

Methods for

# Determining thermal insulating properties with definitions of thermal insulating terms

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- Electrical Research Association
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- Eurisol-UK Association of Manufacturers of Mineral Fibre Insulation
- Gypsum Plasterboard Development Association
- Royal Institute of British Architects
- Structural Insulation Association
- Thermal Insulation Contractors' Association

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# Foreword

BS 874 was first issued in 1939 and revised in 1956 and in 1965.

In the present revision a few changes have been made in the text of the 1965 issue.

The standard has been metricated using SI units [For further information on SI units reference should be made to BS 3763 *“The International System of units (SI)”*]. British units and their conversion factors are shown for reference purposes only (see Appendix F).

Additional references have been added in respect of recent work on this subject. Particular attention is drawn to the appendices describing additional methods of measuring thermal conductivity. The scope and purpose of these additional methods is explained in Appendix A.

The properties of materials, including thermal conductivity, may change during their working life and provision is not made in this standard for the general requirements of thermal insulating materials. Reference should be made to other British Standards according to the type and use of the product.

British Standards dealing with the general requirements of thermal insulating materials are as follows:

BS 1334, *The use of thermal insulating materials for central heating and hot and cold water supply installations.*

BS 1588, *The use of thermal insulating materials in the temperature range 95 °C to 230 °C.*

BS 1902, *Methods of testing refractory materials.*

BS 1902-1A, *Sampling and physical tests.*

BS 2972, *Methods of test for thermal insulating materials*<sup>1)</sup>.

BS 3533, *Glossary of terms relating to thermal insulation.*

BS 3708, *The use of thermal insulating materials between 230 °C and 650 °C.*

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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## Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 30, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

<sup>1)</sup> In process of revision



## Introduction

In expressing the results of tests, or in calculations relative to the passage of heat through materials, a number of technical terms are in use of which a selection is defined below. Of these, terms ending in “ivity” have been used to designate properties normally independent of size or shape, sometimes called specific properties, examples being “conductivity” and “resistivity”. Each quantity defined may be expressed in a variety of units, consequently no units have been explicitly stated in the definitions. A summary of the chief systems in common use is given in Appendix F.

In some of the definitions, reference is made to “hot and cold faces”. In all such cases it is assumed that the system through which heat is flowing has two identifiable isothermal surfaces (not necessarily plane). It should be realized that in some instances, such as furnace work, the “cold” face of the material may in fact be at a fairly high temperature, whilst in refrigeration work, on the other hand, the “hot” face may be below freezing point.

The simplest system is a uniform material, i.e. a material such that if a sample is enclosed between flat parallel hot and cold faces at given temperatures, the steady rate of heat conduction under given constant temperature conditions is proportional to the area of these faces and inversely proportional to the distance between them. Thus concrete faced with plaster is not a uniform material, since two samples having the same dimensions, but with different proportions of plaster thickness to concrete thickness, will conduct heat at different rates under the same temperature conditions.

In practice, heat flow through much more complicated systems has to be considered. All such systems are referred to below as “structures”, and this term may therefore signify objects as diverse as an insulating material made of alternate layers of metal foil and air, an aircraft cabin, a corrugated roof, the wall of a furnace, or a complete building. It is, however, still assumed in the definitions that a hot face and a cold face may be identified.

### Summary of symbols and dimensions for quantities defined

The symbols  $M$ ,  $L$  and  $T$  at the heads of the third to fifth columns in Table 1 are those for the fundamental dimensions of mass, length and time. The symbol  $\theta$  in the sixth column refers to temperature and  $Q$  in the seventh column refers to quantity of heat. The numbers in the third to seventh columns are the power indices of the dimensions appropriate to the various quantities defined. Thus the dimensions of thermal conductivity  $k$  are  $QL^{-1} T^{-1} \theta^{-1}$ .

The quantities defined may, of course, be expressed in terms of mass, length, time and temperature only, in which case the appropriate indices may be found by ascribing to quantity of heat  $Q$  the dimensions  $ML^2 T^{-2}$ .

Table 1 — Summary of symbols and dimensions of quantities

| Symbol   | Quantity                      | Dimensions in terms of |               |             |                         |             |
|----------|-------------------------------|------------------------|---------------|-------------|-------------------------|-------------|
|          |                               | Mass<br>$M$            | Length<br>$L$ | Time<br>$T$ | Temperature<br>$\theta$ | Heat<br>$Q$ |
|          |                               | Index                  |               |             |                         |             |
| $q$      | Thermal transmission          |                        |               | − 1         |                         | 1           |
| $k$      | Thermal conductivity          |                        | − 1           | − 1         | − 1                     | 1           |
| $C$      | Thermal conductance           |                        | − 2           | − 1         | − 1                     | 1           |
| $R$      | Thermal resistance            |                        | 2             | 1           | 1                       | − 1         |
| $f$      | Surface coefficient           |                        | − 2           | − 1         | − 1                     | 1           |
| $U$      | Thermal transmittance         |                        | − 2           | − 1         | − 1                     | 1           |
| $S$      | Shape factor                  |                        | 1             |             |                         |             |
| $c$      | Heat capacity per unit mass   | − 1                    |               |             | − 1                     | 1           |
| $h$      | Heat capacity per unit volume |                        | − 3           |             | − 1                     | 1           |
| $\alpha$ | Thermal diffusivity           |                        | 2             | − 1         |                         |             |
| $r$      | Reflectivity                  |                        |               |             |                         |             |
| $E$      | Emissivity                    |                        |               |             |                         |             |
| $\sigma$ | Stefan's constant             |                        | − 2           | − 1         | − 4                     | 1           |
| $f_r$    | Radiation coefficient         |                        | − 2           | − 1         | − 1                     | 1           |
| $f_c$    | Convection coefficient        |                        | − 2           | − 1         | − 1                     | 1           |
| $\rho$   | Bulk density                  | 1                      | − 3           |             |                         |             |

Some of the quantities, after verbal definition, are accompanied by a defining equation, in which the following symbols and subscripts have been adopted.

$Q$  = quantity of heat

$L$  = thickness of slab with plane parallel faces measured in the direction of heat flow

$A$  = area of hot or cold face

$\theta$  = temperature

$T$  = absolute temperature

#### Subscripts

s = surface

m = medium (air or fluid)

r = radiation

c = convection

1 = hot side

2 = cold side

## 1 General

### 1.1 Scope

This British Standard describes methods for determining thermal insulating properties of materials and includes definitions of thermal insulating terms.

NOTE The titles of the British Standards referred to in this standard are listed on the inside back cover.

### 1.2 Definitions

This clause has been superseded by BS 874-1, which is published as a separate document.

## 2 General principles of measurement

This clause has been superseded by BS 874-1, which is published as a separate document.

## 3 Testing conditions and test reports

This clause has been superseded by BS 874-1, which is published as a separate document.

## 4 Methods for determining thermal properties

### 4.1 General

This clause has been superseded by BS 874-1, which is published as a separate document.

### 4.2 Thermal conductivity

#### 4.2.1 *For materials of moderate or low conductivity*

The method given in this clause has been superseded by BS 874-2.1:1986, which is published as a separate document.

#### 4.2.2 *For materials of medium conductivity in slab form*

##### 4.2.2.1 *General*

Hot face temperature: Up to 100 °C

Thermal conductivity: Greater than 0.15 W/(m K) and less than 2.0 W/(m K).

Details of suitable unguarded hot plate test equipment are described in Appendix G.

The test procedure shall apply to all materials. Additional specific requirements which shall be observed for masonry materials such as pre-cast concrete are listed under 4.2.2.3.

**4.2.2.2 *All materials.*** Two similar specimens of material shall be tested. Their bulk density shall not differ by more than  $\pm 5\%$  from the mean density. They shall be nominally 300 mm square; and actual lengths and widths shall each be measured in at least three widely different positions and the average dimensions determined. Thicknesses of the specimens shall be preferably between 40 mm and 50 mm. For the higher conductivity materials in this range specimen thickness up to 75 mm may be used. Actual thicknesses shall be measured to the nearest 0.2 mm in at least six widely different positions and the average thickness determined. The surfaces of the specimens shall be plane and parallel. The difference in thickness across the full width shall not exceed 2 % of the mean thickness. The deviation from flatness shall not exceed 0.2 mm over the full width as judged by straightedge and feeler gauge.

When the area of the test material is insufficient to provide test specimens in one piece (e.g. most bricks and blocks), the test specimens may be constructed from several pieces. Their thickness shall be the same as the final test specimens. The densities of the pieces used in both specimens shall not differ by more than  $\pm 5\%$  from the mean density. The surfaces between the pieces shall be machined true and joined with a minimum thickness of a suitable adhesive. The width of the joints shall not exceed 1 mm and the total length shall not exceed 1 500 mm for each specimen. Contacts or joints across the heat flow in the specimen are not permitted.

Conditioning of materials shall be in accordance with 3.2.

The specimens shall be placed one on each side of the electrically heated hot plate, and the whole assembly held between the two cold plates which shall be maintained at a constant temperature by liquid flow. The hot and cold face temperatures of the specimens shall be in accordance with 3.1.

Suitable sheet, for example silicone rubber, shall be inserted between the specimens and the plates to improve the thermal contact, and to insulate the thermocouples electrically. To ensure proper thermal contact, the apparatus shall be loaded with an additional pressure of not less than  $0.003 \text{ MN/m}^2$ . This is equivalent to a mass of 30 kg acting over plates of side 300 mm.

The temperatures of each of the hot and cold faces of the specimens shall be measured by a minimum of four fine wire thermocouples. Intimate contact of the thermocouples with the surfaces of the specimens is essential, and they shall be in contact for at least 25 mm from the junction. For materials of thermal conductivity higher than  $0.5 \text{ W/(m K)}$ , the thermocouples shall be cemented into grooves in the surfaces of the specimens. Details and positioning of the thermocouples shall be in accordance with Appendix G.

The whole apparatus shall be enclosed in thermal insulating material, not less than 100 mm thick, to minimize heat losses and the effects of change in the ambient temperature outside the insulation. Suitable insulating materials are detailed in Appendix G.

The ambient temperature outside the insulation shall be within the range of the hot and cold face temperatures and shall not fluctuate by more than  $\pm 3^\circ\text{C}$ .

The thermal conductivity shall be derived from test measurements obtained under steady state conditions: as much as one and a half days may be required after first switching on the electrical input to an unguarded hot plate apparatus. When the readings indicate that conditions are steady, and this is confirmed by two subsequent measurements at not less than 1 h interval, final readings are started. Average temperatures shall be calculated for both the hot and the cold faces, and they shall be valid only when at least three consecutive conductivity values have a maximum spread of 2 %. The temperature difference between the highest and lowest readings in a set of readings on any individual hot face or cold face shall be not greater than  $1^\circ\text{C}$ .

For unguarded hot plate equipment, a correction shall be applied for the heat loss from the sides of the apparatus: this shall be determined by a test under similar conditions of thickness and temperature on a reference material of known thermal conductivity, as determined by the guarded hot plate method (see 4.2.1). Appendix G gives an example of a suitable reference material.

The thermal conductivity value reported shall be the mean of the three corrected equilibrium values.

**4.2.2.3 Masonry materials.** The following additional requirements shall be observed for masonry materials:

- a) The specimen thickness shall be at least three times the maximum nominal aggregate size and preferably between 40 mm and 50 mm.
- b) For dry densities less than  $1800 \text{ kg/m}^3$ , the specimen thickness shall be not greater than one-fifth of the length.
- c) For dry densities of  $1800 \text{ kg/m}^3$  and above, the specimen thickness shall be not greater than one-quarter of the length.
- d) Specimens shall be at least 28 days old prior to testing, and the date of manufacture of the material from which the specimens were prepared shall be reported to the testing authority.
- e) Materials shall be conditioned to constant mass by exposure to the air of a well ventilated room. In case of dispute the material shall be conditioned to a constant mass in an atmosphere of  $65 \pm 5\%$  relative humidity and at  $20 \pm 2^\circ\text{C}$ . Conditioning shall be from an initial wet condition. Accelerated drying of the specimens prior to test shall render the test invalid.
- f) The hot face temperature shall be  $27 \pm 3^\circ\text{C}$ , and the cold face temperature shall be  $10 \pm 3^\circ\text{C}$ , with the further provision that the temperature difference between hot and cold faces shall be not less than  $15^\circ\text{C}$ .
- g) The specimens shall be weighed immediately before and after testing and this shall be followed by the determination of the oven dry density of the specimens.

The moisture content of the specimens at the time of the test shall be calculated as described in 3.3 except that the dry density shall be determined by:

- 1) drying for at least 16 h in a ventilated oven having a temperature controlled at  $105^\circ\text{C}$  to  $110^\circ\text{C}$ ;
- 2) cooling the specimens in a desiccator and weighing them, and
- 3) repeating 1) and 2) until the mass lost in one cycle does not exceed 0.1 gram per millimetre of thickness of the specimen.

The test shall be invalid if:

- 1) there is a variation greater than 0.2 % by volume between the moisture contents before and after testing;
- 2) the average of the two moisture contents determined is less than 1 % by volume (except for materials of which the equilibrium moisture content is less than 1 %) or greater than 5 % by volume (except for materials of which the equilibrium moisture content exceeds 5 %).

#### **4.2.3 For materials of medium conductivity in thin sheet form**

Hot face temperature: up to approximately 100 °C

Thermal conductivity: 0.15 to 2 W/(m K)

Some materials are only available in thin sheet form and for the following method (see Refs. 6, 7, 8 and 18) the test specimen is in the form of a pair of disks 75 mm in diameter and from 3 mm to 15 mm in thickness. Care should be taken to ensure that the faces of the disks are plane and parallel; the deviation from flatness should not exceed 0.05 mm. The disks are placed one on each side of an electrically heated hot plate of the same size, and the whole is clamped between two cold plates of the same size, maintained at a constant temperature by liquid flow. A film of liquid, such as glycerol or oil, is used between the test disks and the plates to improve the thermal contact; absorbent specimens are previously coated with a very thin film of impervious material, e.g. shellac. The temperatures are determined by means of at least two thermocouples attached to each plate. The whole apparatus is enclosed in thermal insulation, from 70 mm to 100 mm thick, to minimize heat losses and the effect of changes in ambient temperature. If the apparatus is operated at temperatures above 40 °C an electrically heated guard tube about 120 mm in diameter is fitted around the apparatus to reduce heat losses.

When conditions have become steady the electrical energy dissipated in the hot plate is measured. The correction for the temperature drop across the liquid films between the disks and the plates is obtained by measurements on metal or fused silica disks of known conductivity, or by measurements on a thick and a thin disk of the test material.

The correction for the heat loss from the sides of the apparatus is obtained by measurements on disks of material of known conductivity, such as ebonite or solid plastics. These disks are to be similar in size to the test disks.

The thermal conductivity is then calculated from the corrected heat flow and from the area and thickness of the disks, together with the corrected hot and cold face temperatures.

#### **4.2.4 For materials at high temperatures**

Hot face temperature: from 100 °C to 600 °C

Thermal conductivity: up to 0.2 W/(m K)

Two similar specimens of the material to be tested are used, each about 50 mm in thickness and 450 mm square. They are placed one on either side of a hot plate, approximately 300 mm square, which is surrounded by a co-planar guard plate 450 mm square externally, with a central square hole 3 mm larger than the hot plate. Two cold plates, each 450 mm square and cooled by water flow, are placed on the outer faces of the specimens. Fine wire thermocouples (e.g. 0.2 mm) are laid in contact with the hot faces and cold faces of the specimens and they are electrically insulated from the hot and cold metal plates by being covered with thin sheets of asbestos paper. The hot plates and the guard plate have independent electrical windings. The edges of the apparatus are covered with thermal insulation at least 70 mm thick (see Refs. 9 and 10).

To carry out a test, the electrical energies are adjusted so that the temperature of the guard plate is equal to that of the hot plate when conditions have become steady. The electrical energy dissipated in the hot plate is measured and the conductivity calculated from a knowledge of this quantity, regarded as flowing through a square of area halfway between that of the hot plate and that of the central hole in the guard plate, together with the observed hot face and cold face temperatures and the thickness of the specimens.

#### 4.2.5 For materials at very high temperatures

Hot face temperature: 400 °C to 1 000 °C

Thermal conductivity: up to 1.5 W/(m K)

A test specimen 450 mm square and of uniform thickness from 50 mm to 80 mm is used. The materials tested in the apparatus may be of various types and are suitably supported horizontally in the apparatus (see Ref. 11).

1) Rigid slabs such as refractory concrete or slabs built up of bricks bonded with cement are normally held in an angle-iron frame about 600 mm square, which is fitted with screws which support the edges of the slab. Thermocouples are cemented to the bottom of shallow grooves in the surfaces of the central 230 mm square test area of the slab. Care should be taken to ensure that the faces of the slab are as flat as practicable, the deviation of the flatness over the upper (cold face) central test area should not exceed 0.2 mm.

2) Semi-rigid slabs and similar materials, such as fibrous mats or plastic compositions, are placed in the apparatus on a flat plate, e.g., of heat-resistant alloy measuring 450 mm × 450 mm by about 3 mm thick. This plate has cuts about 100 mm long in the corners and edges to reduce warping. Where the compressibility of the material makes it necessary, the thickness of the test specimen is maintained by supporting the cold plate on small distance pieces inserted in holes in the test specimen. A correction is applied for the heat flow through the distance pieces.

3) Loose fill materials, such as powders or granules, are packed as uniformly as practicable into a frame about 450 mm square resting on a plate as above. Where necessary, the thickness of the test specimen is maintained as in 2) above or by means of a grid of thin mica sheets. A correction is applied for the heat flow through the distance pieces.

The slab or plate is heated from below by electrical resistors and the quantity of heat flowing through the central area of the specimen is determined by means of a water flow calorimeter plate about 230 mm square supported on the upper face of the specimen.

The calorimeter is supplied with constant temperature water at a steady flow rate from a constant-head tank. The temperature rise of water flowing through the calorimeter is determined by a multiple-junction differential thermocouple or other suitable thermometer. (The calorimeter assembly may be calibrated by an electrical energy input method during a separate calibration test.) A water-cooled co-planar guard ring plate, about 110 mm wide, is fitted around the calorimeter plate to ensure uniform heat flow through the central area of the specimen on which measurements are made. A gap not more than 3 mm wide is maintained between the guard ring plate and the calorimeter plate in order to minimize thermal contact between these plates. The temperatures of the hot and cold surfaces of the central area are measured by means of thermocouples.

The edges of the test specimen are covered with thermal insulating material at least 70 mm thick to minimize heat losses. The exposed surfaces of the calorimeter plate and the differential thermocouple unit are insulated with at least 70 mm of low conductivity thermal insulating material.

When the conditions are steady a series of observations is made of the temperatures, the water-flow rate and the water temperature rise through the calorimeter and the heat flow is calculated from these observations. For each hot face temperature condition, observations are made using at least two different water-flow rates. The thermal conductivity of the central section of the specimen is calculated from the heat flow through the central section, regarded as flowing through a square of area halfway between that of the calorimeter and that of the central hole in the guard plate, together with the observed hot and cold face temperatures and thickness of the central section.

Thermal conductivities at high cold face temperatures are determined by measuring the temperature by means of thermocouples fixed parallel to the faces at known positions inside the test specimen.

#### 4.2.6 For high temperature insulating and refractory materials

Hot face temperature: over 800 °C

Thermal conductivity: up to about 4 W/(m K)

This method is similar to that described in 4.2.5; a detailed description is given in BS 1902.