

Thermal performance of building materials and products — Determination of thermal resistance by means of guarded hot plate and heat flow meter methods — Dry and moist products of medium and low thermal resistance

The European Standard EN 12664:2001 has the status of a
British Standard

ICS 91.100.01; 91.120.10

National foreword

This British Standard is the official English language version of EN 12664:2001. This British Standard together with BS EN 12667:2001 and BS EN 12939:2001 supersedes BS 874-2.1:1986 and BS 874-2.2:1988 which are withdrawn.

The UK participation in its preparation was entrusted by Technical Committee RHE/9, Thermal insulating materials, to Subcommittee RHE/9/2, Thermal properties of insulating materials, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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Thermal performance of building materials and products —
Determination of thermal resistance by means of guarded hot
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medium and low thermal resistance

Performance thermique des matériaux et produits pour le
bâtiment — Détermination de la résistance thermique par la
méthode de la plaque chaude gardée et la méthode
fluxmétrique — Produits secs et humides de moyenne et
basse résistance thermique

Wärmetechnisches Verhalten von Baustoffen und
Bauprodukten — Bestimmung des
Wärmedurchlasswiderstandes nach dem Verfahren mit
dem Plattengerät und dem Wärmestrommessplatten-Gerät
— Trockene und feuchte Produkte mit mittlerem und
niedrigem Wärmedurchlasswiderstand

This European Standard was approved by CEN on 25 June 2000.

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Foreword

This European Standard has been prepared by Technical Committee CEN/TC 89, Thermal performance of buildings and building components, the Secretariat of which is held by SIS.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2001, and conflicting national standards shall be withdrawn at the latest by December 2001.

This document is one of a series of standards on thermal test methods that support product standards for building materials.

The annexes A, B, C, D and E are normative. The annexes F and G are informative.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

Steady state heat transfer properties may be measured by a number of standardized test methods: the choice of the most appropriate method depends on specimen characteristics. This standard covers the guarded hot plate and the heat flow meter methods only.

For routine testing, the operator of these two methods needs only this standard and the relevant product standard, which may impose additional requirements related to specimen preparation or testing conditions.

Detailed requirements for measurements in any testing condition of thermal resistance of any compatible plane specimen are given:

- for the guarded hot plate method, in ISO 8302:1991 and EN 1946-2:1999;
- for the heat flow meter method, in ISO 8301:1991 and EN 1946-3:1999.

This standard provides general information on the apparatus, all mandatory limits for the equipment design and operation, and the specification of testing procedure, for dry and moist specimens, with medium and low thermal resistance, described in relevant technical specifications (e.g. a European product standard or a European technical approval). The information given is technically equivalent to that in ISO 8301:1991 and ISO 8302:1991, for both these methods. It is only intended for the routine testing of specimens (within the limitations of thickness and inhomogeneity, etc. given in annex A) using equipment which has been constructed according to 5.1 and which has already been validated according to EN 1946-3:1999 or EN 1946-2:1999.

It also includes examples of equipment designs that meet the requirements of 5.1, so that the assessment of the accuracy of an equipment designed accordingly does not need an error analysis but only the equipment performance check.

Although this standard can be used for testing dry specimens of high and medium thermal resistance, i.e. on products having a thermal resistance of not less than $0,5 \text{ m}^2\cdot\text{K}/\text{W}$, the simpler procedures of EN 12667:2001 are recommended for such specimens. Measurements on thick products of high and medium thermal resistance are covered in EN 12939, see the Bibliography.

1 Scope

This standard specifies principles and testing procedures for determining, by means of the guarded hot plate or heat flow meter methods, the thermal resistance of test specimens either in the dry state or conditioned to equilibrium with moist air, having a thermal resistance of not less than $0,1 \text{ m}^2\cdot\text{K}/\text{W}$ and a (hygro)thermal transmissivity or thermal conductivity up to $2,0 \text{ W}/(\text{m}\cdot\text{K})$. (It is expected that the thermal resistance of most masonry specimen will be less than $0,5 \text{ m}^2\cdot\text{K}/\text{W}$).

NOTE 1 The lower limit for measurable thermal resistance is due to the effect of contact thermal resistances, which require special testing techniques described in this standard. Although this standard can be used for testing dry specimens of high and medium thermal resistance, i.e. on products having a thermal resistance of not less than $0,5 \text{ m}^2\cdot\text{K}/\text{W}$, the simpler procedures of EN 12667:2001 are recommended for such specimens.

It applies in principle to any mean test temperature, but the equipment design in annex D is essentially intended to operate between a minimum cooling unit temperature of -100°C and maximum heating unit temperature of $+100^\circ\text{C}$.

NOTE 2 Limits to the mean test temperature are only imposed by the materials used in the apparatus construction and by ancillary equipment.

It supplies additional limits for equipment performance and test conditions.

It does not supply general equipment design procedures, equipment error analysis, equipment performance check or the assessment of equipment accuracy.

It supplies example designs of equipment complying with the requirements set down in this standard.

This standard does not supply general guidance and background information (e.g. the heat transfer property to be reported, product-dependent specimen preparations, suggested materials for vapour-tight envelopes when testing moist specimens, procedures requiring multiple measurements, such as those to assess the effect of specimen non-homogeneities, those to test specimens whose thickness exceeds the apparatus capabilities, and those to assess the relevance of the thickness effect). Due to these limitations, this standard shall only be used in conjunction with the product standard relevant to the product to be tested.

Although intended primarily for building materials, it may also be used for specimens of any material that conforms to the requirements specified.

It may be used for specimens made from the core material of hollow masonry units but formed voids are not permitted in the specimen.

This standard does not cover measurements on thick products of high and medium thermal resistance.

2 Normative references

This standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred applies (including amendments).

NOTE References to ISO 8301:1991 and ISO 8302:1991 do not cover the complete test methods, but are limited to such items as equipment design and performance check, not covered by European Standards or parts of them; references to ISO 8301:1991 or ISO 8302:1991 are not needed for routine testing according to this standard.

- | | |
|----------------|--|
| EN 1946-2:1999 | <i>Thermal performance of building products and components — Specific criteria for the assessment of laboratories measuring heat transfer properties — Part 2: Measurements by guarded hot plate method</i> |
| EN 1946-3:1999 | <i>Thermal performance of building products and components — Specific criteria for the assessment of laboratories measuring heat transfer properties — Part 3: Measurements by heat flow meter method</i> |
| EN 12667:2001 | <i>Thermal performance of building materials and products — Determination of thermal resistance by means of guarded hot plate and heat flow meter methods — Products of high and medium thermal resistance</i> |
| EN ISO 7345 | <i>Thermal insulation — Physical quantities and definitions (ISO 7345:1987)</i> |
| EN ISO 9288 | <i>Thermal Insulation — Heat transfer by radiation — Physical quantities and definitions (ISO 9288:1989)</i> |
| EN ISO 9346 | <i>Thermal insulation — Mass transfer — Physical quantities and definitions (ISO 9346:1987)</i> |
| ISO 8301:1991 | <i>Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus</i> |
| ISO 8302:1991 | <i>Thermal insulation — Determination of steady-state thermal resistance and related properties — Guarded hot plate apparatus</i> |

3 Definitions, symbols and units

3.1 Terms and definitions

For the purposes of this standard, the terms and definitions in EN ISO 7345, EN ISO 9288, EN ISO 9346 apply. Most relevant definitions for the measurement of heat transfer properties on medium and low thermal resistance products and the definition of hygrothermal transmissivity are to be found in A.2.

3.2 Symbols and units

Symbol	Quantity	Unit
A	metering area measured on a selected isothermal surface	m^2
A_d	area of the defect	m^2
A_m	area of the metering section	m^2
D_w	moisture diffusivity	m^2/s
E	temperature difference error in non-plane specimens	-
Fo	Fourier's number	-
R	thermal resistance	$\text{m}^2 \cdot \text{K}/\text{W}$
T	transfer factor	$\text{W}/(\text{m} \cdot \text{K})$
T_1	temperature of the warm surface of the specimen	K
T_2	temperature of the cold surface of the specimen	K
T_m	mean test temperature (usually $(T_1 + T_2)/2$)	K
V	volume	m^3
Z_v	moisture resistance	s/m
a	moisture factor	$\text{W} \cdot \text{m}^2/(\text{kg} \cdot \text{K})$
c	specific heat capacity	$\text{J}/(\text{kg} \cdot \text{K})$
d	thickness; average thickness of a specimen	m
e	edge temperature ratio	-
e_h	heat flow meter output voltage	mV
er_p	percent error due to phase changes	-
er_d	percent error due to non-uniform moisture distribution	-
f	calibration factor of the heat flow meter	$\text{W}/(\text{mV} \cdot \text{m}^2)$
f_r	multiplying factor for measured thermal resistance	-
g	density of moisture flow rate	$\text{kg}/(\text{m}^2 \cdot \text{s})$
h_e	latent enthalpy of evaporation per mass	J/kg

Symbol	Quantity	Unit
m	mass (of the specimen)	kg
q	density of heat flow rate	W/m ²
p	deviation of the specimen surface from a true plane	mm
r	thermal resistivity	K·m/W
t	time	s
v	humidity by volume	kg/m ³
v_{sat}	humidity by volume at saturation	kg/m ³
w	moisture content mass by volume	kg/m ³
w_{m}	mean moisture content mass by volume	kg/m ³
ΔR	increments of thermal resistance	m ² ·K/W
ΔT	temperature difference (usually $T_1 - T_2$)	K
Δd	increments of thickness	m
Δm	relative mass change	-
Δt	time interval	s
Δw	change in moisture content (mass by volume)	kg/m ³
Φ	heat flow rate	W
γ	conditioning time factor	s/m ² (or h/cm ²)
δ_v	moisture permeability with regard to humidity by volume	m ² /s
λ	thermal conductivity	W/(m·K)
λ_t	thermal transmissivity	W/(m·K)
λ^*	hygrothermal transmissivity	W/(m·K)
λ_0	thermal conductivity of dry material	W/(m·K)
ξ_d	moisture differential capacity, dw/dz	kg/m ³
ξ	porosity	-
ξ_p	local porosity	-
ρ	density	kg/m ³
φ	relative humidity	-

NOTE The meaning of some additional subscripts is specified in the text.

4 Principle

4.1 Apparatus

Both the guarded hot plate apparatus and the heat flow meter apparatus are intended to establish within homogeneous specimens with flat parallel faces, in the form of slabs, a unidirectional constant and uniform density of heat flow rate. The part of the apparatus where this takes place with acceptable accuracy is around its centre; the apparatus is therefore divided in a central metering section in which measurements are taken, and a surrounding guard section.

4.2 Measuring the density of heat flow rate

With the establishment of steady state in the metering section, the density of heat flow rate, q , is determined from measurement of the heat flow rate, Φ , and the metering area, A , that the heat flow rate crosses.

4.3 Measuring the temperature difference

The temperature difference across the specimens, ΔT , is measured by temperature sensors fixed at the surfaces of the apparatus in contact with the specimen and/or those of the specimens themselves, where appropriate.

4.4 Deriving the thermal resistance or transfer factor

The thermal resistance, R , is calculated from a knowledge of q , A and ΔT if the appropriate conditions given in A.3.2 are realized. From the additional knowledge of the thickness, d , of the specimen, the transfer factor, T , is computed.

4.5 Computing thermal conductivity, thermal transmissivity or hygrothermal transmissivity

The mean thermal conductivity, λ , thermal transmissivity λ_t , or hygrothermal transmissivity λ^* , of the specimen may also be computed if the appropriate conditions to identify them and those given in A.4.3 are realized.

4.6 Apparatus limits

The application of the method is limited by the capability of the apparatus to maintain a unidirectional, constant and uniform density of heat flow rate in the specimen, coupled with the ability to measure power, temperature and dimensions to the limit of accuracy required, see annex A.

4.7 Specimen limits

The application of the method is also limited by the shape of the specimen(s) and the degree to which they are identical in thickness and uniformity of structure (in the case of two specimen apparatus) and whether their surfaces are flat or parallel, see annex A.

5 Apparatus

5.1 General

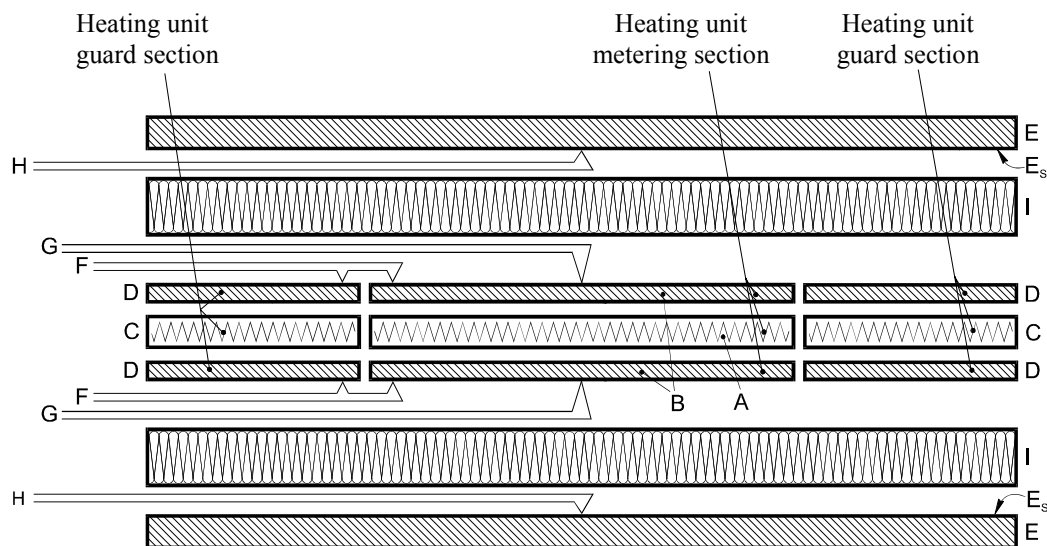
A guarded hot plate apparatus or a heat flow meter apparatus used for measurements according to this standard shall comply with the limits on equipment performance and test conditions given in annex B or annex C of this standard and shall conform with the requirements concerning the assessment of equipment accuracy given in EN 1946-2:1999 or EN 1946-3:1999: this requires that the equipment design, error analysis and performance check be according to section 2 of ISO 8302:1991 or ISO 8301:1991 respectively.

Annex D gives designs of guarded hot plate apparatus which conform with these requirements. For a heat flow meter apparatus see the annex D of EN 12667:2001. If the equipment used is designed precisely in accordance with one of these, an error analysis need not be carried out, even though in all cases a performance check according to EN 1946-2:1999 or EN 1946-3:1999 shall be undertaken for the initial assessment of the equipment.

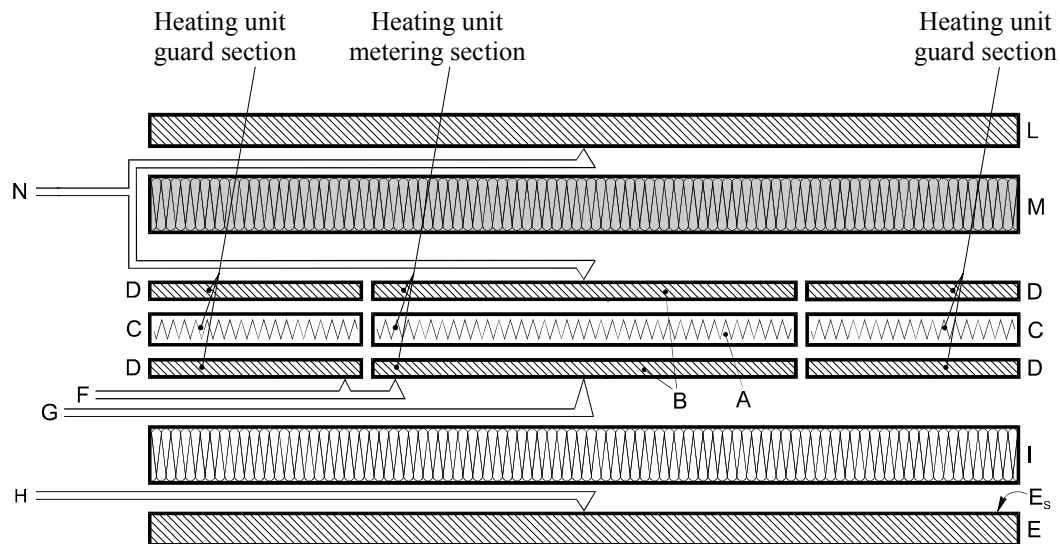
When it is not explicitly stated otherwise, guarded hot plate apparatus requirements are assumed as applicable also to heat flow meter apparatus.

Apparatus width or diameter shall be compatible with aggregate or pore size, see A.3.2.1.

NOTE The preferred overall apparatus width, or diameter, referred to in B.3 is 0,3 m or 0,5 m.



a) Two-specimen apparatus



b) Single-specimen apparatus

Key

- | | |
|---|--|
| A Metering section heater | G Heating unit surface thermocouples |
| B Metering section surface plates | H Cooling unit surface thermocouples |
| C Guard section heater | I Test specimen |
| D Guard section surface plates | L Guard plate |
| E Cooling unit | M Guard plate insulation |
| E _s Cooling unit surface plate | N Guard plate differential thermocouples |
| F Differential thermocouples | |

The gap is the separation between metering section (see A and B) and the guard section (see C and D)

Figure 1 — General features of two-specimen and single specimen guarded hot plate apparatus

5.2 Guarded hot plate apparatus

5.2.1 General

In a guarded hot plate apparatus the heat flow rate is obtained from the measurement of the power input to the heating unit in the metering section. The general features of the apparatus with specimens installed are shown in Figure 1.

There exist two types of guarded hot plate apparatus, which conform to the basic principle outlined in clause 4:

- a) with two specimens (and a central heating unit);
- b) with a single specimen.

5.2.2 Two specimen apparatus

In the two specimen apparatus [see Figure 1a)], a central round or square flat plate assembly, consisting of a heater and metal surface plates, called the heating unit, is sandwiched between two nearly identical specimens. The heat flow rate is transferred through the specimens to separate round or square isothermal flat assemblies, called the cooling units.

5.2.3 Single specimen apparatus

In the single specimen apparatus [see Figure 1b)], the second specimen is replaced by a combination of a piece of insulation and a guard plate. A zero temperature-difference is then established across this combination. Providing all other applicable requirements of this standard are fulfilled, accurate measurements and reporting according to this method may be accomplished with this type of apparatus, but particular reference to the modification of the normal hot plate with two specimens should be made in the test report.

5.2.4 Heating unit

The heating unit consists of a separate central metering section, where the unidirectional constant and uniform density of heat flow rate can be established, surrounded by a guard section separated by a narrow gap.

5.2.5 Metering area

The metering area is the central area of the specimen delimited by the centre line of the gap of the heating unit.

This definition, which applies in principle to thick specimens only, has been retained for all the specimens to be tested according to this standard: due to this approximation, the thickness of the specimen shall be at least ten times the width of the gap.

5.2.6 Edge insulation and auxiliary guards

Additional edge insulation and/or auxiliary guard sections are required especially when operating above or below room temperature, see annex B of EN 1946-2:1999.

5.2.7 Cooling units

The cooling units shall have dimensions at least as large as those of the heating unit, including the guard heater(s). They shall consist of metal plates maintained at a constant and uniform temperature.

5.2.8 Accuracy and repeatability

Accuracy and repeatability depend both on the equipment and on testing conditions. The complete assessment of testing errors in a guarded hot plate apparatus in any specific testing condition shall be carried out in accordance with EN 1946-2:1999. The following is rough information applicable for tests correctly executed when the mean temperature of the test is near the room temperature.

Equipment constructed and operated in accordance with this standard (see also annex B) is capable of measuring thermal properties of medium and low thermal resistance products accurate to within ± 2 %.

The repeatability of subsequent measurements made by the equipment on a specimen maintained within the apparatus without changes in testing conditions is typically better than $\pm 0,5$ %.

When measurements are made on the same reference specimen removed and then mounted again, the repeatability of measurements is normally better than ± 1 %. This larger figure is due to minor changes in testing conditions, like the pressure of the plates on the specimen (which affects contact resistances), the relative humidity of the air around the specimen (which affects its moisture content), etc.

The repeatability of measurements on a moist specimen is a combination of the repeatability of the equipment, which should be better than 1 %, and the repeatability of the testing conditions, in particular moisture content, see annex F.

5.2.9 Accuracy and repeatability when testing low thermal resistance specimens

As stated in 5.2.8, the accuracy of measurements on good quality dry specimens having a thermal resistance equal to or greater than $0,1 \text{ m}^2\cdot\text{K}/\text{W}$ should be better than 2 % for guarded hot plate apparatus. Specimens having thermal resistances between $0,1 \text{ m}^2\cdot\text{K}/\text{W}$ and $0,02 \text{ m}^2\cdot\text{K}/\text{W}$ can be tested according to ISO 8302:1991 only; the corresponding accuracy is progressively reduced to 5 %, see A.3.6.2. When testing moist specimens, there may be additional substantial errors, see 7.2.3.4.

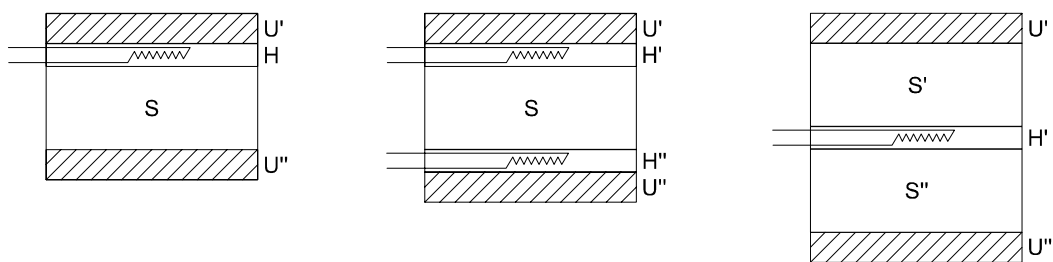
5.3 Heat flow meter apparatus

5.3.1 General

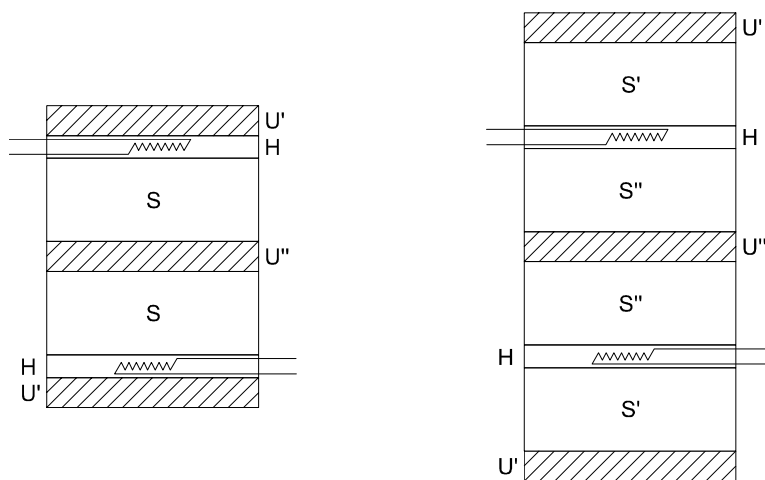
In the heat flow meter apparatus the density of heat flow rate is measured by means of one or two heat flow meter(s) placed against the specimen(s).

The general features of heat flow meter apparatus are shown in Figure 2; they consist of a heating unit, one or two heat flow meters, one or two specimens and a cooling unit. In configuration a), which is called “single-specimen asymmetrical”, the heat flow meter may be placed against either unit; the configuration b) is called “single-specimen symmetrical”; in configuration c), which is called “two-specimen symmetrical”, the specimens should be substantially identical. Each configuration yields equivalent results if used within the limitations stated in this standard.

NOTE There are distinct advantages for each method in practice; brief discussion is included in annex B of ISO 8301:1991.



a) Single-specimen asymmetrical configuration b) Single-specimen symmetrical configuration c) Two-specimen symmetrical configuration



d) Double apparatus

e) Double apparatus

Key

U', U''	Cooling and heating units
H, H', H''	Heat flow meters
S, S', S''	Specimens

Figure 2 — Typical layouts of heat flow meter apparatus configurations

5.3.2 Heat flow meters

The heat flow meter is an assembly that measures the density of heat flow rate through the specimen(s) by a temperature difference generated by this density of heat flow rate crossing the specimen(s) and the heat flow meter itself. Most commonly it consists of a homogeneous core, a surface temperature difference detector (a multi-junction thermopile) and a surface temperature detector(s). The heat flow meter region occupied by the core, where temperature difference detectors are placed, is called the metering area.

A density of heat flow rate q , through the metering area of the device results in an output e_h :

$$q = f e_h$$

The calibration factor f , which correlates e_h and q , is not a constant in all cases, but may depend upon temperature and, to a more limited extent, upon the density of heat flow rate.

5.3.3 Calibration principle

This is a secondary or relative method, since the ratio of the thermal resistance of the specimens(s) to that of a standard specimen(s) is measured. From the measurement of the heat flow rate Φ_s with the standard specimen(s) and Φ_u with the unknown specimen(s) to be measured, the assumption of a constant density of heat flow rate of the metering section and the assumption of the stability of the temperature difference ΔT and the mean temperature T_m , gives the ratio between the thermal resistance R_s of the standard specimen(s) and R_u of the unknown specimen as follows:

$$R_u/R_s = \Phi_s/\Phi_u$$

Calibration procedures are given in ISO 8301:1991.

5.3.4 Limitations due to the calibration

The calibration factor f , is a function of the mean heat flow meter temperature. If a calibration curve has been established in a temperature range, extrapolation is not allowed.

The calibration factor at a given mean heat flow meter temperature may also be a function of the density of heat flow rate. The apparatus shall only be used for densities of heat flow rate within the range covered by the calibration.

5.3.5 Accuracy and repeatability

Accuracy and repeatability depend both on the equipment and on testing conditions. The complete assessment of testing errors in a heat flow meter apparatus in any specific testing condition shall be carried out in accordance with EN 1946-3. The following is rough information applicable for tests correctly executed when the mean temperature of the test is near the room temperature.

The repeatability of subsequent measurements made by the equipment on a specimen maintained within the apparatus without changes in testing conditions is typically better than $\pm 0,5$ %.

When measurements are made on the same reference specimen removed and then mounted again after large time intervals, the repeatability of measurements is normally better than ± 1 %. This larger figure is due to minor changes in testing conditions, like the pressure of the plates and heat flow meter on the specimen (that affect contact resistances) and the relative humidity of the air around the specimen (that affects its moisture content), etc.

The repeatability of measurements on a moist specimen is a combination of the repeatability of the apparatus, which should be better than 1 %, and the repeatability of the testing conditions, in particular moisture content, see annex F.

The accuracy of the calibration of the heat flow meter apparatus depends on the accuracy of the reference material and is normally within ± 2 %.

NOTE The accuracy of the calibration is mainly due to the accuracy of the guarded hot plate method when measuring the properties of reference specimens.

When the limits specified in annex C are met, the heat flow meter method is capable of determining the heat transfer properties within ± 3 % when the mean temperature of the test is near the room temperature.

5.4 Error analysis and equipment performance check

The error analysis (not needed if equipment design conforms with one of the ones in annex D), the equipment performance check and the consequent assessment of the equipment accuracy in the range of testing conditions given in relevant product specifications shall be made according to 5.1.

6 Test specimens

6.1 General

Testing may be split into specimen handling, see below, and actual testing procedure, see clause 7. Some decisions about measurable heat transfer properties, specimen handling and testing conditions shall be taken when starting testing, see A.5. Directions on these decisions shall only be sought in this standard and/or in the relevant product standard applicable to the specimen to be tested.

6.2 Selection and size

One or two specimens shall be selected (from each sample) according to the type of apparatus (see 5.2.2 or 5.2.3 for guarded hot plate apparatus and 5.3.1 for heat flow meter apparatus). The specimen or specimens shall meet the general requirements outlined in A.3 and A.4. When two specimens are required they shall be as identical as possible with thicknesses differing by less than 2 %. The specimen or specimens shall be of such size as to cover the heating unit surfaces completely (including the guard section), without exceeding the overall linear dimension of the heating unit or heat flow meter by more than 3 %. They shall have a thickness according to the relevant product standard and additionally the relationship between the thickness of the test specimen used and the dimensions of the heating unit shall be restricted so as to limit the sum of the imbalance error (guarded hot plate apparatus only) and edge heat loss errors to 0,5 %, see thickness limits of Table A.1 in A.3. For the minimum specimen thickness see A.3.4 and Tables A.1 and A.2.

6.3 Specimen preparation and instrumentation

6.3.1 Conformity with product standards

The preparation of the specimens shall be in accordance with the appropriate product standard; unless otherwise specified in product standards, the general criteria in 6.3.2 and 6.3.3 should be fulfilled.

6.3.2 All specimens except loose-fills

6.3.2.1 Preparation

As building materials and in particular masonry materials exist in many forms, e.g. bricks, blocks and cast slabs, use the method appropriate to the particular form available, e.g. edge to edge gluing of smaller pieces of similar density, (but never with joint surfaces parallel to the faces of the specimen) machining directly from larger pieces or casting directly from a mix. In all cases, ensure that there is a high degree of flatness of the test specimen and that other dimensions are within the tolerances specified.

When edge-to-edge joining or joint gluing is necessary, make the joints between machined surfaces perpendicular to the main specimen surfaces and preferably symmetrical with respect to the line passing through the centre of the specimen and perpendicular to its main surfaces. Keep the number of pieces used to the minimum dictated by the module size of the product, especially in the metering

area. Ensure that, within the metering area, the total joint cross-section does not exceed 0,1 % of the metering area. Use a cold setting adhesive, such as an epoxy or polyester resin for bonding; adhesives approaching the specimen conductivity are preferred. Apply the adhesive to the mating surfaces avoiding impregnation as far as possible. After bonding, either grind flat the faces of each specimen using a surface grinder or milling machine, or hand finish the faces by rubbing with abrasive paper fixed to an engineer's surface plate.

Cure cement and masonry materials from which specimens are to be prepared for 28 days prior to testing and record the date of manufacture. Specimens may initially contain a large amount of water as a consequence of manufacture and preparation. Great care shall be taken in selecting testing conditions with reference to moisture content in order to eliminate mass transfer during the test, or establish conditions for which mass transfer effects are repeatable and well understood, see 7.2.2 and 7.2.3.

The surface of the test specimens shall be made plane by appropriate means (sandpapering, face-cutting in a lathe, and grinding are often used), so that close contact between the specimens and apparatus or interposed sheets can be effected.

For rigid materials, the faces of the specimens shall be made as flat as the apparatus surfaces (see A.3.6.2) and shall be parallel over the total surface area within 2 % of the specimen thickness.

The planeness of the surfaces can be checked with, for example, a good quality engineer's straightedge (straight to 0,01 mm) held against the surface and viewing at grazing incidence with a light behind the straightedge. Departures as small as 25 µm are readily visible. Large departures can be measured using feeler gauges and the straightedge as follows. The straightedge should be supported on a gauge block of known thickness, say 1 mm, at each end of the surface to be checked. Positive and negative deviations can be measured using feeler gauges along a straight line. Eight straight lines should be investigated as follows: the four edges of the surface, the two diagonals and a central cross (two lines parallel to the edges of the surface). When this procedure, applicable to both apparatus and specimen surfaces, is applied to specimen checking, it should be repeated for each face of the specimen.

Scratches, chips or similar defects over and above the naturally occurring surface irregularities in the finished surfaces of cellular or aggregate materials are accepted provided that the total of their surface areas is an acceptable fraction of the metering area and that their maximum depth is an acceptable fraction of the specimen thickness, so as to keep the added thermal resistance due to the corresponding air pockets low. For the purpose of this standard:

- if $(A_d/A_m)(R_a/R) < 0,000\ 5$ the effect may be ignored;
- if $0,000\ 5 \leq (A_d/A_m)(R_a/R) \leq 0,005$ the test may be undertaken, but the presence of the defect shall be mentioned in the test report;

where:

A_d is the overall cross-sectional area of the defects;

A_m is the area of the metering section;

R_a is the thermal resistance of an air layer of thickness equal to the maximum depth of any defect;

R is the thermal resistance of the specimen.

6.3.2.2 Selection and installation of contact sheets

Imperfect apparatus and/or specimen flatness produces contact thermal resistances, see in A.3.6.2 the maximum allowed limit when testing rigid specimens without contact sheets.

When the specimens' thermal resistance is less than $0,3 \text{ m}^2\cdot\text{K}/\text{W}$, or if their flatness does not meet the requirements of A.3.6.2, thin sheets of an adequately compressible material shall be inserted between the specimen surfaces and the plates of the apparatus to establish good thermal contact between them. The thin sheets shall also insulate electrically the thermocouples which are then to be placed on the specimen surfaces to determine the temperature difference across the specimen (see 6.3.2.3).

If all other requirements are met (homogeneity, compressibility, etc.), sheets of the highest thermal conductivity material available should be chosen. When using contact sheets, the thermal resistance of the sheets should be the smallest compatible with the elimination of air pockets.

NOTE 1 Foamed silicone rubber of density about $600 \text{ kg}/\text{m}^3$ and thickness about 0,5 % to 1 % of the overall apparatus size (typically 2 to 3 mm for medium size apparatus) have been found to meet the requirements satisfactorily.

Sufficient clamping pressure, in excess of 10 kPa, is required to produce uniform thermal contact between apparatus surfaces, thermocouples, thermal contact sheets and specimens.

NOTE 2 These high pressures can damage the heat flow transducer of the heat flow meter apparatus, and thus the guarded hot plate apparatus is preferred for tests on specimens having a thermal resistance less than $0,3 \text{ m}^2\cdot\text{K}/\text{W}$.

The use of contact sheets introduces the errors described in A.3.6.3. When the contact resistance is deemed to be too high, an alternative solution to the use of contact sheets is to improve the surface finish of the specimen and/or that of the plates of the apparatus.

NOTE 3 The lowest measurable thermal resistance according to B.5, is $0,02 \text{ m}^2\cdot\text{K}/\text{W}$ (e.g. 0,04 m of structural concrete), but the overall accuracy of 2 % around room temperature may be achieved only when the specimen thermal resistance is equal to or greater than $0,1 \text{ m}^2\cdot\text{K}/\text{W}$.

6.3.2.3 Thermocouples mounted on the specimen

When contact sheets are used, thermocouples mounted on the specimen surfaces, or cemented in shallow grooves accurately machined to a known depth in the specimen surfaces, shall be used to measure the temperature difference through the specimens. The number of uniformly distributed thermocouples on each side of the specimen in the area corresponding to the metering section of the apparatus should be not less than $N \sqrt{A}$, or 2, whichever is greater, where $N = 10 \text{ m}^{-1}$ and A is the area in square metres of one side of the metering section. For the error in the temperature difference when using contact sheets and thermocouples mounted on the specimen, see A.3.6.3.

It is recommended that at least two more thermocouples are added on each side of the specimen in the area corresponding to the metering section of the apparatus.

Thermocouples mounted directly into the surfaces shall either be:

- a) flattened fine wire, or
- b) thin foil types which may be bought ready-made, or
- c) prepared by rolling or pressing the junctions together with about 20 mm of the adjoining wire of conventional thermocouples.

The thermocouples shall be fabricated from a stock of calibrated thermocouple wire, or from wire that has been certified by the manufacturer to comply with Table B.1 of ISO 8302:1991, or they shall be individually calibrated.

NOTE 1 It is important to establish good contact between the junctions and the specimen surfaces. In some circumstances it will be necessary to improve the mounting area locally to achieve this. This can be done effectively and with minimal loss of accuracy by smoothing the surface locally using a machinable, quick-drying filling compound using a thickness of less than 0,5 mm.

The thermocouples shall be taped in position on these prepared surface areas (approximately 15 mm to 20 mm in diameter) using narrow strips of adhesive tape about 2 mm to 4 mm wide placed some 5 mm from the junction itself.

NOTE 2 Wider strips of tape can be used in the guard area to insulate and protect the wire around the edges of the apparatus.

NOTE 3 The clamping pressure exerted on the thermal contact sheets ensures that the thermocouples are firmly in contact with the specimen surfaces during the test. However, when practicable (i.e. if the prepared surface is non-absorbent), a smear of thermoconductive compound loaded with zinc oxide can be introduced between the thermocouple junctions and the surfaces to further improve thermal contact.

6.3.3 Loose-fill materials

When testing loose-fill materials, the thickness of the specimen shall be at least 10 times the mean dimension of the beads, grains, flakes, etc. of the loose-fill material. To prepare the specimen(s) it is recommended that a representative portion, slightly greater than the amount needed for the test, be taken from the sample and weighed before and after it has been conditioned as in 7.2, where applicable. From these masses the percentage mass loss is calculated. An amount of the conditioned material is weighed out such that it will produce one (two) specimen(s) of the desired density using the procedure described in the relevant product standard. As the ultimate volume of the specimen is known, the required mass can be determined. The specimens are then quickly mounted in the apparatus or left to reach equilibrium with the standard laboratory atmosphere (23 °C, 50 % relative humidity), in accordance with the guidelines given in the relevant product standard or in 7.2.

7 Testing procedure

7.1 General

A testing procedure is the complete set of operations to determine the desired heat transfer property performed on the specimen prepared as indicated in 6.3. These may be split into the conditioning, described in 7.2, and the remaining operations to run a test with the guarded hot plate or heat flow meter apparatus, as described in 7.3

7.2 Conditioning

7.2.1 General

There are basically two measurement procedures for masonry materials: on dry and moist specimens.

NOTE 1 The theoretical background for measurements on moist or dried materials is given in [1] and [2], see also Bibliography.

Conditioning shall be according to relevant product standards.

NOTE 2 Drying requires the definition of the conventional dry state, see 7.2.2. A conventional dry state is produced by heating in a well ventilated oven at 105 °C or as specified in the relevant product standards. The drying process should not alter the chemical and physical nature of the material. If the value of the thermal conductivity is required at different moisture contents, or at the equilibrium moisture content of the material in the laboratory environment, then condition the specimen without oven drying to constant mass by exposure to the air of a conditioning chamber held at (23 ± 2) °C and appropriate relative humidity within ± 5 %, see 7.2.3.2.

7.2.2 Conditioning for measurements on dry materials

Routine measurements should, as far as possible, be carried out on dry materials.

Dry the specimen to constant mass in a ventilated oven at 105 °C to 110 °C that takes the air from an environment at (23 ± 2) °C and (50 ± 5) % relative humidity. Constant mass is considered to have been established when the change in the mass of the test specimen over a 24 h period is random and less than the equivalent of 0,1 kg/m³ (or 0,01 % by volume).

After drying, the test specimen shall be enclosed in a vapour-tight envelope. The envelope shall be sufficiently impermeable to prevent a change in moisture content greater than 0,01 kg/(m³·h), see annex G.

NOTE 1 An envelope with a moisture (diffusion) resistance $Z_v > 10^5$ s/m is sufficient.

The mass of the specimen shall be measured before and after the test, to determine the relative mass change according to 8.1.2.

A vapour-tight envelope may be omitted if the rate of moisture accumulation in the test specimen during the test is lower than 0,01 kg/(m³·h) and no visible condensation occurs on the cold plate.

NOTE 2 A vapour-tight envelope can change the contact resistances and special precautions may have to be taken to measure surface temperatures correctly.

7.2.3 Conditioning for measurements on moist materials

7.2.3.1 General

Measurements on moist materials are necessary to establish the thermal transmissivity of the moist material, λ^* , at a moisture content in equilibrium with 50 % relative humidity, 23 °C or to establish the general relationship between λ^* and the moisture content. These measurements should normally, however, not be routine measurements but performed at special occasions to establish the necessary relationships for each material, product or building component. If routine measurements are planned on moist materials, testing accuracy and testing times shall be carefully assessed, see 7.2.3.4.

7.2.3.2 Conditioning in a specified atmosphere

Condition the test specimens to the required moisture content before the test. This standard is restricted to moisture contents in the hygroscopic range, that is moisture contents in equilibrium with 98 % relative humidity or lower.

NOTE 1 Information on testing at higher moisture contents, is given in [1] in the Bibliography.

NOTE 2 Preferred moisture contents are:

- 1) in equilibrium with 50 % relative humidity (due to the requirements in the product standards);
- 2) in equilibrium with 80 % relative humidity (because, above this level, the estimation of errors, as given in 7.2.3.4, is no longer valid).

The conditioning procedure to a nearly uniform distribution is carried out in two steps.

Step 1. Place the test specimen in an atmosphere 23/xx or in a ventilated oven at 40 °C, 70 °C or 105 °C. Periodically remove and weigh the specimen to determine mass changes until:

$$\Delta w < \Delta w_1$$

where:

- 23/xx signifies a controlled atmosphere with a temperature of (23 ± 2) °C and a relative humidity of $(xx \pm 5)$ %, xx being any relative humidity between 0 % and 98 %;
- Δw is the change in moisture content, in kg/m³, during a period of d^2 hours, d being the specimen thickness expressed in centimetres;
- Δw_1 is the appropriate limiting value of moisture content change, in kg/m³.

NOTE 3 Annex F gives guidance on the determination of Δw_1 .

In many cases, the moisture content is already in the hygroscopic range when the product is delivered to the testing laboratory. In this case, step 1 may be omitted and only step 2 is needed.

Step 2. Place the test specimen in an atmosphere of 23/xx for at least γd^2 hours, where γ is the conditioning time factor and d is the specimen thickness expressed in centimetres.

NOTE 4 Annex F gives guidance on the determination of γ .

After conditioning, the test specimen shall be enclosed in a vapour-tight envelope. The envelope shall be impermeable enough to prevent a change in moisture content larger than 0,01 kg/m³ per hour.

NOTE 5 This criterion is explained in annex G. In practice, an envelope with a moisture (diffusion) resistance $Z_v > 10^5$ s/m is sufficient.