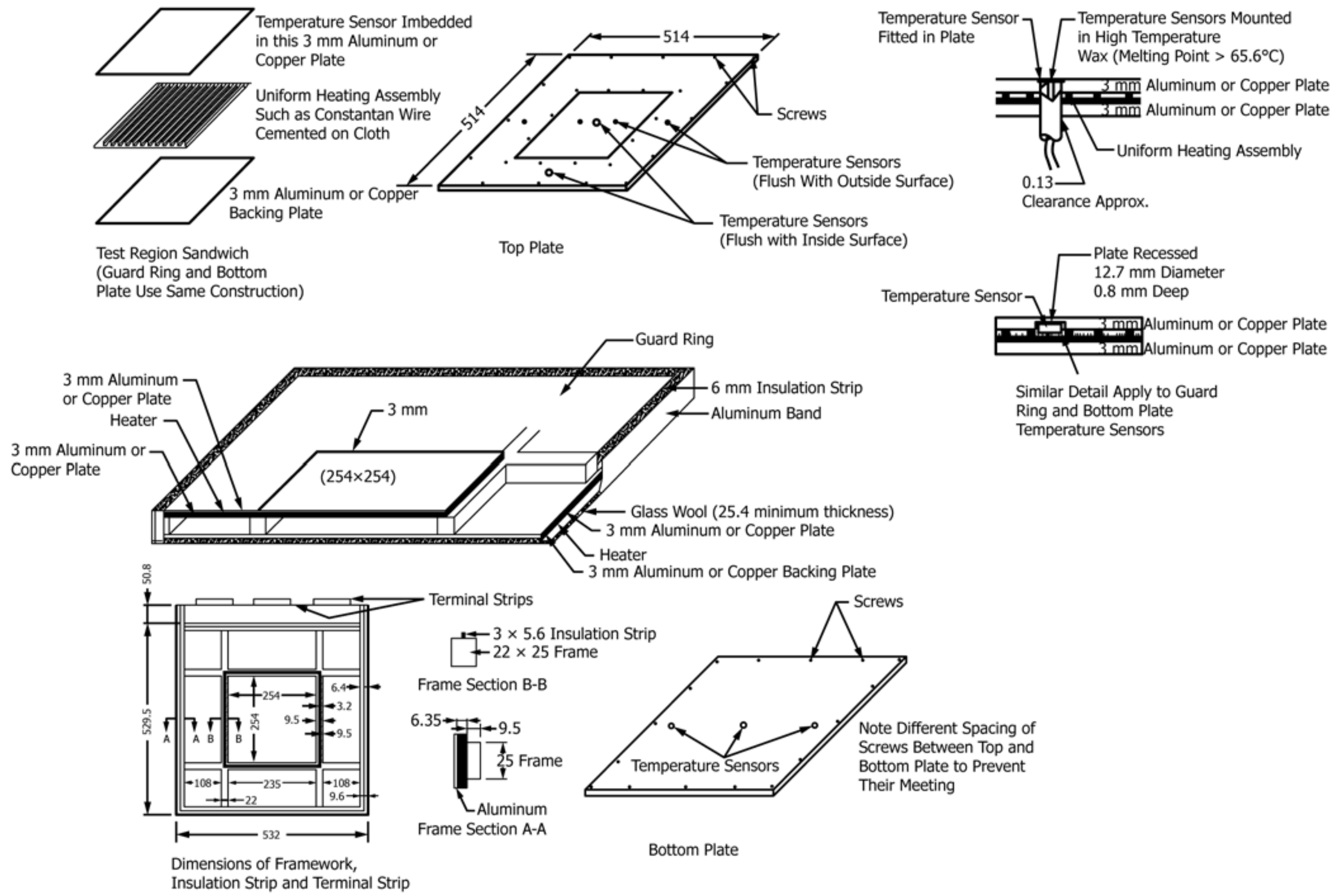

FIG. 2 Example of a Hot Plate Apparatus, Dimensions in mm

6.5 *Controlled Atmosphere Chamber*—The hot plate shall be housed in an environmental chamber that can be maintained at selected temperatures between 1 and 20°C, or lower (see 8.1.2.1.) The test chamber wall temperature shall be ±0.5°C of the air in the chamber. The relative humidity shall be maintained between 20 and 80 %.

6.6 *Hood*—The hot plate shall be covered with a hood to control air flow.

6.6.1 *Option 1: Still Air Condition*—A box-shaped hood made of fabric on a frame with the dimensions shown in Fig. 1 is needed to cover the plate so as to maintain still air conditions over the specimen. The fabric cover must be breathable so that heat buildup is minimized inside the hood. Thin elastic knits have been successfully used to reduce air velocity in this application.

6.6.2 *Option 2: Air Velocity Condition*—An air flow hood is needed that provides 1.0 m/s of air velocity over the batting/fabric specimen in the horizontal direction. The height of the air space above the bare plate or specimen should stay the same from test to test. Therefore, the position of the hood needs to be adjustable relative to the plate surface, or the plate surface needs to be adjustable relative to the fixed position of the hood to accommodate varying sample thicknesses and to prevent air from flowing into the edge of the sample.

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

6.7.1 *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 inside the chamber. The relative humidity sensing devices shall have an overall accuracy of at least ±4 %.

6.7.2 *Air Temperature Sensors*—Air temperature sensors with an overall accuracy of ±0.1°C shall be used. The sensors shall have a time constant not exceeding 1 min. Placement of sensors is described under test conditions for each option.

6.7.3 *Air Velocity Indicator*—For Option #2, 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 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. Spatial variations in air velocity shall not exceed ±10 % of the mean value.

NOTE 2—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 15 mm distance is to be the distance from the plate or test specimen to the anemometer sensing element (wire)—not to the bottom of the sensing element housing. If the batting system surface is uneven due to quilting, measure from the sample's highest (thickest) point.

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

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

6.7.6 *Air Velocity Variations*—Air velocity variations shall not exceed ±5 % of the mean value for data averaged over 1 min.

7. Sampling and Specimen Preparation

7.1 *Sampling*—Test three specimens from each laboratory sampling unit. Indicate whether the specimens are new or have been laundered, dry cleaned, or used, or combination thereof.

7.2 *Specimens*—Battings may be tested alone or a batting/fabric system can be created by placing a cover fabric under the batting on the plate and on top of the batting during testing. Alternatively, batting/fabric systems can be sewn together the way they would be used in a product. Specimens should be less than 50 mm in thickness.

7.3 *Specimen Preparation*—Use test specimens large enough to cover the surface of the hot plate test section and the guard section completely. Do not compress or stretch batting samples during handling because this will affect their thickness and density and the resulting insulation values. Remove any undesirable wrinkles from fabrics prior to layering them with battings by smoothing them, flatting them under weights, or steam ironing them (assuming heat will not damage the fabrics).

8. Test Conditions

8.1 *Option 1: Still Air Condition with Box Hood Over Plate:*

8.1.1 *Temperature of the Test Plate, Guard Section, and Bottom Plate*—Maintain the temperature of these sections at 35 ± 0.5°C and without fluctuating more than ±0.1°C during a test. The temperature differential between the test plate and guard sections should be maintained within ± 0.2°C during a test.

8.1.1.1 The standard hot plate temperature is 35°C; however, thick samples may require a higher plate temperature and a lower air temperature to generate adequate levels of power (heat loss) during a test. Therefore, a higher plate temperature can be used, if necessary.

8.1.2 *Air Temperature*—Maintain the air temperature of the air under the hood between 1 and 15°C without fluctuating more than ±0.1°C during a specimen test. Bare plate tests should be conducted at 20°C.

8.1.2.1 *Discussion*—Select an air temperature that will maintain a power level within the accurate operating range of the instrument while maintaining the plate temperature at 35°C. Thick samples may require a lower air temperature to generate adequate levels of power (heat loss) during a test. The temperature in the chamber may be several degrees lower than the temperature measured inside the box hood because the plate will provide heat to the air inside the hood. Hot plates with sweating capability have water in them and must be drained prior to using air temperatures below freezing.

8.1.2.2 Measure the air temperature 508 mm (20 in.) above the center of the plate. The measurement location is critical for test accuracy because there will be some thermal stratification under the hood.

8.1.3 *Relative Humidity*—Maintain the relative humidity of the air under the hood between 20 and 80 % without fluctuating more than ±4 % during a test.

8.1.3.1 The relative humidity has little or no effect on batting/fabric insulation under steady-state conditions. Under transient conditions, the absorption of moisture from the air will generate heat in the fabric, and the desorption of moisture will produce a cooling effect.

8.1.3.2 Measure the relative humidity in the air under the box hood 508 mm (20 in.) above the center of the plate.

8.1.4 *Air Velocity*—Do not measure air velocity under the hood since there is no forced air convection over the specimen (i.e., still air conditions).

8.2 *Option 2: Air Velocity Condition with Forced Air Flowing Over the Plate:*

8.2.1 *Temperature of the Test Plate, Guard Section, and Bottom Plate*—Maintain the temperature of these sections at 35 ± 0.5°C and without fluctuating more than ±0.1°C during a test. The temperature differential between the test plate and guard sections should be maintained within ±0.2°C during a test.

8.2.2 *Air Temperature*—Maintain the air temperature of the air flowing over the plate between 1 and 15°C without fluctuating more than ±0.1°C during a specimen test. Bare plate tests should be conducted at 20°C.

8.2.2.1 *Discussion*—Select an air temperature that will maintain a power level within the accurate operating range of the instrument while maintaining the plate temperature at 35°C. Thick samples may require a lower air temperature to generate adequate levels of power (heat loss) during a test. Hot plates with sweating capability have water in them and must be drained prior to using air temperatures below freezing.

8.2.2.2 Measure the air temperature in the air flow hood just before the air starts to flow over the plate.

8.2.3 *Relative Humidity*—Maintain the relative humidity of the air flowing over the plate between 20 and 80 % without fluctuating more than ±4 % during a test.

8.2.3.1 The relative humidity has little or no effect on fabric insulation under steady-state conditions. Under transient conditions, the absorption of moisture from the air will generate heat in the fabric, and the desorption of moisture will produce a cooling effect.

8.2.3.2 Measure the relative humidity in the air flow hood just before the air starts to flow over the plate.

8.2.4 *Air Velocity*—Maintain a level of air velocity at 1.0 m/s without fluctuating more than ±0.1 m/s over the duration of the test measurement. Measure air velocity as specified in 6.7.3.

9. Procedure

9.1 Measure the bare plate thermal resistance, (R_{cbp}), in the same manner as that for R_{ct} except that the test plate shall not be covered with a test specimen and the air temperature shall be 20°C.

9.2 Measure the total thermal resistance, (R_{ct}), by placing a batting or batting/fabric system on the test plate. Place the test specimen on the test plate with the side normally facing the human body towards the test plate. In the case of multiple layers, arrange the specimens on the plate as on the human body. Eliminate wrinkles within the test specimen and air gaps between the specimen and the plate or between specimen layers by smoothing without compressing.

9.3 After the batting or batting/fabric system reaches steady-state conditions, record measurements for power input, plate temperature, and air temperature every 1 min for a minimum test period of 30 min to determine the total thermal resistance of the specimen plus the air layer, (R_{ct}).

10. Calculation

10.1 Calculate the total thermal resistance, (R_{ct}), for a batting or batting/fabric system, including the surface air layer resistance using Eq 1:

$$R_{ct} = (T_s - T_a)\, A/H_c \tag{1}$$

where:

R_{ct} = total thermal resistance (insulation) provided by the batting/fabric system and air layer ($m^2 \cdot K/W$),
A = area of the plate test section (m^2),
T_s = surface temperature of the plate (°C),
T_a = air temperature (°C), and
H_c = power input (W).

10.1.1 Average data from three specimens to determine the average total thermal resistance, R_{ct} for the laboratory sampling unit.

10.1.2 Determine the intrinsic thermal resistance provided by the batting or batting/fabric system alone, R_{cf}, by subtracting the thermal resistance value measured for the air layer, R_{cpb} (that is, bare plate test) from the average total thermal resistance value measured for the batting/fabric system and air layer, R_{ct}.

10.1.3 To convert the insulation values measured in SI units to clo units, multiply by 6.45. R_{ct} is often designated as I_t and R_{cf} is designated as I_f when insulation is expressed in clo units.

11. Optional Parameters and Thermal Indexes

11.1 *Thickness*—Determine the thickness of the batting or batting/fabric system to the nearest 0.5 mm under a light pressure of 0.1 kPa or less following a method such as that described in ISO 9073-2.

11.2 Determine the weight per unit area of the batting or batting/fabric system to the nearest 0.1 g/m^2 according to Test Methods D3776.

11.3 Calculate the bulk density, B, of the batting or fabric, using Eq 2:

$$B = M/t \tag{2}$$

where:

B = bulk density, kg/m^3,
M = mass/unit area of fabric, g/m^2, and
t = thickness of batting or fabric, mm.

11.3.1 The bulk density should only be calculated for homogeneous samples, that is, the batting by itself or the fabric layer by itself. Therefore, the thickness of the sample should be uniform (that is, quilted samples with thick and thin areas should not be used).

11.4 Calculate the intrinsic insulation per unit thickness for the batting or batting/fabric system in clo/cm.

11.5 Calculate the intrinsic insulation per unit weight for the batting or batting/fabric system in clo/kg/m^2. The weights of all fabric and batting layers must be included in the calculation.

12. Report

12.1 State that the specimens were tested as directed in ASTM Test Method D1518. Indicate whether Option 1: Still Air Condition or Option 2: Air Velocity Condition was used.

12.2 Report the composition and construction of the battings and fabrics tested, and whether the specimens are new or have been laundered, dry cleaned, or used, or combination thereof. Report the order and orientation of the specimen layers on the hot plate if a batting/fabric system was tested.

12.3 Report the environmental conditions used during the test.

12.4 Report the total insulation of the bare plate, R_{cpb}, the average total insulation value of the samples and boundary air layer, R_{ct} or I_t, and the average intrinsic insulation value of the samples, R_{cf} or I_f.

12.5 Report any modification to the test or pre-treatment of the samples.

12.6 *Optional*—Report the weight, thickness (and method used to measure it), intrinsic insulation per unit thickness, the intrinsic insulation per unit weight, and bulk density of the samples.

13. Precision and Bias

13.1 *Precision*—The precision of this test method is based on an interlaboratory study of D1518 conducted in 2011. A single laboratory participated in this study, testing two materials, under two different conditions. Every "test result" represents the average of three individual determinations. The laboratory reported three replicate test results for each material. Except for the use of only one laboratory, Practice E691 was followed for the design and analysis of the data; the details are given in a research report.[4]

13.1.1 *Repeatability Limit (r)*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "*r*" value for that material; "*r*" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D13-1130.

TABLE 1 Intrinsic Thermal Insulation ($m^2 \cdot K/W$)

Option	Average, $\bar{x}$	Repeatability Standard Deviation, S_r	Repeatability Limit, r
Option 1: Still air condition with box hood, Batting alone	0.278	0.007	0.021
Option 1: Still air condition with box hood, Batting with two shell fabrics	0.334	0.004	0.011
Option 2: Air velocity condition, Batting alone	0.292	0.007	0.019
Option 2: Air velocity condition, Batting with two shell fabrics	0.340	0.012	0.033

13.1.2 Repeatability limits are listed in Table 1 and are used as specified in Practice E177.

13.1.3 Any judgment in accordance with 13.1.1 would normally have an approximate 95 % probability of being correct; however, the precision statistics obtained in this ILS must not be treated as exact mathematical quantities which are applicable to all circumstances and uses. The limited number of laboratories reporting replicate results guarantees that there will be times when differences greater than predicted by the ILS results will arise, sometimes with considerably greater or smaller frequency than the 95 % probability limit would imply. Consider the repeatability limit as a general guide, and the associated probability of 95 % as only a rough indicator of what can be expected.

13.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method; therefore, no statement on bias is being made.

13.3 The precision statement was determined through statistical examination of 12 results, from a single laboratory, on two materials, under two conditions.

14. Keywords

14.1 batting; bulk density; fabric; hot plate; insulation; thermal resistance