Designation: D 7024 – 04

Standard Test Method for Steady State and Dynamic Thermal Performance of Textile Materials[1,2]

This standard is issued under the fixed designation D 7024; 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.

1. Scope

1.1 This test method covers the determination of the overall thermal transmission coefficient due to conduction for dry specimens of textile fabrics, battings, and other materials and the determination of the temperature regulating factor (TRF) defined below.

1.2 *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]

D 123 Terminology Relating to Textiles
D 1518 Test Method for Thermal Transmittance of Textile Materials
D 1776 Practice for Conditioning and Testing Textiles
D 1777 Method for Measuring Thickness of Textile Materials

3. Terminology

3.1 *Definitions:*

3.1.1 *temperature difference, ΔT*—temperature difference between two surfaces of a fabric, °C.

3.1.2 *temperature regulating factor, TRF*—amplitude of the temperature variation of the hot plate divided by the product of the amplitude of the hot plate flux variation and the steady state R-value, all determined according to the test protocol described below. The temperature regulating factor is useful in comparing fabrics that store and release energy and thereby regulate their surface temperature.

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

4. Summary of Test Method

4.1 In order to determine the steady state R-value and the temperature regulating for a sample fabric, the apparatus of Fig. 1 is used. Fabric is sandwiched between a hot plate and two cold plates, one on either side of the hot plate. A controlled flux, either constant or varying, is maintained for the hot plate while the cold plates are maintained at constant temperature. To measure the steady state thermal resistance (R-value) of the fabric, the controlled flux is constant and the test proceeds until steady state is reached. To measure the temperature regulating factor (TRF), the flux is varied sinusoidally with time.

5. Significance and Use

5.1 This method provides for the determination of the steady state thermal resistance of a fabric or layers of fabrics and for the determination of the temperature regulating factor (TRF) as defined below. This test method is considered satisfactory for acceptance testing of commercial shipments because the round robin testing shows high precision and no bias for testing of textile fabrics and foams.

5.1.1 If there are differences of practical significance between reported test results for two laboratories (or more), comparative test should be performed to determine if there is a statistical bias between them, using competent statistical assistance. As a minimum, use the samples for such a comparative test that are as homogeneous as possible, drawn from the same lot of material as the samples that resulted in disparate results during initial testing and randomly assigned in equal numbers to each laboratory. The test results from the laboratories involved should be compared using a statistical test for unpaired data, a probability level chosen prior to the testing series. If bias is found, either its cause must be found and corrected, or future test results for that material must be adjusted in consideration of the known bias.

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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] The test apparatus described below is covered by a patent. Interested parties are invited to submit information regarding the identification of an alternative(s) to this patented item to the ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

[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.

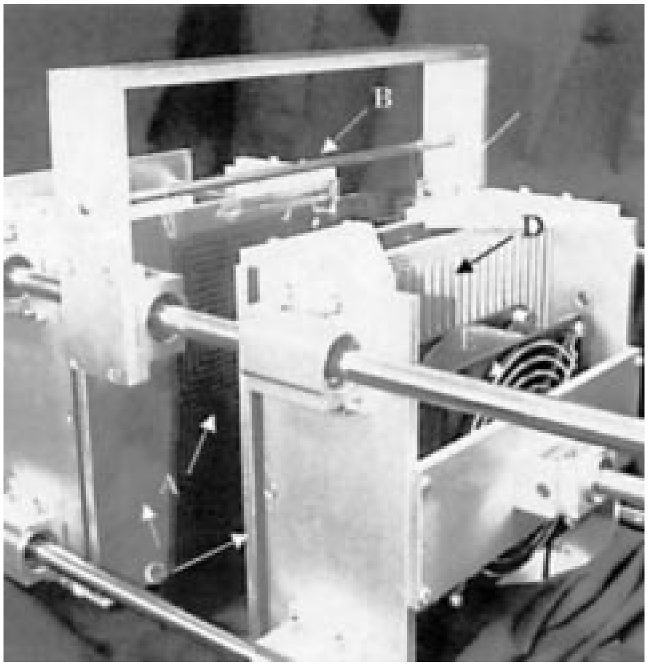

FIG. 1 Major Components of the Test Apparatus

5.2 This test method is useful in quality and cost control during manufacture. It can be used to establish criteria for establishing thermal and comfort parameters for textiles particularly used in the clothing industry.

6. Apparatus

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. The apparatus is shown in Fig. 1.

6.1 The test instrument, with major components labeled, is shown in Fig. 1. In the center of the device is a flexible heater (A) that is made of a sturdy polymer material (Kapton®) that is pliable due to the heater's thinness (0.25 mm). A thin etched metal foil is contained inside the polymer sheet to provide resistance heating. Since the heater is very thin and light, the time constant of the heater is negligible compared to the cycle time of the tests performed (see Test Protocol below). Above the heater is a metal rod (B) from which the textile specimen is hung. The specimen is large enough to cover the heater on both sides. On both sides of the heater are aluminum cold plates (C). These plates are cooled to a specified temperature using thermoelectric coolers sandwiched between the cold plates and heat sinks. Heat from the cooled plates is rejected via the aluminum heat sinks (D) and attached fans (E). The hot and cold plates are both 205 by 205 mm (8 by 8 in.). The cold plates are 4.76 mm ($\frac{3}{16}$ in.) thick. The hot plate and cold plates are suspended on linear bearings so that during operation, the cold plates can be pressed against the textile specimen at constant pressure provided by a compression spring. The pressure used should be a common pressure used when measuring fabric thickness. Temperatures are measured by thermocouples attached to the surfaces of the heater and cold plates. All energy inputs and temperatures are recorded by a computer data acquisition system.

6.2 Fig. 2 shows an exploded drawing of the apparatus.

7. Sampling

7.1 *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 7.2.

7.2 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).

7.3 Sample shipments of garments or other textile materials as agreed upon between purchaser and supplier.

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

8. Preparation of Test Specimens

8.1 *Specimen Preparation*—Cut the test specimens large enough to cover completely the entire surface of both sides of the hot plate, or at least 460 mm (18 in.) by 205 mm (8 in).

8.2 *Room Condition*—The room is which testing occurs is to be maintained at 21 ± 1°C (72 ± 2°F) and 65 % relative humidity ±2 %.

8.3 *Conditioning*—Allow the test specimens to come into equilibrium with the atmosphere of the testing room. 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.

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

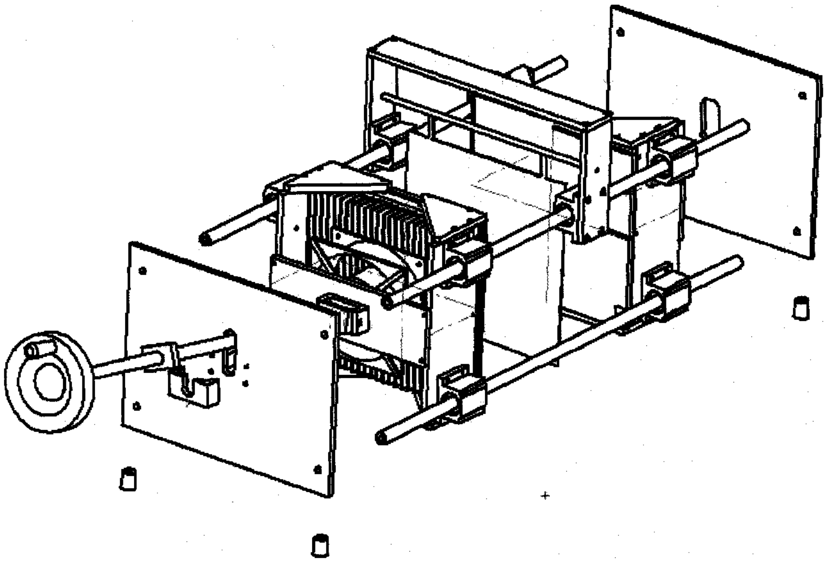

FIG. 2 Exploded View of Apparatus

9. Procedure

9.1 The test protocol is intended to provide data needed to calculate a temperature regulating factor (TRF) for the fabric. Software controls the hot plate heat rate in a sinusoidal fashion with a period of 15 minutes. The midpoint of the sinusoid is typically 150 W/m^2 and the amplitude above and below the midpoint is typically 100 W/m^2.

9.2 The cold plates are maintained at a constant temperature through feedback controllers implemented in the software. The measured cold plate temperatures are compared to the desired temperature and the voltages output to the thermoelectric coolers are varied to maintain a constant temperature. Each cold plate is controlled by a separate feedback loop. The user selects the cold plate temperature.

9.3 Two tests are performed on each fabric, one to measure the steady-state R-value and the other to determine the TRF. For the R-value test, the flux through the hot plate is kept constant, typically at 250 W/m^2, by setting the amplitude of the sinusoidal variation to zero. The cold plate temperature, Tcold, is kept constant, typically at 20°C. The test is run until the hot plate temperature, Thot, reaches a steady-state constant value. For example:

$$q = \frac{1}{R}(T_{hot} - T_{cold}) = \frac{1}{R}\Delta T \quad \text{hence, } R = \frac{\Delta T}{q} \qquad (1)$$

In one test the cold plate temperature was 20°C and the hot plate reached 36.3°C while the flux was 250 W/m^2. Therefore:

$$R = \frac{16.3}{250} = 0.0652 \mathrm{m}^{2\circ}\mathrm{C}/w$$

9.4 For the transient TRF test, the flux through the hot plate varies sinusoidaly, typically about a mean flux of 150 W/m^2. It is desirable for the temperature variation of the hot plate to be centered about the mid-point of the phase-change region for the fabric being tested. This can be accomplished by adjusting the cold plate temperature based on the results of the steady-state test. For example from Eq 1:

$$T_{cold} = T_{hot} - q \cdot R \qquad (2)$$

Continuing the example, if the mid-point of the phase-change region is 23°C then:

$$T_{cold} = 23 - 150 \cdot 0.0652 = 13.2°\mathrm{C}$$

9.5 Next the amplitude of the sinusoidal variation needs to be determined so that the hot plate temperature stays within the phase transition temperature range. Continuing with our example, if the phase transition of the fabric occurs within 23 ± 6°C we can compute conservative estimates of the maximum and minimum flux using Eq 1:

$$q_{max} = \frac{1}{R}(T_{max} - T_{cold}) = \frac{1}{0.0652}(29 - 13.2) = 242 \text{ w/m}^2$$

$$q_{min} = \frac{1}{R}(T_{min} - T_{cold}) = \frac{1}{0.0652}(17 - 13.2) = 58 \text{ w/m}^2$$

Hence the amplitude about the mean of 150 W/m^2 is 184 W/m^2.

9.6 Two cycles of 15 min in length are run, varying the energy input to the hot plate. The plate temperature for the second cycle is recorded.

TABLE 1 Results of Precision Testing

	6327 R-value, Sample 1 and 2	6327 TRF, Sample 1 and 2	6520 R-value, Sample 1 and 2	6520 TRF, Sample 1 and 2	5355 R-value, Sample 1 and 2	5355 TRF, Sample 1 and 2	Average for R Value	Average for TRF
Average of Cell Averages	0.181	0.501	0.074	0.815	0.092	0.903	0.116	0.739
Std Dev of Cell Averages	0.009	0.073	0.004	0.043	0.003	0.013	0.005	0.043
Std Dev as % of mean	5.24 %	14.59 %	4.76 %	5.26 %	3.53 %	1.47 %	4.69 %	5.82 %
Repeatability Std Dev	0.001	0.014	0.002	0.022	0.002	0.015	0.002	0.017
Reproducibility Std Dev	0.010	0.074	0.004	0.047	0.004	0.019	0.006	0.047

10. Calculations

10.1 The steady state R-value is obtained from the first test by dividing the steady state temperature difference by the flux. The steady state test data can also be used to determine the thermal resistivity, thermal transmittance, thermal conductivity, thermal conductance and clo calculated according to the definitions in Terminology D 123.

10.2 During the second cycle, the amplitude of the temperature variation of the hot plate ($T_{max} - T_{min}$) and the amplitude of the flux variation ($q_{max} - q_{min}$) are determined. At the end of the second cycle, the temperature amplitude is divided by the flux amplitude and R-value to determine the TRF. For example, for a particular fabric, the maximum temperature (T_{max}) reached during the test was 28°C and the minimum temperature was 18°C. The maximum flux (q_{max}) was 242 W/m^2 and the minimum flux (q_{min}) was 58 W/m^2. The steady-state R-value was 0.0652°C m^2/W. The TRF was calculated as follows:

(3)

11. Report

11.1 State that the specimens were tested as directed in Test Method D 7024. Describe the materials or products sampled and the method of sampling used.

11.2 Report the following information:

11.2.1 Hot and cold plate temperatures and flux during the steady state test.

11.2.2 Steady state R-value of the fabric, R. The thermal resistivity, thermal transmittance, thermal conductivity, thermal conductance and clo may be optionally reported.

11.2.3 Cold plate temperature, minimum and maximum temperatures of the hot plate, and minimum and maximum flux during the transient test.

11.2.4 Temperature regulating factor of the fabric, TRF.

11.2.5 Plot of variation of hot plate temperature about the mean for the second cycle of the transient test.

12. Precision and Bias

12.1 A precision and bias study was carried out in accordance with ASTM E 691 by two labs and two technicians at each lab with two samples of each of three fabrics—a total of 96 fabric tests. Results are summarized in Table 1.

12.1.1 6327, is a 7 mm, 2 lb/ft^2 density, helmet foam, the average of cell averages for the TRF over all samples and the 4 testers was 0.501, differing little over labs, testers, or samples. 6520 is a 2 mm foam, 6 lb/ft^2 density, boot foam. Fabric 5355, is a coated fleece. These fabrics were selected because they have a range of TRF values, from 0.5 to 0.9.

12.1.2 The repeatability standard deviation has been determined to be less than 3 % of the mean value of the TRF for three different fabrics tested as described above. The reproducibility standard deviation is less than 6.7 % of the mean value.

12.2 Bias cannot be assessed because the proposed test method in this standard is the only way to determine the TRF. However, heat transfer theory predicts that there will be no bias if instruments are properly calibrated.