Standard Test Method for Thermal Transmittance of Textile Materials[1]

1. Scope

1.1 This test method covers the determination of the overall thermal transmission coefficients due to the combined action of conduction, convection, and radiation for dry specimens of textile fabrics, battings, and other materials within the limits specified in 1.2. It measures the time rate of heat transfer from a warm, dry, constant-temperature, horizontal flat-plate up through a layer of the test material to a relatively calm, cool atmosphere.

1.2 For practical purposes, this test method is limited to determinations on specimens of fabrics, layered fabric assemblies, and battings having thermal transmittances (U_2, as defined in 3.1.2) within a range of 0.7 to 14 W/m^2·K and thicknesses not in excess of 50 mm.

1.3 The coefficients obtained apply strictly only to the particular specimens tested and for the specified thermal and environmental conditions of each test. This test method gives values that are valid for comparison under the same conditions of test, that is, with the specified air velocity, temperature difference between the warm plate and the cool air, and air gap for measuring cool air temperature.

1.4 The values stated in metric units are to be regarded as the standard. Conversion factors, for thermal conductance and conductivity and thermal resistance and resistivity, to other units in common use are given in Tables 1-5

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:*

D 123 Terminology Relating to Textiles[2]

D 1777 Method for Measuring Thickness of Textile Materials[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *bulk density*, *n*—apparent mass per unit volume.

3.1.1.1 *Discussion*—In testing the thermal transmittance of fabrics, bulk density is calculated from the fabric weight per unit area and the thickness value used to calculate thermal conductivity.

3.1.2 *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 movement 0.1 m/s, or roughly the insulation value of typical indoor clothing.[3,4] (Syn. intrinsic clo).

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

3.1.3 *heat transfer coefficient*, *n*—see *thermal transmittance.*

3.1.4 *intrinsic clo*, *n*—see clo.

3.1.5 *specific clo*, *n*—the specific thermal resistance in clo units per unit thickness.

3.1.6 *thermal conductance*, *n*—see *thermal transmittance.*

3.1.7 *thermal conductivity*, *n*—time rate of unidirectional heat transfer per unit area, in the steady-state, between parallel planes separated by unit distance, per unit difference of temperature of the planes.

3.1.7.1 *Discussion*—Numerically, thermal conductivity equals the product of the heat transfer coefficient and the distance separating the planes. Thus, *k*, the thermal conductivity of the fabric only, is the product of U_2 and the fabric thickness. Units of thermal conductivity are W/m·K.

3.1.8 *thermal resistance*, *n*—reciprocal of thermal transmittance.

3.1.9 *thermal resistivity*, *n*—reciprocal of thermal conductivity.

3.1.10 *thermal transmittance*, *n*—time rate of unidirectional heat transfer per unit area, in the steady-state, between parallel planes, per unit difference of temperature of the planes (Syn. thermal conductance, heat transfer coefficient).

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

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[2] *Annual Book of ASTM Standards*, Vol 07.01.

[3] American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

[4] Gagge, A. P., Burton, A. C., Bazett, H. C., *Science,* Vol 94, Nov. 7, 1941, pp. 428–430.

TABLE 1 Conversion Factors for Thermal Conductivity[A]

To Convert Thermal Conductivity From to	Multiply by									
	W/m·K[B]	W·cm/m²·K	W/cm·K	cal/s·cm·K	kg-cal/h·m·K	kg-cal·cm/ h·m²·K	Btu/h·ft·°F	Btu·in/ h·ft²·°F	in/clo	mm/clo
W/m·K	1.	$1. \times 10^{+2}$	$1. \times 10^{-2}$	2.388×10^{-3}	8.598×10^{-1}	$8.598 \times 10^{+1}$	5.778×10^{-1}	6.934	6.093	$1.548 \times 10^{+2}$
W·cm/ m²·K	$1. \times 10^{-2}$	1.	$1. \times 10^{-4}$	2.388×10^{-5}	8.598×10^{-3}	8.598×10^{-1}	5.778×10^{-3}	6.934×10^{-2}	6.093×10^{-2}	1.548
W/cm·K	$1. \times 10^{+2}$	$1. \times 10^{+4}$	1.	2.388×10^{-1}	$8.598 \times 10^{+1}$	$8.598 \times 10^{+3}$	$5.778 \times 10^{+1}$	$6.934 \times 10^{+2}$	$6.093 \times 10^{+2}$	$1.548 \times 10^{+4}$
cal/s·cm·K	$4.187 \times 10^{+2}$	$4.187 \times 10^{+4}$	4.187	1.	$3.6 \times 10^{+2}$	$3.6 \times 10^{+4}$	$2.419 \times 10^{+2}$	$2.903 \times 10^{+3}$	$2.551 \times 10^{+3}$	$6.480 \times 10^{+4}$
kg-cal/ h·m·K	1.163	$1.163 \times 10^{+2}$	1.163×10^{-2}	2.778×10^{-3}	1.	$1. \times 10^{+2}$	6.720×10^{-1}	8.064	7.087	$1.8 \times 10^{+2}$
kg-cal·cm/ h·m²·K	1.163×10^{-2}	1.163	1.163×10^{-4}	2.778×10^{-5}	$1. \times 10^{-2}$	1.	6.720×10^{-3}	8.064×10^{-2}	7.087×10^{-2}	1.8
Btu/h·ft·°F	1.731	$1.731 \times 10^{+2}$	1.731×10^{-2}	4.134×10^{-3}	1.488	$1.488 \times 10^{+2}$	1.	$1.2 \times 10^{+1}$	$1.055 \times 10^{+1}$	$2.679 \times 10^{+2}$
Btu·in/ h·ft²·°F	1.442×10^{-1}	$1.442 \times 10^{+1}$	1.442×10^{-3}	3.445×10^{-4}	1.240×10^{-1}	$1.240 \times 10^{+1}$	8.333×10^{-2}	1.	8.788×10^{-1}	$2.232 \times 10^{+1}$
in/clo	1.641×10^{-1}	$1.641 \times 10^{+1}$	1.641×10^{-3}	3.920×10^{-4}	1.411×10^{-1}	1.411×10^{-1}	9.482×10^{-2}	1.138	1.	$2.540 \times 10^{+1}$
mm/clo	6.461×10^{-3}	6.461×10^{-1}	6.461×10^{-5}	1.543×10^{-5}	5.556×10^{-3}	5.556×10^{-1}	3.733×10^{-3}	4.480×10^{-3}	3.937×10^{-2}	1.

[A] Units are given in terms of: (1) the absolute joule per second, or watt; (2) the calorie (International Table) = 4.1868 J; (3) the British thermal unit (International Table) = 1055.06 J; and (4) the clo (unit of clothing resistance) = 0.155 K·m²/W.

[B] Recommended (SI) units.

TABLE 2 Conversion Factors for Thermal Transmittance[A]

To Convert Thermal Transmittance From to	Multiply by					
	W/m²·K[B]	W/cm²·K	cal/s·cm²·K	kg-cal/h·m²·K	Btu/h·ft²·°F	clo^{-1}
W/m²·K	1.	$1. \times 10^{-4}$	2.388×10^{-5}	8.598×10^{-1}	1.761×10^{-1}	1.548×10^{-1}
W/cm²·K	$1. \times 10^{+4}$	1.	2.388×10^{-1}	$8.598 \times 10^{+3}$	$1.761 \times 10^{+3}$	$1.548 \times 10^{+3}$
cal/s·cm²·K	$4.187 \times 10^{+4}$	4.187	1.	$3.6 \times 10^{+4}$	$7.373 \times 10^{+3}$	$6.480 \times 10^{+3}$
kg-cal/h·m²·K	1.163	1.163×10^{-4}	2.778×10^{-5}	1.	2.048×10^{-1}	1.8×10^{-1}
Btu/h·ft²·°F	5.678	5.678×10^{-4}	1.356×10^{-4}	4.882	1.	8.788×10^{-1}
clo^{-1}	6.461	6.461×10^{-4}	1.543×10^{-4}	5.556	1.138	1.

[A] Units are given in terms of: (1) the absolute joule per second, or watt; (2) the calorie (International Table) = 4.1868 J; (3) the British thermal unit (International Table) = 1055.06 J; and (4) the clo (unit of clothing resistance) = 0.155 K·m²/W.

[B] Recommended (SI) units.

3.1.10.1 *Discussion*—Thermal transmittance is expressed as watts per square metre of test specimen per kelvin difference between the hot plate and the cool atmosphere (W/m²·K).

Thermal transmittance for three different cases is determined in this method:

U_1 = combined thermal transmittance of the test specimen and air.

U_{bp} = thermal transmittance of the plate without fabric cover ("bare plate"). This property reflects the instrument constant and is used to standardize the plate, and, in conjunction with U_1, is used in the calculation of U_2.

U_2 = thermal transmittance of fabric only. This value corresponds to the *C* value (W/m²·K) defined and used by ASTM and ASHRAE.[4] In the calculation of this value the assumption is made that the boundary layers of the bare plate and the boundary layers of the fabric are equal. Experimental results indicate that the U_2 values are valid when tested within the limits specified in Section 1.

3.1.11 *total clo, n*—the intrinsic clo plus the thermal resistance from the air boundary.

3.1.12 For definitions of other textile terms used in this method, refer to Terminology D 123.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *effective insulation ratio, n*—indicates the increase in insulation afforded by the fabric in comparison to the uncovered test plate under specified conditions of test.

3.2.2 *mean temperature, n*—the average of the hot plate temperature and the temperature of the calm, cool air that prevailed during the test.

4. Significance and Use

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

4.2 The measurement of heat transfer coefficients is a very difficult and highly technical field, and it is not practical in a

TABLE 3 Conversion Factors for Thermal Resistivity[A]

To Convert Thermal Resistivity[B]	Multiply by									
From to	m·K/W[B]	m^2·K/W·cm	cm·K/W	cm·K·s/cal	m·K·h/kg-cal	m^2·K·h/kg-cal·cm	ft·°F·h/Btu	ft^2·°F·h/Btu·in	clo/in	clo/mm
m·K/W	1.	$1. \times 10^{-2}$	$1. \times 10^{+2}$	$4.187 \times 10^{+2}$	1.163	1.163×10^{-2}	1.731	1.442×10^{-1}	1.641×10^{-1}	6.461×10^{-3}
m^2·K/W·cm	$1. \times 10^{+2}$	1.	$1. \times 10^{+4}$	$4.187 \times 10^{+4}$	$1.163 \times 10^{+2}$	1.163	$1.731 \times 10^{+2}$	$1.442 \times 10^{+1}$	1.641×10^{-1}	6.461×10^{-1}
cm·K/W	$1. \times 10^{-2}$	$1. \times 10^{-4}$	1.	4.187	1.163×10^{-2}	1.163×10^{-4}	1.731×10^{-2}	1.442×10^{-3}	1.641×10^{-3}	6.461×10^{-5}
cm·K·s/cal	2.388×10^{-3}	2.388×10^{-5}	2.388×10^{-1}	1.	2.778×10^{-3}	2.778×10^{-5}	4.134×10^{-3}	3.445×10^{-4}	3.920×10^{-4}	1.543×10^{-5}
m·K·h/kg-cal	8.598×10^{-1}	8.598×10^{-3}	$8.598 \times 10^{+1}$	$3.6 \times 10^{+2}$	1.	$1. \times 10^{-2}$	1.488	1.240×10^{-1}	1.411×10^{-1}	5.556×10^{-3}
m^2·K·h/kg-cal·cm	$8.598 \times 10^{+1}$	8.598×10^{-1}	$8.598 \times 10^{+3}$	$3.6 \times 10^{+4}$	$1. \times 10^{+2}$	1.	$1.488 \times 10^{+2}$	$1.240 \times 10^{+1}$	$1.411 \times 10^{+1}$	5.556×10^{-1}
ft·°F·h/Btu	5.778×10^{-1}	5.778×10^{-3}	$5.778 \times 10^{+1}$	$2.419 \times 10^{+2}$	6.720×10^{-1}	6.720×10^{-3}	1.	8.333×10^{-2}	9.482×10^{-2}	3.733×10^{-3}
ft^2·°F·h/Btu·in	6.934	6.934×10^{-2}	$6.934 \times 10^{+2}$	$2.903 \times 10^{+3}$	8.064	8.064×10^{-2}	$1.2 \times 10^{+1}$	1.	1.138	4.480×10^{-3}
clo/in	6.093	6.093×10^{-2}	$6.093 \times 10^{+2}$	$2.551 \times 10^{+3}$	7.087	7.087×10^{-2}	$1.055 \times 10^{+1}$	8.788×10^{-1}	1.	3.937×10^{-2}
clo/mm	$1.548 \times 10^{+2}$	1.548	$1.548 \times 10^{+4}$	$6.480 \times 10^{+4}$	$1.8 \times 10^{+2}$	1.8	$2.679 \times 10^{+2}$	$2.232 \times 10^{+1}$	$2.540 \times 10^{+1}$	1.

[A] Units are given in terms of: (1) the absolute joule per second, or watt; (2) the calorie (International Table) = 4.1868 J; (3) the British thermal unit (International Table) = 1055.06 J; and (4) the clo (unit of clothing resistance) = 0.155 K·m^2/W.
[B] Recommended (SI) units.

TABLE 4 Conversion Factors for Thermal Resistance[A]

To Convert Thermal Resistance	Multiply by					
From to	m^2·K/W[B]	cm^2·K/W	cm^2·K·s/cal	m^2·K·h/kg-cal	ft^2·°F·h/Btu	clo
m^2·K/W	1.	$1. \times 10^{+4}$	$4.187 \times 10^{+4}$	1.163	5.678	6.461
cm^2·K/W	$1. \times 10^{-4}$	1.	4.187	1.163×10^{-4}	5.678×10^{-4}	6.461×10^{-4}
cm^2·K·s/cal	2.388×10^{-5}	2.388×10^{-1}	1.	2.778×10^{-5}	1.356×10^{-4}	1.543×10^{-4}
m^2·K·h/kg-cal	8.598×10^{-1}	$8.598 \times 10^{+3}$	$3.6 \times 10^{+4}$	1.	4.882	5.556
ft^2·°F·h/Btu	1.761×10^{-1}	$1.761 \times 10^{+3}$	$7.373 \times 10^{+3}$	2.048×10^{-1}	1.	1.138
clo	1.548×10^{-1}	$1.548 \times 10^{+3}$	$6.480 \times 10^{+3}$	1.8×10^{-1}	8.788×10^{-1}	1.

[A] Units are given in terms of: (1) the absolute joule per second, or watt; (2) the calorie (International Table) = 4.1868 J; (3) the British thermal unit (International Table) = 1055.06 J; and (4) the clo (unit of clothing resistance) = 0.155 K·m^2/W.
[B] Recommended (SI) units.

TABLE 5 Miscellaneous Conversion Factors

Properties	To Convert from a Value Expressed as	To a Value Expressed as	Multiply by
Mass per unit area	oz/yd^2	g/m^2	33.91
	mg/cm^2	g/m^2	10.0
Thickness	in.	mm	25.4
	1/1000 in. (mil)	mm	0.0254
Bulk density	lb/ft^3	kg/m^3	16.02
	(oz/yd^2)/in	kg/m^3	1.335
	(g/m^2)/mm	kg/m^3	1.0

test method of this scope to establish details sufficient to cover all contingencies. Departures from the instructions of Test Method D 1518 may lead to significantly different test results. Technical knowledge concerning the theory of heat flow, 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. Any significant departures are to be reported with the results.

4.3 Test Method D 1518 for the determination of the thermal transmittance of textile materials is considered satisfactory for acceptance testing of commercial shipments of textile materials because the test method has been used in the trade for acceptance testing. And it is the best test method known for this purpose.

4.3.1 In case of a dispute arising from differences in reported results when using Test Method D 1518 for acceptance testing of commercial shipments, the purchaser and the supplier should conduct comparative tests to determine if there is a statistical bias between their laboratories. Competent statistical assistance is recommended for the investigation of bias. As a minimum, the two parties should take a group of test specimens which are as homogeneous as possible and which are from a lot of material of the type in question. The test specimens should then be sent to each laboratory for testing. The average results from the two laboratories should be compared using Student's *t*-test for paired data and an acceptable probability level chosen by the two parties before testing is begun. If a bias is found, either its cause must be found and corrected or the purchaser and the supplier must agree to interpret future test results with consideration to the known bias.

5. Apparatus (Fig. 1, Fig. 2, and Fig. 3)

NOTE 1—The drawings and illustrations are intended as suggested designs only. The final design of equipment, including necessary wiring, will be dictated by the choice of the electrical measuring and control equipment.

5.1 *Hot Plate*—A guard ring flat plate composed of a test plate, guardring, and bottom plate as follows, each electrically maintained at a constant temperature in the range of human skin temperature [33 to 36°C (91.4 to 98.8°F)].

5.1.1 *Test Plate*—The test plate portion of the hot plate shall be at least 150 mm (6.0 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 and painted a dull black to approximate the emissivity of the human skin. The heating element shall consist of parallel wires, preferably of constantan metal, insulated from, but mounted within 3 mm (0.1 in.) of the upper plate.

5.1.2 *Guard Ring*—The guard ring bordering the test plate shall be at least 63.5 mm (2.5 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.

5.1.3 *Bottom Plate*—The bottom plate shall be of the same thickness, composition, and type of construction as the test plate and guard ring. 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 by a wooden framework 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. 3. The purpose of the bottom plate is to prevent a downward loss of heat from the test plate and guard ring.

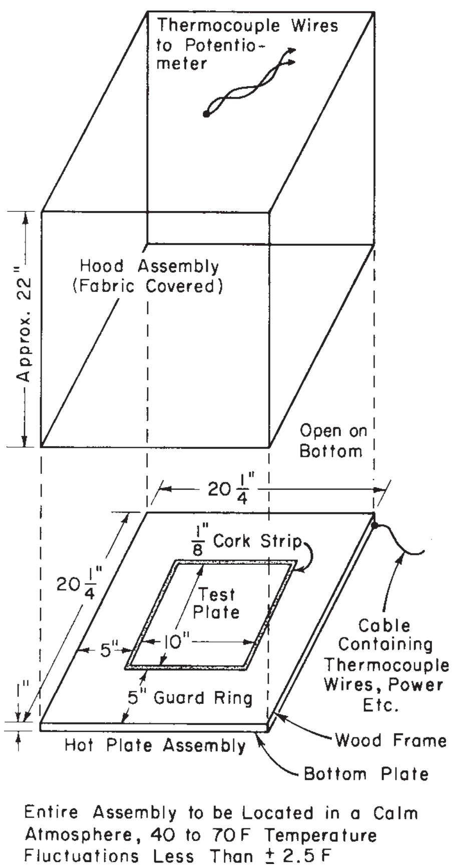

FIG. 1 Guard Ring Hot Plate For Thermal Transmittance Test

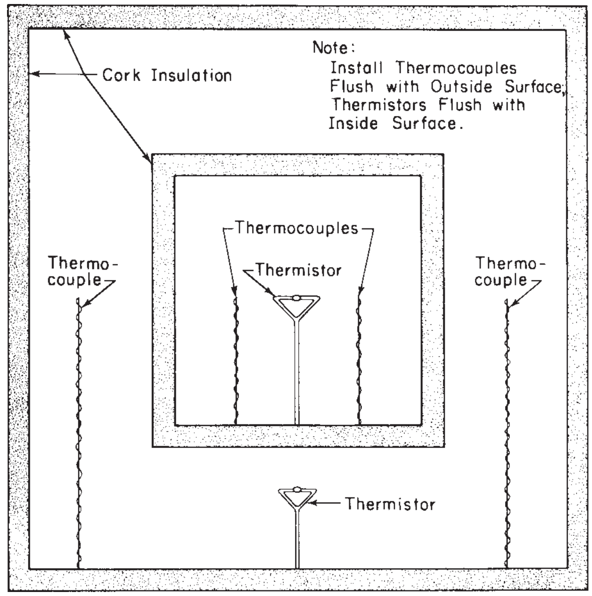

FIG. 2 Hot Plate, Top View, Showing Location of Thermistors and Thermocouples on Test Section and Guard Ring

5.2 *Temperature Control*—Separate control of the temperatures of the three sections of the hot plate (test plate, guard ring, and bottom plate) shall be established by independent adjustments of the heater currents through adjustable transformers, variable impedances, or intermittent heating cycles. Automatic regulation of temperatures is recommended. Use a constant voltage supply, controlled to ±1 % to minimize fluctuations in temperature.

5.3 *Power-Measuring Instruments*—One of any of the following instruments shall be used for measuring power:

5.3.1 Wattmeter,

5.3.2 Watt-hour meter and clock,

5.3.3 Voltmeter and ammeter, or

5.3.4 Either a voltmeter *or* an ammeter can be used if the test plate heater resistance at operating temperature is exactly known. These devices shall be operated in accordance with standard practice and shall be calibrated to measure power with an accuracy of ±2 %.

5.4 *Clocks*—When heater power is supplied on an intermittent basis, a running-time clock, energized in synchronism with the heater, shall be used to indicate the total time of heating. Another similar clock shall be used to indicate either the total time or the time during which the heater is not energized. The total limit of error of such clocks shall be less than 1 % under service conditions.

5.5 *Equipment for Measuring the Several Plate Temperatures*:

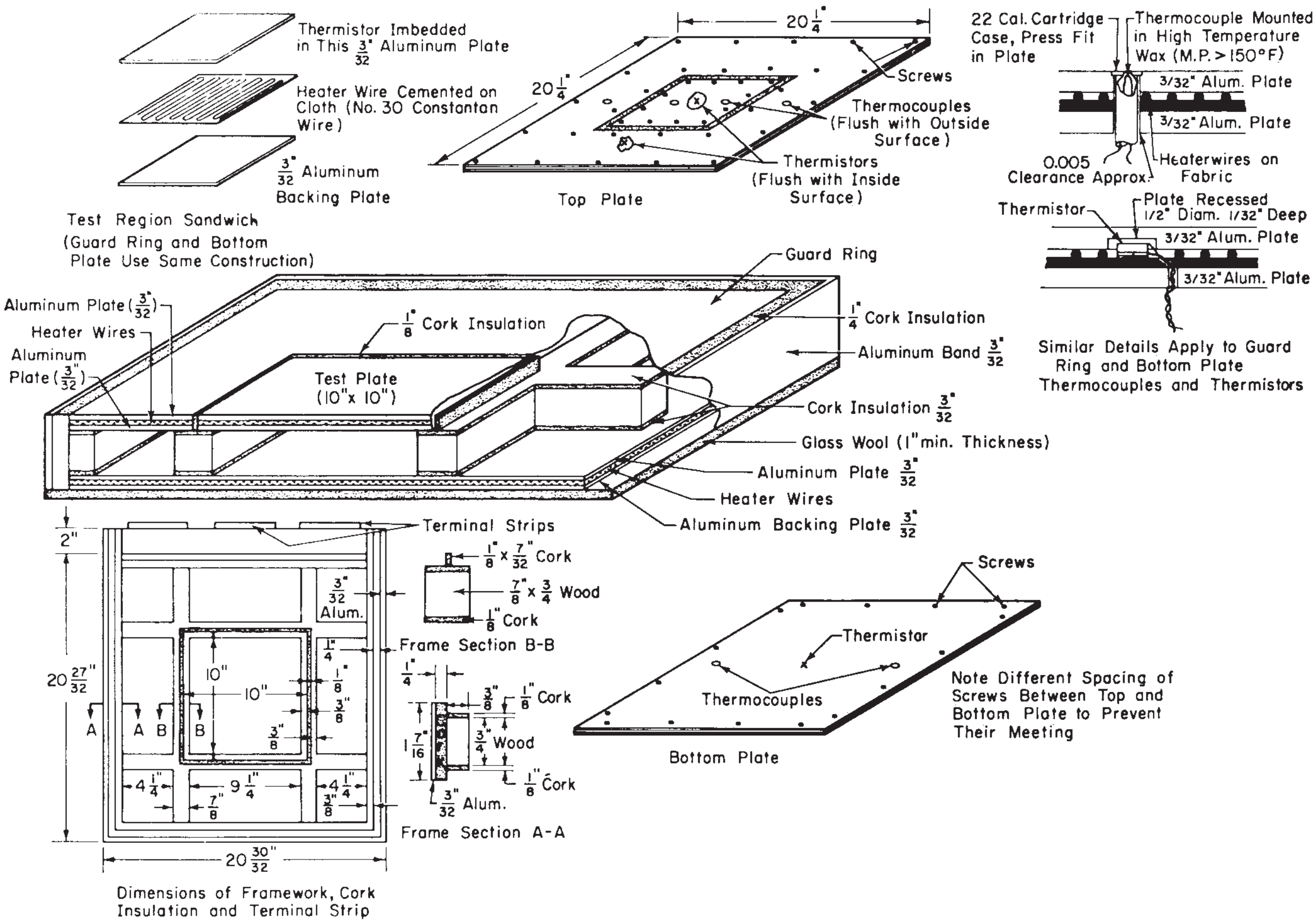

FIG. 3 Apparatus for Measurement of Thermal Transmittance, Showing Dimensions

5.5.1 *Thermocouples*—The test plate, guard ring, and bottom plate shall each contain one or more thermocouples made of a junction of wires of copper and constantan, each of B & S Gage No. 30 [0.255 mm (0.01 in.)]. After calibration, these thermocouples shall be positioned within the material of the plates as close to the external plate surfaces as physically possible [1.6 mm (0.06 in.)] to measure the temperatures of the respective surfaces.

5.5.2 *Ice Bath*, as a reference junction for the thermocouples, or equivalent device.

5.5.3 *Potentiometer*, accurate within ±2.5 µV, to measure the thermocouple emf's.

5.5.4 *Switch*—A thermocouple selector switch for separately connecting to each set of thermocouples.

5.6 *Test Chamber*—A chamber to house the hot plate that can be maintained at selected temperatures between 4.5 and 21.1°C (40 to 70°F) with a constancy of ±0.5°C (± 2.5°F). The walls of the test chamber shall not be highly reflective, and the wall temperature shall be equal to that of the air in the chamber. The chamber shall be equipped with the following instruments for maintaining the relative humidity at 50± 30 % for maintaining the air temperature, and for controlling the air velocity at the approximate rate of 0.1 m/s (0.33 ft/s). The hood for maintaining nearly still air conditions, shown in Fig. 1, is needed.

5.6.1 *Relative Humidity Measuring Equipment*—Either a wet-and-dry bulb psychrometer or a calibrated humidity-sensitive electrical conductor.

5.6.2 *Air Temperature Detector*—A thermocouple similar to those in the plates is suspended with the measuring junction exposed to the air at a point 500 mm (20.0 in.) above the center of the test plate, inside hood.

5.6.3 *Air Velocity Indicator*—Any calibrated means of measuring air velocity at the specified rate.

6. Sampling

6.1 *Lot Sample*—for acceptance testing take a lot sample as directed in the applicable material specification, or as agreed upon between purchaser and supplier. In the absence of such a specification or other agreement, take a laboratory sample as directed in 6.2.

6.2 Take a laboratory sample from each roll or piece of fabric in the lot sample. The laboratory sample should be full width and at least 600 mm (24 in.) long and should not be taken any closer to the end of the roll or piece of fabric than 1 m (1 yd).

6.3 Sample shipments of garments or other textile materials as agreed upon between purchaser and seller.

6.4 Test three specimens from each laboratory sample, unless otherwise specified in the material specification.

7. Preparation of Test Specimens

7.1 *Modification of a Thick Material to Facilitate Testing*—Materials more than 25-mm (1–in.) thick, such as some fibrous battings, require an extremely long period for reaching equilibrium. In such a case, if the specimen has a homogeneous structure, and it is physically possible to slice through the material in such a manner as to split it into two or more uniform layers thinner than the original, one of the thin layers may be tested and its coefficient determined. (This is not applicable to fabric assemblies or to otherwise heterogeneous material.)

7.2 *Specimen Preparation*—Cut the test specimens large enough to cover completely the entire surface of the hot plate and the guard plates, or about 510 mm (20 in.) square. Remove any wrinkles from the test specimens by allowing to hang free or by ironing. For quilted fabrics or batts, sew or seal the edges or use retaining slats during the testing.

7.3 *Conditioning*—Allow the test specimens to come into equilibrium with the atmosphere of the testing chamber. Moisture equilibrium for testing is considered as having been reached when the rate of increase in mass of a sample or specimen does not exceed that specified for the material being tested.

7.3.1 In the absence of a specified rate, an increase of less than 0.1 % of the sample mass after a 2-h exposure is considered satisfactory.

8. Preparation and Standardization of Apparatus

8.1 *Test Conditions*—Unless otherwise specified in the detail specification, use the following test conditions:

8.1.1 *Temperature of the Test Plate, Guard Ring, and Bottom Plate*—Select a temperature in the range from 33 to 36°C (91.4 to 98°F) to be maintained for the duration of the test for the test plate, guard ring, and the bottom plate.

8.1.2 *Maximum Difference in Temperature*—Maintain and stabilize the test equipment to have a maximum temperature difference between either the guard ring or bottom plate and the test plate of ±0.3°C.

8.2 *Temperature of Test Chamber* (External to the Hood)—Maintain the average temperature of the test chamber at a specified temperature between 4.5 and 21.1°C (40 to 70°F) with a range in temperature not to exceed ±0.5°C (±2.5°F).

8.3 *Relative Humidity Within the Test Chamber*—Maintain the relative humidity within the test chamber at a selected level between 20 and 80 % with a range not to exceed ±5 %.

9. Procedure

9.1 Determine the thickness of the original specimen and, if necessary (see 6.1), the component layer to be tested to within 0.3 mm (0.01 in.) at a loading pressure of 0.07 kPa (0.01 psi) as directed in Method D 1777. Use any suitable thickness gage having a presser foot diameter of at least 50 mm (2 in.).

9.2 Spread the test specimen flat on the hot plate with the finished side up, unless otherwise specified. Ensure good thermal contact by smoothing out any abnormal wrinkles or air pockets between the specimen and the plate surface. Unless otherwise specified, use no supplemental loading beyond the intrinsic mass of the specimen.

9.3 Bring the hot plate to the operating temperature and allow the system (specimen plus plate) to reach equilibrium, defined as that state in which the test-plate temperature and the power input remains constant. The temperature shall be held within ±0.5°C and the average temperature shall not be allowed to drift more than ±0.05°C during a period of 30 min. To ensure a constant power input for the duration of the test, the temperature equilibrium shall be maintained using an on-off ratio for power of 50 to 60 % of the time required to complete the test.

9.4 After the assembly reaches equilibrium conditions, record measurements for each of the following conditions at least every 3 min. The average of these measurements taken over a period of 30 min shall be sufficient to determine the combined transmittance coefficient of the specimen plus the air, U_1.

9.4.1 Test plate temperature,

9.4.2 Test plate heater wattage,

9.4.3 Air temperature,

9.4.4 Guard ring temperature, and

9.4.5 Bottom plate temperature.

NOTE 2—If the foregoing observations are not consistent with equilibrium conditions, the test shall not be valid and shall be repeated after establishment of equilibrium.

9.5 *Bare Plate*—Measure the bare-plate transmittance coefficient, U_{bp}, in the same manner as that for U_1 except that the hot plate shall be uncovered during this measurement.

10. Calculations

10.1 Calculate the combined transmittance of the specimen plus the air, U_1, to within 0.005 W/m^2·K, using Eq 1:

$$U_1 = P/[A \times (T_p - T_a)] \tag{1}$$

where:
P = power loss from test plate, W,
A = area of test plate, m^2,
T_p = test plate temperature, °C, and
T_a = air temperature, °C.

10.2 Calculate the bare-plate transmittance, U_{bp}, as for U_1 in 10.1.

10.3 Calculate the intrinsic transmittance of the fabric alone, U_2, using Eq 2 or Eq 3:

$$1/U_2 = (1/U_1) - (1/U_{bp}) \tag{2}$$

or

$$U_2 = (U_{bp} \times U_1)/(U_{bp} - U_1) \tag{3}$$

10.4 Calculate the intrinsic thermal conductivity of the fabric alone, k, using Eq 4:

$$k = U_2 \times t_i/1000 \tag{4}$$

where:
t_i = thickness of the specimen, mm, at 0.07 kPa pressure.

10.5 Calculate the intrinsic thermal resistance of the fabric alone, R (Note 3), using Eq 5:

$$R = 1/U_2 \tag{5}$$

NOTE 3—The addition of values of R measured independently for two or more fabrics (one fabric of which is less than 1.3 mm thick) to calculate the thermal resistance of an ensemble, is often invalid, due to the influence of one fabric on the thermal resistance associated with the other. For example, a fleece-lined windbreaker affords far more insulation, in moving air, than the sum of the insulation of the lining and outer fabric taken separately.

10.6 Calculate the intrinsic thermal resistivity of the fabric alone, R' (Note 3), using Eq 6:

$$R' = 1/k \quad (6)$$

10.7 Calculate the intrinsic thermal resistance in Clo units using equation (7):

$$\text{Intrinsic Clo} = 1.137/U \quad (7)$$

10.8 Calculate the specific thermal resistance in Clo units using equation (8):

$$\text{Specific Clo} = 1.137/k \quad (8)$$

10.9 Calculate the bulk density, B, of the fabric, using Eq 9:

$$B = M/t \quad (9)$$

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

10.10 Calculate the split-specimen coefficient, U_2, for the thin section in accordance with 10.1, 10.2, and 10.3. Calculate the U_2 of the original section by multiplying the thin section coefficient by the thickness ratio of the thin section to the original section, using Eq 10:

$$U_{20} = U_{2t} \times (t_t/t_0) \quad (10)$$

where:
U_{20} = original split-specimen coefficient,
U_{2t} = thin section, split-specimen coefficient,
t_t = thickness of thin section, and
t_0 = thickness of the original section.

10.11 Calculate the mean temperature, T_m, for each determination using Eq 11:

$$T_m = (T_a + T_p)/2 \quad (11)$$

where:
T_a = atmosphere temperature, and
T_p = plate surface temperature.

10.12 Calculate the effective insulation ratio, I_r, using Eq 12:

$$I_r = U_{bp}/U_1 \quad (12)$$

10.13 To convert heat transfer quantities from SI to mixed, engineering, or clothing units or vice-versa multiply by the appropriate factor from Tables 1-5.

11. Report

11.1 State that the specimens were tested as directed in ASTM Test Method D 1518. Describe the materials or products sampled and the method of sampling used.

11.2 Report the following information:

11.2.1 Mean temperature of the test.

11.2.2 Average heat transfer coefficient of the bare plate alone, U_{bp},

11.2.3 Average of the heat transfer coefficient of the plate and fabric combined, U_1,

11.2.4 Thermal conductance of the fabric, U_2,

11.2.5 Fabric weight, thickness, and bulk density, and

11.2.6 Thermal conductivity, resistance, and resistivity of the fabric, as required.

11.2.7 The temperature and relative humidity used.

12. Precision and Bias

12.1 *Summary*—In comparing two single observations for the thermal transmittance expressed as U_2, the difference should not exceed 4.5 % of the average of two observations in 95 out of 100 cases when both observations are taken by the same well-trained operator using the same piece of testing equipment and specimens randomly drawn from the same sample of material. Larger differences are likely to occur under other circumstances.

12.2 *Interlaboratory Test Data*—An interlaboratory test was run in 1980 and 1981 in which randomly drawn samples of five materials were tested in each of five laboratories. Two operators in each of the five laboratories tested two specimens of each material. The components of variance for the thermal transmittance results are shown in Table 6. Components of variance expressed as coefficients of variation were calculated as follows:

TABLE 6 Components of Variance

Single-operator component	2.2 % of the average
Between-laboratory component	10.7 % of the average

12.3 *Critical Difference*—For the components of variance reported in Table 6, two averages of observed values should be considered significantly different at the 95 % probability level if the differences equal or exceed critical differences shown in Table 7.

TABLE 7 Critical Difference for the Components of Variance

Number of Observations in Each Average	Critical Difference, % of Grand Average for the Condition Noted[A,B]	
	Single Operator Precision	Between Laboratory Precision
1	6.2	29.7
5	2.8	13.2
10	2.0	9.4

[A] The critical differences were calculated using $t = 1.960$, which is based on infinite degrees of freedom.

[B] To convert the values of critical differences to units of measure, multiply the critical difference by the average of the two specific sets of data being compared, then divide by 100.

12.4 *Confidence Limits*—For the components of variance in Table 6 single averages of observed values have 95 % confidence limits (Note 4) in Table 8.

TABLE 8 Confidence Limits

Number of Observations in Each Average	Width of 95 % Confidence Limits, % of Grand Average for the Condition Noted	
	Single Operator Precision	Between Laboratory Precision
1	4.4	20.9
5	2.0	9.4
10	1.4	6.6

NOTE 4—The tabulated values of the critical differences and confidence limits should be considered to be a general statement, particularly with respect to between-laboratory precision. Before a meaningful statement can be made about two specific laboratories, the amount of statistical bias,

if any, between them must be established, with each comparison being based on recent data obtained on specimens randomly drawn from one sample of the material to be evaluated.

12.5 *Bias*—The value of the thermal transmittance can only be defined in terms of a specific test. Within this limitation Test Method D 1518 has no known bias.

13. Keywords

13.1 batting; textile fabrics; thermal transmittance