BRITISH STANDARD

BS 4745:2005

Determination of the thermal resistance of textiles — Two-plate method: fixed pressure procedure, two-plate method: fixed opening procedure, and single-plate method

ORIGINAL

CONTROLLED

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British Standards

Committees responsible for this British Standard

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Association of Consulting Scientists
Association of Suppliers to the British Clothing Industry
British Apparel and Textile Confederation
British Measurement and Testing Association
British Textile Machinery Association
British Textile Technology Group
Defence Procurement Agency
Furniture Industry Research Association
National Wool Textile Export Corporation
S A T R A Technology Centre
Society of Dyers and Colourists
Textile Institute
UK Textile Laboratories Forum
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Contents

Foreword

This British Standard has been prepared by Technical Committee TCI/24. It supersedes BS 4745:1990, which has been withdrawn.

The method has been derived from ISO 5085-1:1989, *Textile determination of thermal resistance of textiles — Part 1: Low thermal resistance*, and has been modified by TCI/24.

Three methods for the determination of thermal resistance are described, as referred to in the scope. The method used must be agreed between interested parties because the results from the different methods are not necessarily comparable.

Related standards are:

— ISO 5085-2, *Textiles — Determination of thermal resistance of textiles — Part 2: High thermal resistance.*

— BS 874-1, BS 874-3.1, BS 874-3.2: Methods for determining thermal insulation properties.

This new edition of BS 4745 incorporates technical changes only. It does not reflect a full review or revision of the standard, which will be undertaken in due course.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 9 and a back cover.

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1 Scope

This part of BS 4745 specifies three methods for the determination of the resistance of fabrics, fabric assemblies or fibre aggregates in sheet form to the transmission of heat through them in the steady state condition. It applies to materials whose thermal resistance is up to approximately 0.2 $m^2 \cdot K/W$.

These methods are suitable for materials up to 20 mm thick (above this thickness, edge losses become appreciable). Advice on suitable components for constructing the apparatus is given in Annex A and means of calculating the thermal conductivity are described in Annex B.

Three methods are described:

a) two-plate method: fixed pressure procedure;

b) two-plate method: fixed opening procedure;

c) single-plate method.

Either of the two-plate methods is suitable for materials that, when in use, have their outer faces shielded from the ambient air, e.g a blanket when covered by a bedspread.

The single-plate method is suitable for materials that, when in use, have their outer faces exposed to the ambient air (e.g. bedspreads and outerwear).

The two-plate methods are generally preferred on accuracy and reproducibility grounds.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the reference cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN ISO 5084, *Textiles — Determination of thickness of textiles and textile products.*

ISO 139, *Textiles — Standard atmospheres for conditioning and testing.*

ISO 8302, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Guarded hot plate apparatus.*

3 Terms and definitions

For the purposes of this British Standard, the following terms and definitions apply.

3.1
thermal resistance
R
ratio of the temperature difference between the two faces of a test specimen to the rate of flow of heat per unit area normal to the faces. It is analogous to electrical resistance in the case of current flow through an electrical conductor

3.2
thermal conductivity
k
quantity of heat that passes in unit time through unit area of a slab of infinite extent and of unit thickness when unit difference of temperature exists between the faces of the slab

NOTE 1 $R = \frac{d}{k}$

where

d is the thickness of the slab.

NOTE 2 For a flat material having parallel faces, thermal conductivity is the reciprocal of thermal resistance per unit thickness .

NOTE 3 Since a textile is a heterogeneous system consisting of fibres and air, the term thermal conductivity does not have its usual precise meaning since, in addition to conduction, heat can be transferred through a textile by radiation and possibly by convection. The heat transfer rate incorporated in the definition is therefore the overall transfer by conduction and by radiation (and by convection where applicable).

3.3
togmeter
equipment described in **6.1**

4 Units

The SI unit of thermal resistance R is the square-metre kelvin per watt ($m^2 \cdot K/W$).

NOTE A practical unit of thermal resistance, widely used in the field of textiles and clothing, is the tog:
1 tog = 0.1 $m^2 \cdot K/W$.

The SI unit of thermal conductivity k is the watt per metre kelvin [W/(m·K)].

5 Principle

The temperature drop across a material of known thermal resistance (the standard resistance) and across a specimen of the material under test in series with it are measured and the thermal resistance of the specimen is determined from the values obtained.

The principle of the apparatus is that, for conductors in series with respect to the direction of heat flow, the ratio of the temperature drop across the conductors is equal to the ratio of their thermal resistance.

6 Apparatus

6.1 General

The apparatus shall be as shown in Figure 1. The apparatus shall be horizontal, with the heat flow upwards, designed so that the measurements are made with the test specimen in the horizontal position.

6.2 Principal parts

6.2.1 *Mild-steel disc* (A), 330 mm in diameter and approximately 6 mm thick, which has been annealed to relieve internal stresses.

6.2.2 *Electric heaters* (B1 and B2), clamped to the lower face of the disc A to give an even distribution of heat and capable of maintaining the temperature specified in **9.1** and **9.2**.

6.2.3 *Disc of insulating board* (C), of thermal resistance within the range 0.075 $m^2 \cdot K/W$ to 0.125 $m^2 \cdot K/W$ and of thickness between 5 mm and 25 mm. The disc shall be 330 mm in diameter and in contact with the hot plate of the apparatus. The surfaces of the disc shall be smooth, flat and parallel.

6.2.4 *Cold plate* (D), the surfaces of which shall be smooth, flat and parallel, and which results in an applied pressure of 6.9 Pa over the whole of the area of 855 cm^2, i.e. a circle of diameter (330 ± 1) mm.

— *Fixed pressure method:* In the case of the fixed pressure method, the plate shall be made of a suitably light material so that the mass of the plate itself, when resting on the specimen, provides the required pressure of 6.9 Pa. In use, the plate shall be placed gently on top of the specimen, taking care not to compress the specimen.

— *Fixed opening method:* Using a suitable thickness gauge, the thickness of the test specimen shall be measured under a pressure of 6.9 Pa. Three thickness gauges shall be placed at regular intervals around the edge of the top plate. The thickness gauges shall be set to the measured thickness of the specimen and the coldplate shall be placed on top.

6.2.5 *Insulation* (E), to reduce heat wastage.

6.2.6 *Temperature sensors* (T_1, T_2 and T_3). These sensors shall be 0.20 mm to 0.315 mm diameter copper-constantan thermocouples, calibrated to 0.01 K, or equally accurate sensors of similar size. The temperature sensors shall be fixed permanently in good thermal contact with separate 25 mm diameter discs of approximately 0.1 mm thick copper foil, which are fixed, with an epoxy-resin or similar adhesive, in small grooves in the surfaces of the disc C and the cold plate D. Aluminium foil discs, 0.006 mm thick and 140 mm in diameter, shall be stuck centrally over sensors T_2 and T_3, the whole of the exposed faces of C and D shall be painted with dull black lacquer to ensure an emissivity approaching unity.

NOTE A suitable indicator device or recorder is recommended for recording temperatures.

6.2.7 *Automatic temperature control*, achieved by means of a temperature-sensitive element (M), incorporated in a control system.

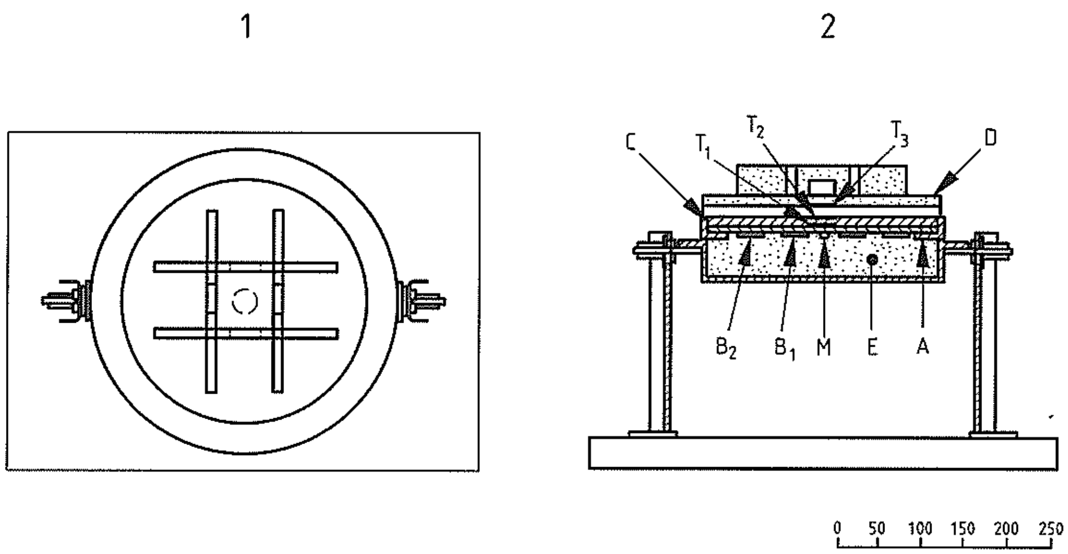
6.3 Cabinet

The apparatus shall be enclosed in the cabinet as shown in Figure 2.

NOTE The cabinet provides a shield against neighbouring sources of radiant heat and controlled ventilation across the face of the apparatus.

The extractor fan shall draw air past the apparatus from the standard atmosphere in the room through an adjustable slot at the other end of the cabinet. The fan characteristics shall be such that the air speed past the test specimen is within the range 0.25 m/s to 1 m/s.

Dimensions in millimetres



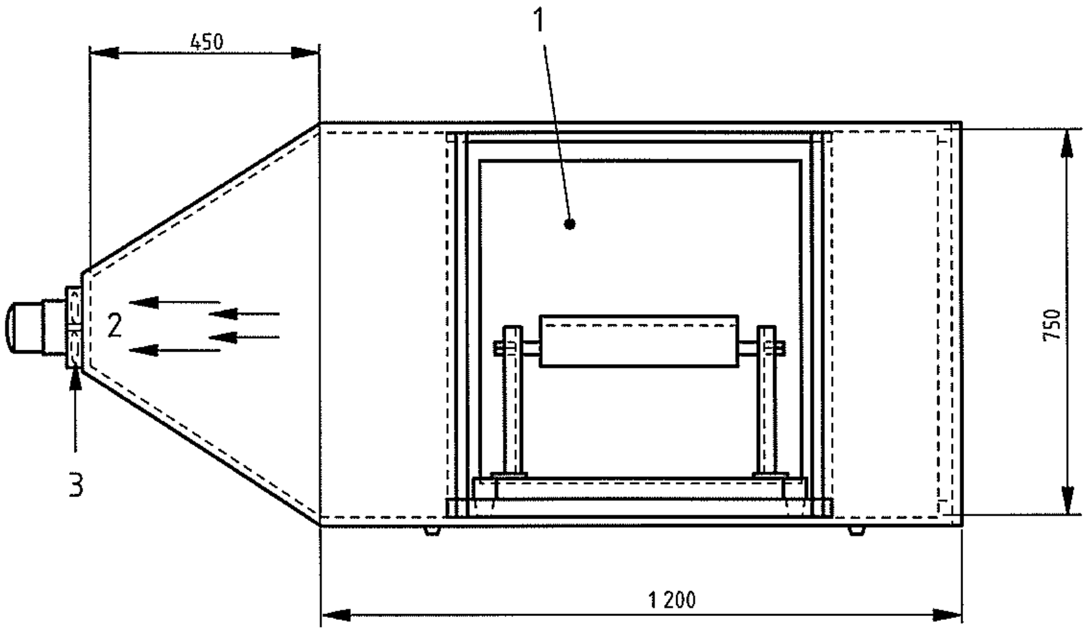
Key

1 Plan

2 Section

Figure 1 — Diagram of the apparatus

All dimensions in millimetres and approximate



Key

1 Observation window

2 Air flow

3 Extractor fan (air speed past specimen: 0.25 m/s min., 1 m/s max.)

Figure 2 — Side elevation of cabinet

7 Calibration of the standard thermal resistance

Calibrate the standard thermal resistance by one of the following procedures.

a) Conduct tests with samples of known thermal resistance, treating the standard thermal resistance as the unknown quantity to be evaluated, as described in **10.1** and **11.2**.

b) Use the method described in Annex A.

c) Use a guarded hot plate apparatus conforming to ISO 8302 to measure the heat flow, with the mean temperature of the standard thermal resistance being between 309 K and 313 K.

NOTE The temperature drop should be measured with an external calibrated thermocouple as opposed to the thermocouples that form part of the togmeter.

8 Atmosphere for conditioning and testing

The conditioning and testing atmosphere shall be one of the standard atmospheres for testing textiles defined in ISO 139.

9 Test specimens

Cut circular test specimens of diameter 330 mm, avoiding creases and folds. Condition them by laying them flat in the standard atmosphere for testing textiles for 24 h. Where possible, test three specimens of each sample.

10 Procedure

10.1 Two-plate method: Fixed pressure procedure

Lay the conditioned test specimen on the hot plate of the apparatus and place the cold plate gently on top of it, taking care not to compress the surface of the test specimen. Shield the edges from the airflow, e.g. by wrapping a strip of woven blanket or masking tape round the apparatus.

Switch on the electric heaters and adjust the temperature controller so that T_2 registers a temperature within the range 304 K to 308 K. Maintain a steady state of temperature at each of the thermocouple sites T_1, T_2 and T_3 for a period of not less than 30 min before considering a test to be completed, and ensure that the fluctuations in the various temperature levels do not exceed 0.1 K throughout this period.

NOTE For materials of low bulk density (e.g. blankets), the duration of a test from the switching on of the heaters, and including the steady state period, is approximately two hours but, for denser materials, it will be longer (approximately three hours).

Record, to the nearest 0.01 K, the temperatures registered by T_1, T_2 and T_3.

10.2 Two-plate method: fixed opening procedure

Using a suitable thickness gauge, measure the thickness of the specimen according to BS EN ISO 5084 under a pressure of 6.9 Pa.

Set the three thickness gauges on the top plate to this measured thickness.

Lay the conditioned test specimen on the hot plate of the apparatus and place the top plate on top.

Shield the edges from the airflow, e.g. by wrapping a strip of woven blanket or masking tape round the apparatus.

Switch on the electric heaters and adjust the temperature controller so that T_2 registers a temperature within the range 304 K to 308 K. Maintain a steady state of temperature at each of the thermocouple sites T_1, T_2 and T_3 for a period of not less than 30 min before considering a test to be completed, and ensure that the fluctuations in the various temperature levels do not exceed 0.1 K throughout this period.

For materials of low bulk density (e.g. blankets), the duration of a test from the switching on of the heaters, and including the steady-state period, is approximately two hours but, for denser materials, it will be longer (approximately three hours).

Note, to the nearest 0.01 K, the temperatures registered by T_1, T_2 and T_3.

10.3 Single-plate method

Lay the conditioned test specimen on the hot plate (with the edges shielded) but leave its outer face uncovered and place the cold plate underneath the apparatus. Support the cold plate, e.g. by three corks, to allow air circulation and cover with a circular piece of hardboard or metal sheet to the upper face of which a sheet of aluminium foil has been stuck in order to shield the cold plate from the radiant heat emitted by the apparatus. T_3 is now used to measure the air temperature.

Record, to the nearest 0.01 K, the temperatures registered by T_1, T_2 and T_3. Repeat the test without a test specimen (i.e. conduct a bare-plate test).

11 Calculation and expression of results

11.1 Contact resistance

NOTE Because of the finite size of the temperature sensors, a small temperature difference exists between T_2 and T_3 when the hot and cold plates are placed in contact. This is indicative of a contact thermal resistance for which allowance needs to be made in evaluating the thermal resistance of a test specimen.

When the hot and cold plates of the apparatus are in contact and a steady state has been established, calculate the contact resistance using the following equation:

$$\frac{R_c}{R_s} = \frac{\theta_2 - \theta_3}{\theta_1 - \theta_2}$$

where

R_c is the contact resistance;

R_s is the thermal resistance of the "standard";

θ_1 is the temperature registered by T_1;

θ_2 is the temperature registered by T_2;

θ_3 is the temperature registered by T_3.

11.2 Thermal resistance of test specimen by the two-plate methods

When a steady state has been established, calculate the thermal resistance R_f of the test specimen (see Annex C) using the following equation:

$$\frac{R_f + R_c}{R_s} = \frac{\theta'_2 - \theta'_3}{\theta'_1 - \theta'_2}$$

where

R_c and R_s are as defined in **11.1**;

θ'_1 is the temperature registered by T_1;

θ'_2 is the temperature registered by T_2;

θ'_3 is the temperature registered by T_3.

Now

$$\frac{R_f}{R_s} = \frac{R_f + R_c}{R_s} - \frac{R_c}{R_s}$$

Thus

$$\frac{R_f}{R_s} = \frac{\theta'_2 - \theta'_3}{\theta'_1 - \theta'_2} - \frac{\theta_2 - \theta_3}{\theta_1 - \theta_2}$$

Since R_s is known, R_f can be calculated.

11.3 Thermal resistance of test specimen by the single-plate method

In this case, calculate the sum of two thermal resistances in series, i.e. that of the test specimen itself and that of the ambient air (the latter being sometimes referred to as the surface resistance at the exposed face of the test specimen).

When a steady state has been established

$$\frac{R_f + R_c + R_a}{R_s} = \frac{\theta_2'' - \theta_a}{\theta_1'' - \theta_2''}$$

where

R_a is the thermal resistance of the ambient air;

R_c, R_s and R_f are as defined in **11.1** and **11.2**;

θ_1'' is the temperature registered by T_1;

θ_2'' is the temperature registered by T_2;

θ_a is the temperature registered by T_3 (i.e. the ambient air temperature).

When the test is repeated without the test specimen (i.e. a "bare-plate" test) and a steady state has been established

$$\frac{R_f + R_a}{R_s} = \frac{\theta_2''' - \theta_a}{\theta_1''' - \theta_1'''}$$

where

θ_1''' is the temperature registered by T_1;

θ_2''' is the temperature registered by T_2;

θ_a is the temperature registered by T_3.

Hence

$$\frac{R_f}{R_s} = \frac{\theta_2'' - \theta_a}{\theta_1'' - \theta_2''} - \frac{\theta_2''' - \theta_a}{\theta_1''' - \theta_2'''}$$

Since R_s is known, R_f can be calculated.

Calculation of the thermal conductivity k is shown in Annex B.

12 Test report

The test report shall state:

a) that the procedure was conducted in accordance with BS 4745;

b) which of the three methods was used;

c) the thermal resistance of each specimen tested and the mean thermal resistance (see Clause **11**);

d) the conditioning atmosphere used.

Annex A (normative)
Calibration of standard thermal resistance

Calculation of the standard resistance or checking of the calibration is carried out using calibrated heat flow discs embedded in a material of thermal conductivity very close to that of the disc. Cut a disc of suitable material, nominally 330 mm in diameter, with a recess in the centre of the lower surface to take the heat flow disc. Embed the heat flow disc in the recess using a thermal conduction paste or silicone rubber. Place the disc in the apparatus on top of the standard resistance and apply a load to the top surface to ensure good contact between the disc and the standard.

By measuring the output *H*, in millivolts, from the heat flow disc and the temperature drop $\theta_2 - \theta_1$, in kelvin, across the standard, as registered by thermocouples T_1 and T_2, the thermal resistance R_s of the standard can be calculated, in squaremetre kelvins per watt, from the equation

$$R_s = \frac{\theta_2 - \theta_1}{HC_d}$$

where

C_d is the calibration constant of disc.

Annex B (normative)
Thermal conductivity

Calculation of the thermal conductivity *k* of a test specimen requires knowledge of the thickness of the material under the conditions of the thermal resistance test. For a test specimen under a pressure of 6.9 Pa:

$$k = \frac{d \times 10^{-3}}{R_f}$$

where

k is the thermal conductivity (W/m·K)

d is the thickness (mm)

R_f is the thermal resistance (m^2·K/W)

or

$$k = \frac{d \times 10^{-2}}{R_f}$$

R_f is the thermal resistance (togs).

Annex C (informative)
Accuracy

The value determined for the thermal resistance R_f of a test specimen depends upon the accuracy of the determination of the temperature and the variation in R_s with the mean temperature of the disc (see **6.2**). As a consequence, the estimated value of R_f relative to R_s is subject to an error not exceeding 2 %. This error applies to any programme of work conducted with a particular apparatus. However, the determination of the value of R_s is itself subject to an error of 2.5 % and, taking this into account, it is considered that the determination of R_f with the apparatus described in this standard method is subject to an overall error of 3 % to 3.5 %.

Bibliography

ISO 5085-2:1990, *Textiles — Determination of thermal resistance of textiles — Part 2: High thermal resistance.*

BS 874-1, *Methods for determining thermal insulation properties — Part 1: Introduction, definitions and principles of measurement.*

BS 874-3.1, *Methods for determining thermal insulation properties — Part 3: Tests for thermal transmittance and conductance — Section 3.1: Guarded hot-box method.*

BS 874-3.2, *Methods for determining thermal insulation properties — Part 3: Tests for thermal transmittance and conductance — Section 3.2: Calibrated hot-box method.*

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