BS 874 : Part 3 : Section 3.2 : 1990

British Standard Methods for

Determining thermal insulating properties

Part 3. Tests for thermal transmittance and conductance

Section 3.2 Calibrated hot-box method

Méthodes de détermination des propriétés d'isolation thermique
Partie 3. Essais de la transmittance et de la conductance thermiques
Section 3.2 Méthode de la boîte chaude étalonnée

Verfahren zur Bestimmung der Wärmedämmung
Teil 3. Prüfung des Wärmedurchgangs und der Wärmeleitfähigkeit
Abschnitt 3.2 Verfahren mit kalibriertem Wärmeschrank

British Standards Institution

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Foreword

This Section of BS 874 was prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Policy Committee.

Previous editions of BS 874 summarized the methods available for determining thermal insulating properties, and indicated which methods were applicable to various materials intended for use in a variety of temperature ranges, but the methods themselves were not defined in detail.

The growing importance of energy conservation and the need to have reliable information about the insulating properties of materials requires detailed specifications of the test methods. Accordingly, a complete revision of the standard is being undertaken, with each test method being fully specified. The full revision of BS 874 will take several years to complete, and it has therefore been decided to issue each test method as a separate section of BS 874 as and when it is completed, thus gradually replacing the 1973 edition.

The method presented in this Section may be used as an alternative to the guarded hot-box method given in Section 3.1 and was not originally in **4.3** of BS 874 : 1973.

It should be appreciated that experience in the use of the method is limited and revisions of this Section may become necessary as more experience is gained in the use of the method.

The accuracy levels and the reproducibility which may be expected from the method are not well established. Precision experiments, of the type described in BS 5497 : Part 1 are necessary before reliable estimates for these can be given.

It is recommended that this Section of BS 874 be read in conjunction with BS 874 : Part 1 and BS 874 : Section 3.1.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Contents

Method

0 Introduction

The method described in this Section is intended for tests on large building elements such as parts or sections of walls, roofs, floors, etc., where the thermal properties may not be uniform due to the method of fabrication and the materials used.

The method may be used as an alternative to the guarded hot-box method of BS 874 : Section 3.1. A slightly modified procedure, given in appendix A of BS 874 : Section 3.1 : 1987, enables tests to be made on smaller elements such as window systems.

The design and construction of an apparatus suitable for application of the method is a complex subject and needs to be based on sound scientific principles. While the calibrated hot-box apparatus is simpler in design and operation than the guarded hot-box of BS 874 : Section 3.1, detailed calibration procedures are required in order to produce measurements of comparable accuracy. This Section gives guidelines for apparatus design and outlines appropriate calibration procedures.

It is important that users of this method are fully conversant with the principles of heat flow and with precise thermal measurement techniques. All instruments used in this method are required to be traceable to the National Physical Laboratory (NPL) or to a laboratory acceptable to NPL.

1 Scope

This Section of BS 874 describes a method for determining the steady-state thermal transmittance and thermal conductance of construction elements using the calibrated hot-box apparatus.

The method is suitable for construction elements with thermal transmittances and conductances in the range 0.1 W/(m^2·K) to 15 W/(m^2·K) for testing within a temperature range of −50 °C to 50 °C.

Apparatus designed in accordance with this Section is capable of measurement to an accuracy of ± 5 % on test elements of uniform thermal conductance (i.e. elements with no thermal bridges between surfaces) in the conductance range 0.5 W/(m^2·K) to 5 W/(m^2·K).

NOTE 1. The potential for achieving these levels of accuracy will depend upon the apparatus, its calibration particulars, and the type of test specimen being measured. The determination of thermal transmittances or conductances below 0.5 W/(m^2·K) requires measurements of high precision, and therefore may be less accurate. Determination of thermal transmittances or conductances in the range above 5 W/(m^2·K) may also be less accurate as there may be higher surface temperature variations and difficulties with measurement of representative surface temperatures. Additionally, greater inaccuracies are to be expected for test elements of non-uniform conductance (i.e. elements with thermal bridges between surfaces).

Some building elements may pose difficult problems of measurement, and careful consideration is required before a test method is chosen. The method is considered particularly appropriate for elements with surface projections or thick metal faces, which could cause difficulties if measured in the conventional guarded hot-box configuration of BS 874 : Section 3.1.

Thermal conductance measurements are not appropriate on elements of particulary non-uniform construction (see clause **7**).

The method does not provide for measurements where there is transport of air through the test element during the test.

NOTE 2. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purpose of this Section of BS 874, the definitions given in BS 874 : Part 1 apply.

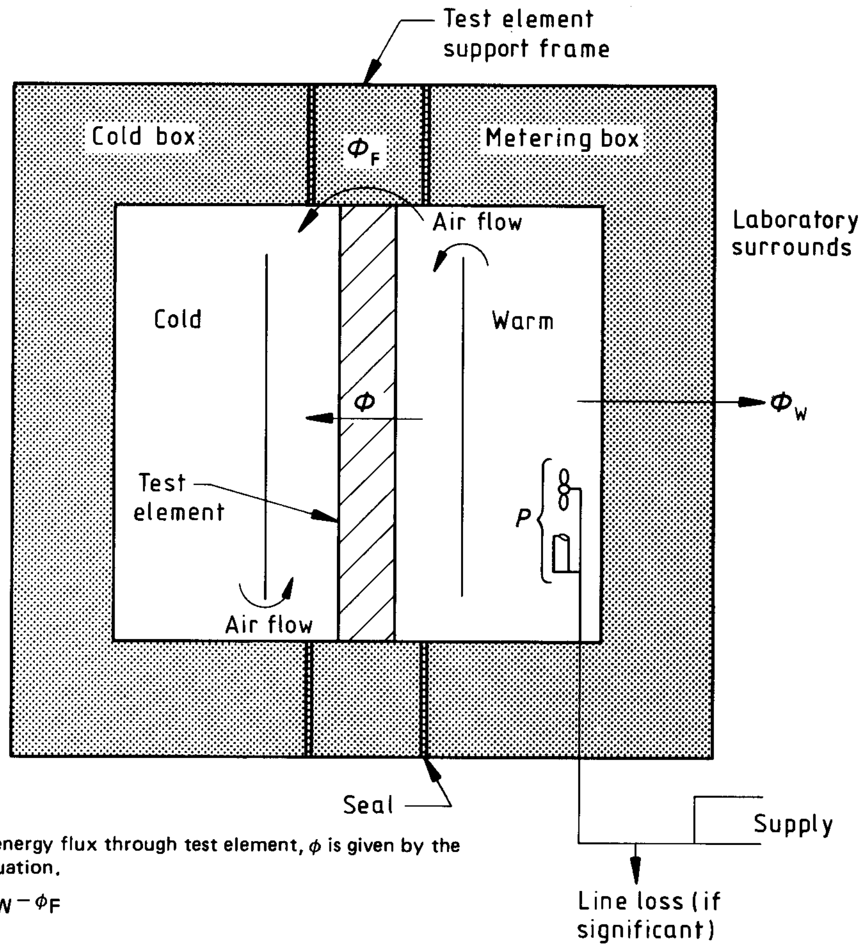
3 Principle

The basis for the method is the measurement, at equilibrium, of the heat flux through the test element and the corresponding temperature difference(s) across it. The apparatus is shown schematically in figure 1 and consists of two principal items, a metering box and a cold box, between which the test element, usually assembled in a support frame, is placed.

Heat supplied to the metering box passes through the test element to the cold box, which is maintained at a constant low temperature. The heat flux through the test element is determined from the total power supplied to the metering box, correcting for losses or gains through the metering box walls and the flanking loss (see **4.4**) to the cold box occurring around the perimeter of the specimen (see figure 1). These corrections are determined from prior calibration measurements using specimens of known thermal properties.

It is important that both of these corrections be kept small. Heat flow through the metering box walls is restricted by making them of high thermal resistance, and, where appropriate, controlling external ambient temperature fluctuations (see **4.2.2**). To reduce flanking losses, the test element is usually well insulated around its perimeter (see **4.4.2**).

NOTE. More complicated versions of this type of apparatus have been built, in which the metering box is enclosed in a temperature screen or guard (to control metering box wall heat exchanges) and in which the test panel edges are also guarded (to minimize flanking losses). Although not dealt with specifically in this Section of BS 874, such an apparatus, when properly designed and constructed, may be taken to meet all the requirements of the present method.



NOTE. The energy flux through test element, ϕ is given by the following equation.

$$\phi = P - \phi_W - \phi_F$$

where

P is the power supplied to metering box (in W)

ϕ_W is the heat flux to laboratory surrounds (in W)

ϕ_F is the flanking loss (in W)

Figure 1. Calibrated hot-box apparatus

Heat may be supplied to the metering box at a constant rate, in which case the apparatus slowly reaches the desired equilibrium condition. Alternatively, the temperature in the metering box may be kept constant by suitable control of the heat input. When thermal equilibrium is achieved, i.e. when the temperatures on each side of the test element and the heat flux through it are essentially constant, then the final measurements are taken.

Heat exchange at the hot and cold surfaces of the test element involves both convective and radiative components. The former depends upon air temperature and air speed, while the latter depends upon the temperatures and emissivities of surfaces seen by the element surface. The effects of heat transfer to or from a surface by convection and radiation are conveniently combined in the concept of an environmental temperature and a surface heat transfer coefficient. Thermal transmittance is defined between two environmental temperatures and therefore suitable temperature measurements are required to enable these to be determined (see appendix B of BS 874 : Section 3.1 : 1987). This is particularly important with test elements of low thermal resistance for which the surface resistances form a significant fraction of the total resistance.

Strictly, the thermal conductance of a building element is a meaningful term only if its faces are isothermal. However, if the test element is sufficiently uniform, it is acceptable to take area-weighted surface temperatures for the calculation of thermal conductance even though small temperature variations are present. If the thermal properties are sufficiently non-uniform to produce significant surface temperature variations, then the attribution of a thermal conductance is to be avoided (see clause 7 of BS 874 : Section 3.1 : 1987).

Normally the test element will be the same size as the open face of the metering box (see figure 1), but in some instances, in particular for the testing of window units, it may be smaller. For this type of test, the test element is surrounded by a panel of known thermal properties, enabling the heat flux through the test element to be deduced from the total heat input. The necessary adaptations to the method for measurements on small test elements are described in appendix A of BS 874 : Section 3.1 : 1987.

4 Apparatus

4.1 General

The apparatus shall comprise the components shown schematically in figure 1, together with the necessary instrumentation to control and measure the temperatures on each side of the test element and enable the heat flux through it to be determined.

When designing the apparatus, the required heating and cooling capacities shall be determined having regard to:

(a) the range of thermal transmittances for which the apparatus is designed;

(b) the construction of the two boxes;

(c) the range of laboratory temperatures likely to be encountered during tests.

All instruments used in this method shall be traceable to NPL or to a laboratory acceptable to NPL.

NOTE. The apparatus may be designed either for manual operation or for automatic control. However, automatic control of both metering and cold space temperature is recommended, so that the power input will be automatically adjusted for fluctuations in the temperature of the laboratory environment. Such fluctuations should not be large and in any instance need to be corrected for. It is also beneficial if the laboratory temperature can be controlled.

4.2 Metering box

4.2.1 *Requirements of the metering box*

NOTE 1. The metering box provides a controlled warm environment at constant temperature. It is normally of square or rectangular cross section with one open face.

The open face of the metering box shall be provided with an air-tight perimeter seal so that when it contacts the test element system (see figure 1), air flow between the metering box and the laboratory surrounds is prevented.

NOTE 2. The contact width of the seal may extend across the full thickness of the metering box walls. Compressible foam rubber in conjunction with a clamping device has been found satisfactory for use as an air-tight seal.

The walls of the metering box shall be impervious to air transfer and sufficiently well insulated to ensure that any heat flux through the walls is small compared with that through the test element.

NOTE 3. A minimum thermal resistance of the metering box walls of 2.5 $m^2 \cdot K/W$ is recommended.

NOTE 4. A sandwich construction of two metal or plywood skins with insulating material between them is considered satisfactory for the metering box walls. It is advisable that the wall insulation be substantially free of cracks, voids, or any other imperfections likely to adversely affect wall thermal resistance. Highly conducting structural members passing through the walls of the box should be avoided. Likewise, any protective facings crossing the metering box open perimeter insulation should preferably be of low thermal conduction. Plywood or similar facing used for this purpose should be kept as thin as possible.

The test area shall be defined as the plane area of specimen directly exposed to the internal controlled environment of the metering box (or, if the test element is not plane, then the plane projection of specimen area).

NOTE 5. The test area will usually be that of the whole of the test element.

The linear dimensions of the test area shall be at least 1 m and not less than five times the maximum thickness of any test element.

NOTE 6. The depth of the metering box is governed by the practical constraints of its construction and the equipment it is to house, but it should be kept as small as possible without sacrificing uniform air distribution in order to reduce heat exchange with the laboratory environment.

If transmittance measurements are being made, a baffle shall be fixed in the metering box, parallel to the surface of the test element, in order to provide a radiating surface of near uniform temperature.

NOTE 7. It is recommended that a baffle be fixed in the metering box for all measurements to assist in producing uniform air velocities and temperature distributions.

When testing vertical construction elements, the baffle shall extend the full width of the metering box, and shall have gaps at the top and bottom to allow air circulation unless the specific test conditions require otherwise.

NOTE 8. When testing vertical construction elements, the baffle can assist in providing a laminar air stream over the surface, and its distance from the test element can give a measure of control of the vertical temperature gradient in the air stream. The magnitude of this gradient will depend on the air speed, on the distance between the baffle and the surface of the test element, and on the conductance of the element. It is recommended that the temperature gradient in the air stream should not exceed 1 K/m for test elements of thermal transmittance up to 1 $W/(m^2 \cdot K)$ and a maximum of 2 K/m for elements of higher transmittance. The temperature gradient can be altered by suitable combination of air speed and baffle position. It should be noted that the air speed will influence the convective coefficient and thus only limited adjustment of air velocity may be possible. If desired, circulating fans may be installed in the metering box to assist natural convection if it is required to achieve particular values of convection coefficient that cannot be obtained by using natural convection alone. In this case means should be provided to measure the air speed across the test element surface.

When testing horizontal construction elements, the baffle shall extend the full width of the metering box; the presence of gaps at either end depends upon the exact test conditions required.

NOTE 9. When testing horizontal construction elements, the use of a horizontal baffle in the metering box can assist in achieving the desired boundary conditions. It may, for example, be used in conjunction with fans to produce an air stream across the face of the test element. Alternatively, it may be moved further away from the test element, so that natural convection currents are established. In this latter case the baffle may, if required, be extended at each end to close any gaps.

Where conditions of natural convection in the metering box are required, the distance between the baffle and the test element shall be not less than 150 mm.

Where higher air speeds are imposed across the face of the test element, for example by fans, to assist control of air velocity and air temperature gradient, it is permitted to gradually reduce the distance between the baffle and the test element to a minimum of 40 mm at an air velocity of 3 m/s or greater. The direction of any forced air flow should, where possible, be such as to supplement natural convection (i.e. downwards for vertical test elements). When forced air flow is applied, means shall be provided for measuring the velocity of the air stream over the face of the test element.

NOTE 10. It is important to ensure that air temperature sensors are placed outside the boundary layer associated with each surface. See **4.5.3**.

If the fans and their motors are installed inside the metering box, then their power consumption shall be measured (taking account of any phase angle) and added to that supplied by the heater. If only the fan blades are inside the metering box, then the heat contribution of the blades shall be determined, possibly from measurements of the apparent change in conductance of a suitable test element with and without the fans in use.

All surfaces in the metering box that can radiate to the surface of the test element shall be of matt black finish, and shall have a total hemispherical emissivity of at least 0.9.

A low temperature, extended source heater shall be installed in the metering box behind the baffle and so shielded that it neither radiates directly to the surface of the test element nor produces local hot spots on the baffle.

NOTE 11. Resistance wire has been found satisfactory for the construction of the heater.

The power consumption of the heater shall be measured to an accuracy of ± 0.25 %. The total uncertainty in the determination of the net power input into the metering box due to the heater and fans, after correcting for heat exchange through the walls, flanking loss (see **4.4**), and any power dissipation in the leads, shall not exceed ± 3 %.

4.2.2 *Limitation of heat exchange through the metering box walls.* As part of the procedure to ensure that the heat flux through the test element is accurately determined, the heat exchange through the sides and back of the metering box shall be measured and corrected for. This correction shall not exceed 20 % of the total power supplied to the metering box.

NOTE 1. For test elements of high thermal resistance, even with well insulated metering box walls, this may be difficult to achieve, particularly if the temperature of the external laboratory can differ significantly from that within the metering box. In such instances, additional measures may be necessary, such as the control of laboratory temperature, or the use of a temperature controlled screen on the metering box (e.g. see note to clause **3**).

One method of measuring the heat flux through the sides and back of the metering box is to install a thermopile to measure the average temperature difference between the inner and outer surfaces of the metering box (see figure 2). Thermocouple junctions installed on the side walls of the metering box for this purpose shall be distant from the plane of the open face of the metering box by at least the thickness of the metering box walls. There shall be a sufficient number of thermocouples in the thermopile to ensure that the heat flow can be estimated with sufficient accuracy to meet the necessary criterion for the net power input specified in **4.2.1**.

NOTE 2. As a guide, there should be at least one differential pair of junctions for each 1 m^2 of metering box wall surface area.

NOTE 3. The product of the average temperature difference across the metering box walls, obtained from the thermopile, and the heat exchange coefficient for the metering box provides an estimate of the correction to be applied. The heat exchange coefficient for the metering box may be calculated from its dimensions and the known thermal conductivities of its constituent materials, provided that these properties are sufficiently well defined, and that any contribution from the adjoining specimen frame is included. However, it is recommended that the heat exchange coefficient for the metering box be measured directly in the apparatus itself (possibly in combination with flanking loss calibrations, see **4.4**, **4.8** and appendix A).

4.3 Cold box

NOTE 1. The cold box provides a controlled environment at constant low temperature, and is usually insulated to reduce the load on the cooling system.

Temperature control shall be achieved using a heat exchanger and a cooled circulating medium such as water or air, controlled by a suitable combination of cooling and intermittent heating. The height and width of the cold box shall be not less than the corresponding dimensions of the metering box.

If thermal transmittance measurements are being made, then a baffle shall be installed in the cold box, the design criteria being the same as those already described for the metering box (see **4.2.1**). In cases where it is required to assess the performance of a particular structural form, it is permissible for the design of baffle to reflect that form: in that case the details of the baffle design shall be included in the test report.

Where higher surface coefficients are required in the cold box, as in the case of the simulation of outside conditions on test elements, this shall be achieved by higher air velocities over the face of the test element.

NOTE 2. The direction of any forced air flow should, where possible, be such as to supplement natural convection (i.e. upwards for vertical test elements).

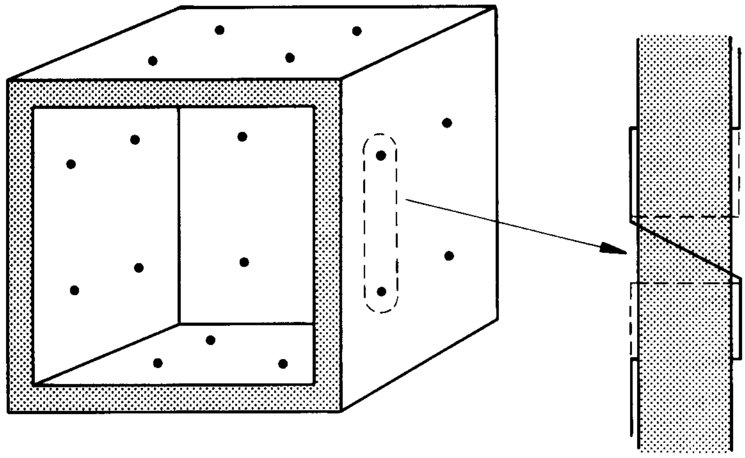


Figure 2. Metering box wall thermopile

When forced air flow is applied, means shall be provided for measuring the velocity of the air stream over the face of the test element.

NOTE 3. It is recommended that the temperature gradient in the air stream over the face of the test element should not exceed 1 K/m for test elements of thermal transmittance up to 1 W/(m^2·K) and a maximum of 2 K/m for elements of higher transmittance.

Direct radiation exchange between any cooling element in the cold box and the surface of the test element shall be prevented by suitable shielding. If the cold box is to be operated at temperatures approaching or below 0 °C then consideration shall be given to potential problems of condensation and icing.

All surfaces in the cold box which can radiate to the surface of the test element shall be of matt black finish, and have a total hemispherical emissivity of at least 0.9.

There shall be an air-tight seal between the cold box and the test element assembly (see figure 1).

NOTE 4. The cold box air-tight seal may be similar to that used in the metering box.

4.4 Flanking losses

4.4.1 *General*

During a test measurement, heat will flow from the metering box to the cold box around the edges of the test element outside of the test area. This heat flux is defined as the flanking loss, and a correction shall be made for this, along with the metering box wall heat flow correction, when determining the heat flow through the specimen.

NOTE 1. This view of flanking loss is somewhat simplified. In reality, the correction for flanking loss has also to account for edge effects within the test element itself, and any relevant edge interactions with metering and cold box wall heat flows.

NOTE 2. The magnitude of the flanking loss depends upon the thickness and apparent thermal conductivity of the test element at its boundary, and the type of surrounding construction. The relative influence of flanking loss diminishes as the ratio of test area to the test area perimeter increases. Thus, in larger hot-boxes, although flanking losses are usually higher, their resultant effects are relatively less significant.

4.4.2 *Limitation of flanking losses*

NOTE 1. Insulating the edges of the test element around the perimeter of the test area will assist in reducing flanking losses.

Consideration shall be given to providing a well insulated support frame to house the test element.

NOTE 2. Any such support frame should not be narrower than the thickest test element that it will house.

NOTE 3. It is recommended that the thermal resistance of the support frame insulation around the edges of the test area be at least 2.5 m^2·K/W. It is usually convenient for the metering box, cold box, and test element support frame to have nominally the same cross-sectional dimensions and insulation properties.

With very heavy specimens, such as masonry walls, it will usually be impractical to provide sufficient support for these within a specimen frame solely by using insulation. However, any highly conducting (i.e. metal) support members or facings used for this purpose shall be confined to the exterior (laboratory) edge of the frame insulation, unless they are designed specifically for edge-guarding purposes (see note to clause **3**). Otherwise, on the interior side, around the perimeter of the test area, the use of a combination of foam insulation material faced with plywood or similar intermediate conductivity material is permissible for load spreading purposes. Such additional facings shall be kept as thin as possible to reduce flanking losses.

4.5 Temperature measurement equipment

4.5.1 *General.* For the measurement of thermal conductance, the mean surface temperature over the metering area on each face of the test element is required. Measurement of thermal transmittance requires that air and mean radiant temperatures are measured in the hot and cold boxes, so that the two environmental temperatures may be calculated.

Thermocouples generally will be the most commonly used thermometers for this test method (see clause **6** of BS 874 : Part 1 : 1986 for more detailed discussion) but the use of other suitable thermometers is not excluded.

Thermocouples shall be made from a stock of calibrated wire or wire which has been certified by the supplier to comply with BS 4937 to a tolerance of ± 0.4 % otherwise individual thermocouple calibration shall be required.
A potentiometer for digital voltmeter with a resolution of 1 μV or better shall be used to measure the output from the thermocouples. The uncertainty in the measurement of temperature difference between the hot and cold faces of the test element at a point shall not exceed ± 1 % of the temperature difference. The uncertainty in the measurement of the voltage output from a thermopile shall not exceed ± 4 μV.

4.5.2 *Surface temperatures.* Thermocouples made from wire not exceeding 0.25 mm in diameter shall be used for measuring surface temperatures to minimize heat conduction along the wires. Thermocouples shall be in intimate contact with the surface for at least 25 mm from their junctions. They shall be cemented or taped securely to the surface, following isothermals where possible.

A sufficient number of thermocouples shall be used to enable the mean surface temperature to be determined, as follows. For homogeneous test elements there shall be a minimum of nine on each face, uniformly distributed over the test area. For large test areas, this number shall be increased as necessary such that there is at least one thermocouple per 0.5 m^2 of test area. If the test element is non-homogeneous, then sufficient additional thermocouples shall be placed to provide representative temperatures for each discrete region of the element, the average surface temperature being determined on the basis of the proportionate areas of each region. Within each discrete region the variability of temperature shall be explored to determine the position of the thermocouples.

For the measurement of mean radiant temperatures of surfaces 'seen' by the test element in metering and cold boxes, there shall be a minimum of nine thermocouples, appropriately distributed on each surface to take account of its relative radiant influence on the test element.

4.5.3 *Air temperatures.* For the measurement of air temperatures in the metering and cold boxes there shall be a minimum of nine thermocouples in the air spaces on each of the test elements, uniformly distributed in relation to the test area. For large test areas, this number shall be increased as necesssary such that there is at least one thermocouple per 0.5 m^2 of adjacent test area.

Thermocouples shall be positioned outside the boundary layer associated with each surface. Where air movement is by natural convection, thermocouples shall be placed not closer than 75 mm to a surface. Where an air velocity is imposed it is permitted gradually to reduce this distance, but it shall not be less than 20 mm at an air velocity of 3 m/s or greater. Thermocouples shall be shielded from radiation if their junction diameter is greater than 1 mm.

4.6 Temperature of the apparatus

When equilibrium has been reached, any fluctuations in the average air temperature on the hot and cold sides of the metering area shall not exceed 1 % of the air-to-air temperature difference between hot and cold over a period of at least 8 h.

4.7 Performance checking

After construction of the apparatus, the following performance checks shall be carried out in order to establish its satisfactory operation. Check:

(a) that temperatures and temperature gradients are sufficiently uniform;

(b) the effects of air velocities in the boxes;

(c) that the control systems are satisfactory;

(d) that, during calibration procedures (**4.8**), the heat flux through a test element and the temperature difference across it for a given mean test element temperature are proportional to each other.

4.8 Calibration procedures

4.8.1 *General*

In order to determine the heat flux through the test area from the power supplied to the metering box, allowance shall be made for any heat exchange with the laboratory environment (see **4.2.2**), and also the flanking loss around the perimeter of the test element (**4.4**).

NOTE. The magnitude of these corrections to the power input depend not only on the constituent insulation properties of the metering box, and the test element and its support frame, but also on the presence of additional conducting members such as cables, facings, etc., which may cross the various insulating regions. It is not usually practical to provide estimates of corrections for these effects based wholly on calculation.

4.8.2 *Calibration tests and calibration test elements*

Estimation of the corrections required to account for these effects shall be provided by carrying out prior calibration measurements on the apparatus using test elements of known thermal conductance. These calibration elements shall be effectively opaque to thermal radiation and impermeable to air transfer.

NOTE 1. It is recommended that the calibration elements should not contain internal cavities or voids where significant internal convection may occur, and that their properties do not change significantly with time.

The conductances, thicknesses, mounting and positioning of the calibration elements shall as far as possible cover the likely ranges of those for proposed test elements.

Conductances of the calibration elements shall be determined either from the known thermal conductivites of their components, as determined using the guarded hot-plate apparatus (see BS 874 : Section 2.1), or by prior measurement using the guarded hot-box method (see BS 874 : Section 3.1). Such equipment used for this purpose shall be traceable to NPL, or to a laboratory acceptable to NPL.

NOTE 2. It is particularly convenient for conductance determinations to be carried out using the guarded hot-box method if the calibrated hot-box apparatus undergoing calibration can be alternatively set up as a guarded hot-box for this purpose.

The range of applied conditions for the series of calibration tests shall cover that likely to be experienced in test element measurements.

NOTE 3. This applies to the external laboratory environment as well as to the applied conditions within metering and cold boxes.

4.8.3 *Correction factors for test element measurements* (see appendix A)

Since sample properties are known, estimates of the combined influence of laboratory temperature and flanking loss can be calculated from the results of each calibration measurement. These shall be used to build up a directory of correction factors for application in the subsequent measurements on the test elements.

NOTE 1. It is usually convenient to define correction factors to account for laboratory temperature effects and flanking losses separately. Appendix A considers some aspects of this procedure in more detail.

In any subsequent test element measurement, the particular flanking loss correction applied shall be that most appropriate for the thickness, conductivity and edge support details of the element at its boundary, as inferred from the calibration results.

NOTE 2. It is permissible to use numerical computational procedures to assist in the interpretation of flanking effects provided that such procedures have been demonstrated as being satisfactory on the basis of previous calibration measurements.

The accuracy assigned to measurements made on test elements using this apparatus shall take into account the results obtained from the calibration tests.

4.8.4 *Calibration verification checks*

Regular calibration verification checks shall be carried out to ensure that the performance of an apparatus does not change significantly with time (e.g. due to insulation ageing, cracking). Any observed change in calibration aspects of the apparatus shall be carefully investigated, and corrective measures taken as appropriate.

NOTE. It is recommended that such checks are carried out at least annually.

5 Test elements

5.1 General

NOTE 1. It is clearly desirable that the construction element to be tested is representative in terms of materials and construction of those used in practice. However, considerable caution should be exercised before assuming that the results of measurements on test elements can be directly applied in practice.

There shall be no pathways for air leakage from the hot to the cold side of the element during a test. Test elements with continuous vertical cavities, such as cavity walls, shall be sealed at their outer edges to prevent air exchange with the external environment, and the edges shall also be insulated to provide a thermal resistance of at least $2.5\ m^2 \cdot K/W$.

NOTE 2. It is recommended that the test elements be mounted in an insulated support frame (see **4.4.2**) and sealed around the perimeter of the test area adjoining the support frame. Mounting, positioning, and sealing procedures should be consistent with those of appropriate calibration measurements (see **4.8**).

NOTE 3. Test elements such as windows are normally tested in a special surround panel. Details of the procedure in this case are given in appendix A of BS 874 : Section 3.1 : 1987.

Careful consideration shall be given to the relevance of the test conditions selected (temperatures and air velocities) to those applicable to the test element in practice. For example, high air velocities may affect the thermal transmission properties of some low density, open textured, insulation materials by causing air movement within them; for such materials the boundary air velocities in normal use shall be considered. In addition, the thermal properties of some materials are temperature dependent and consideration shall be given to the relevance of the hot and cold face temperatures to practical conditions.

In the case of non-homogeneous test elements such as walls built of concrete blocks, the test area shall as near as possible be representative of an infinite panel of the same construction. The relative sizes of the metering area, the individual components of the wall and the bonding arrangement shall be considered carefully.

NOTE 4. The importance of this factor increases as the ratio of the component area to metering area rises, and failure to consider this may give a result that is not representative of full-scale constructions.

5.2 Test elements smaller than the metering area

The thermal transmittance of elements smaller than the metering area shall be measured with the calibrated hot-box by following the procedures given in appendix A of BS 874 : Section 3.1 : 1987.

5.3 Conditioning of test elements

If, after assembly, test elements are likely to undergo any change that will affect the thermal conductance or transmittance, e.g. variation of moisture content of porous material or recovery from compression of fibrous materials, then the element shall be conditioned prior to the test unless the purpose of the test is specifically to look for such a change.

Where moisture considerations are important, the following shall apply for any test measurement.

(a) The moisture content shall be known.

NOTE 1. A measurement on, for example, a masonry wall is meaningless without this information.

(b) There shall not be any significant change in moisture content during the course of a test.

NOTE 2. The change in moisture content is dependent on the material and environmental conditions. A change in moisture content of 0.2 % *V/V* can give rise to a 2 % change in thermal conductivity of some low density masonry materials. Also, the transport of moisture and associated latent heat effects may affect the measured result.

(c) Dependent on the purpose of the test, the moisture content shall be at a realistic level (see item (i) of clause **8**).

Conditioning shall be undertaken to satisfy (b) and (c).

Test elements containing moisture shall be conditioned in well-ventilated ambient indoor surroundings. The conditioning period shall be sufficiently long to achieve effective equilibrium for the purposes of the test.

NOTE 3. A progressive change in mass of 0.1 % or less per week, with random variations, is normally taken as a criterion for establishment of effective equilibrium. (This will usually imply moisture levels of 5 % or less by volume in most conditioned masonry specimens.)

Accelerated conditioning techniques are permitted provided that the thermal properties of the specimen are not adversely affected (e.g. the required curing periods for concrete or mortar should be allowed prior to any accelerated drying). If accelerated conditioning is used, then it shall be followed by natural conditioning in the laboratory to ensure that effective equilibrium is established.

NOTE 4. Moisture contents of test elements are normally determined gravimetrically by drying to constant mass at 105 °C (or such other temperature as is appropriate). But alternatively, indirect methods of measurements are acceptable provided they are of proven accuracy.

Where it is not practicable to weigh the whole of the test element, conditioning shall be monitored by weighing a smaller sample element constructed at the same time as the test element and stored adjacent to it over the conditioning period. In order to reproduce in the small sample the drying characteristics of the test element, consideration shall be given to the path along which moisture diffuses during drying.

NOTE 5. For example, the drying of a test wall can be simulated with a separate small section of the same material, sealed at its edges and the two external faces exposed to the drying environment.

Where appropriate, the mean moisture level over a test shall be estimated by averaging measured values taken before and after the test. Where it is not practicable to weigh the whole of the test element, small sections shall be taken from suitable positions near the edge of the test element.

It shall be ascertained that the latent heat associated with any moisture change over the period of the test is small in comparison with the energy transmitted through the test element during the same period.

NOTE 6. If measurements are required to be made at moisture contents other than those obtained with these conditioning procedures, humidity control may be required in the apparatus.

6 Test procedure

Install the test element between the boxes and fix in position the number of thermocouples in accordance with **4.5.2**, as appropriate for homogeneous or non-homogeneous surfaces. Clamp the boxes to the test element/support frame taking care that all seals are air-tight. Check all fans, thermocouples and instruments for correct operation.

Establish the required temperatures and environmental conditions in the apparatus.

NOTE 1. A minimum temperature difference between the hot and cold air temperatures of 20 K is recommended if measurement of thermal transmittance is to yield accurate results. Since the thermal properties of some materials are temperature dependent, the choice of hot and cold temperatures needs to reflect the conditions of use. It is customary in thermal conductivity tests for building control purposes on masonry samples for the equilibrium temperatures on the hot and cold sides of the apparatus to be 27 ± 3 °C and 10 ± 3 °C respectively. See BS 874 : Section 2.1.

Where appropriate, control the external laboratory temperatures to minimize metering box wall heat exchanges (**4.2.2**).

Take readings only when the apparatus has reached equilibrium.

Once equilibrium has been reached, i.e. when the temperatures, the power supplied, and the computed results begin to vary randomly rather than continuously increasing or decreasing, continue the test for at least a further 8 h and do not terminate the test until measurements of thermal transmittance or conductance, averaged over at least two successive 4 h periods, differ by less than 1 %

NOTE 2. The time required for the apparatus to reach equilibrium can vary from a matter of hours to a week or so. It will depend upon the apparatus, the test element and the method of control. It will take longer with test elements of high thermal capacity or with substantial insulation on them.

7 Expression of results

The results to be reported in clause **8** shall be the average of the final, successive sets of measurements. If there are small periodic variations in temperature or power in the apparatus due to the operation of the control systems (but within the limits specified in **4.6**), then a greater number of sets of data shall be averaged, which will lead to a more reliable result.

The thermal conductance, Λ (in W/(m^2·K)), shall be calculated as follows.

$$\Lambda = \frac{\phi}{A\,(T_{s1} - T_{s2})}$$

where

ϕ is the heat flux through the metering area (in W), i.e. the rate of heat supplied to the metering box, including power supplied to any fans and corrected where necessary for:

(a) heat flux through the metering box walls;

(b) flanking loss around the perimeter of the test area;

(c) any power loss in the leads to the heater or to the fans in the metering box.

A is the test area defined in **4.2.1** (in m^2);

T_{s1} is the average surface temperature of the test element in the metering box (in °C);

T_{s2} is the average surface temperature of the test element in the cold box (in °C).

A thermal conductance value shall not be quoted if there are local variations in temperature on either face (associated with thermal bridges) exceeding 20 % of the difference between average face temperatures, or if the test element is a window system.

The thermal transmittance, U (in W/(m^2·K)), shall be calculated as follows.

$$U = \frac{\phi}{A(T_{e1} - T_{e2})}$$

where

T_{e1} is the environmental temperature in the metering box (in °C);

T_{e2} is the environmental temperature in the cold box (in °C).

The surface coefficients h_1 and h_2 (in W/(m^2·K)) are given by the following equations:

(1) surface coefficient (hot face)

$$h_1 = \frac{\phi}{A(T_{e1} - T_{s1})};$$

(2) surface coefficient (cold face)

$$h_2 = \frac{\phi}{A(T_{s2} - T_{e2})}.$$

NOTE. The surface resistance at each face is the reciprocal of the appropriate suface coefficient.

For transmittance measurements, where it is not possible to determine surface heat transfer coefficients due to the nature of the test element (e.g. because of irregular surface geometry, excessive local surface temperature variations), the surface coefficients for a reference calibration element of similar thermal resistance shall be measured under the same conditions of temperature and air velocities as those applied for the test element. These surface coefficients shall be assumed to also apply for the test element transmittance measurements.

8 Test report

The test report shall include the following information:

(a) the name and address of the laboratory undertaking the test;

(b) the method of test, i.e. calibrated hot-box method, BS 874 : Section 3.2, including dimensions and disposition of temperature sensors;

(c) the orientation of the test element and the direction of heat flow;

(d) a description of the test element, including all relevant dimensions and materials used in its construction;

(e) whether natural or forced convection is used and, if forced, what air speeds;

(f) where applicable, the methods of weighting used to calculate mean surface temperatures;

(g) the measured thermal conductance and/or transmittance and the uncertainties in these measurements;

(h) if thermal transmittance measurements are reported, the measured heat transfer coefficients and their method of determination;

(i) details of any conditioning treatment and, where appropriate, the moisture content by volume before and after the test and the mean moisture content during the test;

(j) the average environmental, air, and surface temperatures (as appropriate) on each face of the test element;

(k) details of corrections (metering box walls, flanking, etc.) applied to the metering box heat input and brief outline of the calibration procedures used to obtain these;

(l) the external laboratory temperature (average, maximum and minimum) and mean relative humidity over the duration of the test;

(m) the date of start of the test and its duration;

(n) details of any special baffle design (see **4.3**).

Appendix

Appendix A. Calibration procedures

A.1 General

These are designed to provide metering box and flanking loss corrrection estimates to apply in calibrated hot-box test measurements. They rely on prior measurements using calibration specimens of known uniform conductance.

A.2 Method

In a calibrated hot-box test, the measured power, P (in W) supplied to the metering box can be expressed by the following.

$$P = \phi + \phi_W + \phi_F \qquad \text{(A1)}$$

where

- ϕ is the energy flux (in W) through the test element;
- ϕ_W is the energy flux (in W) through the metering box wall (including any component through the support frame);
- ϕ_F is the flanking loss (in W).

It is convenient to relate ϕ, and ϕ_F, in terms of the measured surface temperature difference ΔT across the calibration element, and ϕ_W to the average surface temperature difference ΔT_W across the metering box walls. Equation A1 may then be written

$$P = \alpha \Delta T + \beta \Delta T_W + \gamma \Delta T \qquad \text{(A2)}$$

where

- α is the heat exchange coefficient (in W/K) of the calibration element, derived from $\alpha = \Lambda A$, Λ being its conductance (in $W/(m^2 \cdot K)$) and A the test area (in m^2);
- β is a heat exchange coefficient (in W/K) for heat flows to or from the laboratory surrounds (primarily through the metering box walls);
- γ is a flanking heat loss coefficient (in W/K).

NOTE. Alternatively, α and γ may be defined in terms of the measured environmental temperature difference across the calibration element, in which case α will then be expressed as the product of the calibration element thermal transmittance U (in $W/(m^2 \cdot K)$) with the test area A (in m^2).

By carrying out calibration measurements with different calibration test elements (i.e. known α), at different applied conditions (i.e. ΔT, ΔT_W), equation A2 can be used to infer β and γ behaviour. This forms the basis for the calibration procedures.

Example. One possible approach that can be used is as follows. With a given calibration element (known α), vary both warm and cold side temperatures to produce different temperature differences (ΔT, ΔT_W) across the element and metering box walls, but retain the same mean temperature (i.e. same α) for the element.

Using equation A2 in the form

$$\frac{P}{\Delta T} = (\alpha + \gamma) + \beta \frac{\Delta T_W}{\Delta T} \qquad \text{(A3)}$$

then simple plotting and/or linear regression techniques may be used to extract the appropriate β and γ coefficients. Figure 3 shows an example of results obtained using this approach.

Supposing that the heat exchange coefficient $\alpha = \Lambda A$ for the calibration test element was 2.54 W/K (as determined from measured material thermal conductivity, thickness, and exposed test area). Thus from figure 3, the coefficient defining heat exchanges with the laboratory is

$\beta = 1.87$ W/K

and the flanking loss coefficient for the particular calibration test element system measured

$\gamma = 2.72 - 2.54 = 0.18$ W/K.

This procedure is then repeated for different calibration elements.

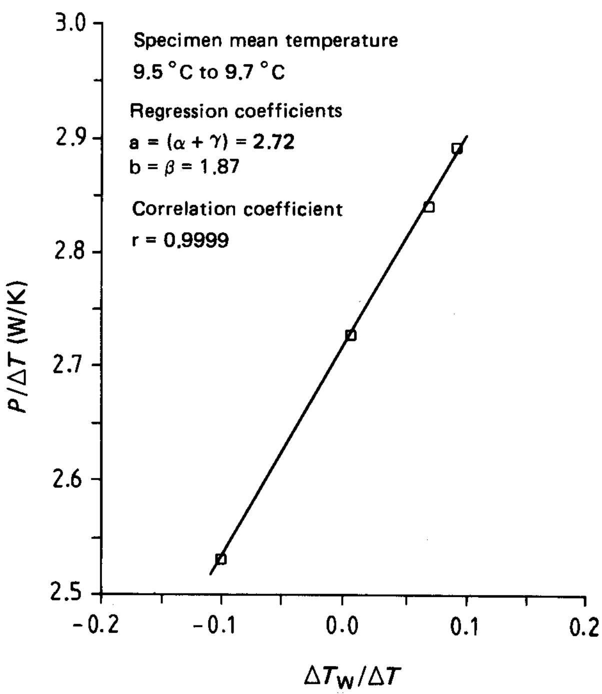


Figure 3. Example of determination of metering box wall and flanking coefficients

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Publications referred to.

BS 874 Methods for determining thermal insulating properties
Part 1 Introduction, definitions and principles of measurement
Part 2 Tests for thermal conductivity and related properties
Section 2.1 Guarded hot-plate method
Part 3 Tests for thermal transmittance and conductance
Section 3.1 Guarded hot-box method

BS 4937 International thermocouple reference tables

BS 5497* Precision of test methods
Part 1 Guide for the determination of repeatability and reproducibility for a standard test method by inter-laboratory tests

*Referred to in the foreword only.

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