BS EN 12667:2001

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

The European Standard EN 12667:2001 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 12667:2001. This British Standard together with BS EN 12664 and BS EN 12939 supersedes BS 874-2.1:1986 and BS 874-2.2:1988.

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.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

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This British Standard, having been prepared under the direction of the Engineering Sector Committee, was published under the authority of the Standards Committee and comes into effect on 15 March 2001

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English version

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

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 de haute et moyenne résistance thermique

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

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

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

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Contents

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 and D are normative.

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 specimens, with high and medium 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 equipment designed accordingly does not need an error analysis but only the equipment performance check.

Measurements on products of medium and low thermal resistance and on moist products of any thermal resistance are covered in EN 12664. Measurements on thick products of high and medium thermal resistance are covered in EN 12939.

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 having a thermal resistance of not less than 0,5 $m^2 \cdot K/W$

NOTE 1 The above limit is due to the effect of contact thermal resistances. An upper limit for measurable thermal resistance depends upon a number of factors described in this standard, but a unique figure cannot be assigned.

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 °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, 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 should be used in conjunction with the product standard relevant to the product to be tested.

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

This standard does not cover measurements on moist products of any thermal resistance or 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 *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*

EN 1946-3:1999 *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*

EN 12664	*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*
EN 12939	*Thermal performance of building materials and products — Determination of thermal resistance by means of guarded hot plate and heat flow meter methods — Thick products of high and medium thermal resistance*
EN ISO 7345	*Thermal insulation — Physical quantities and definitions* (ISO 7345:1987)
ISO 8301:1991	*Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus*
ISO 8302:1991	*Thermal insulation — Determination of steady-state thermal resistance and related properties — Guarded hot plate apparatus*

3 Definitions, symbols and units

3.1 Terms and definitions

For the purposes of this standard, the terms and definitions in EN ISO 7345 apply. Most relevant definitions for the measurement of heat transfer properties on high and medium thermal resistance products 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
R	thermal resistance	$m^2 \cdot K/W$
T	transfer factor	W/(m·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
c	specific heat capacity	J/(kg·K)
d	thickness; average thickness of a specimen	m
e	edge number ratio	-
e_h	heat flow meter output voltage	mV
f	calibration factor of the heat flow meter	$W/(mV \cdot m^2)$

Symbol	Quantity	Unit
m	mass (of the specimen)	kg
q	density of heat flow rate	W/m²
r	thermal resistivity	K·m/W
ΔR	increments of thermal resistance	m²·K/W
ΔT	temperature difference (usually T_1 - T_2)	K
Δd	increments of thickness	m
Δm	relative mass change	-
Δt	time interval	s
Φ	heat flow rate	W
λ	thermal conductivity	W/(m·K)
λ_t	thermal transmissivity	W/(m·K)
ξ	porosity	-
ξ_P	local porosity	-
ρ	density	kg/m³

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 into 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, $\mathcal{T}$, is computed.

4.5 Computing thermal conductivity or thermal transmissivity

The mean thermal conductivity, λ, or thermal transmissivity, λ_t, 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 equipment which conform with these requirements. 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.

5.2 Guarded hot plate apparatus

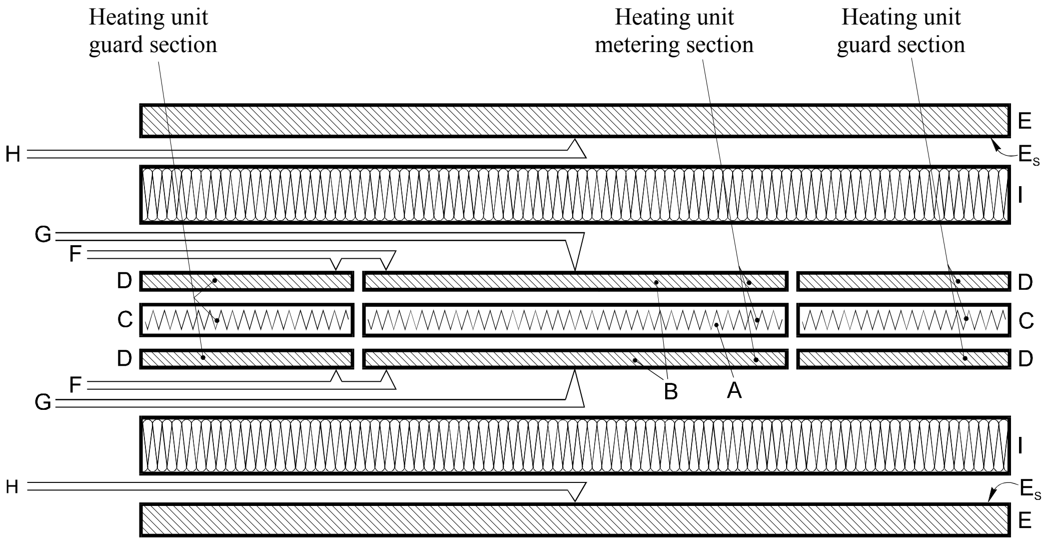
5.2.1 General

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.

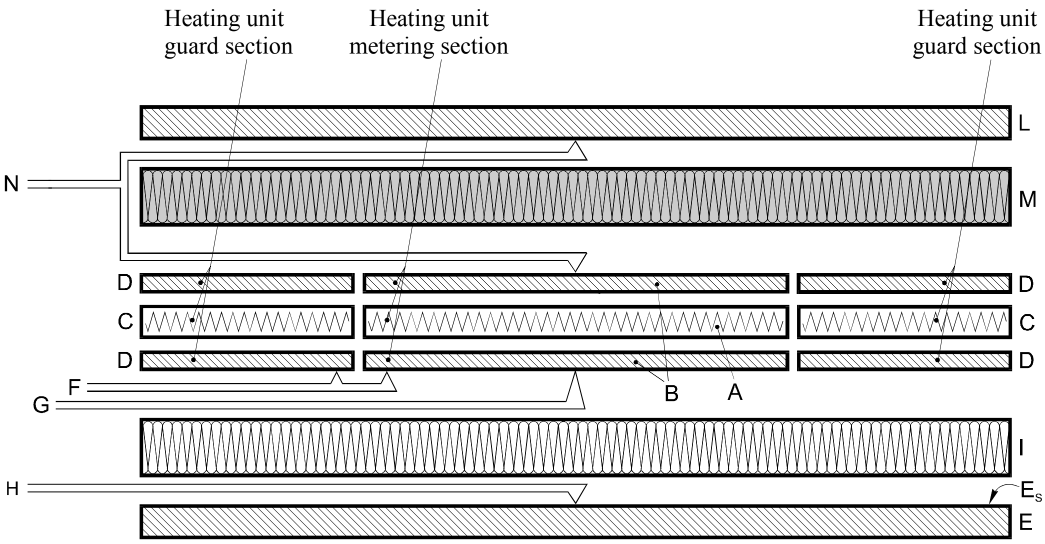
There exist two types of guarded hot plate apparatus, which conform to the basic principle outlined in clause 4:

a) with two specimens (and a central heating unit);

b) with a single specimen.



a) Two-specimen apparatus



b) Single-specimen apparatus

Key

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

5.2.2 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)], one of the specimens 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 high and medium 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 ±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.

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 configuration in practice; brief discussion is included in annex B of ISO 8301:1991.

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:

$$q = f e_h$$

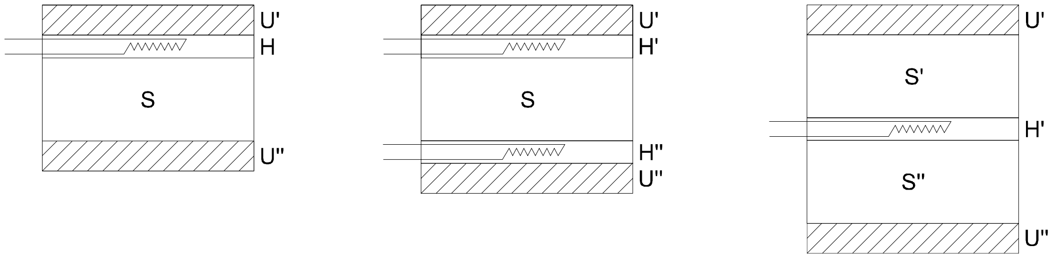
The calibration factor, f, which correlates e_h and q, is not a constant in all cases, but may depend upon temperature and, to a more limited extent, upon the density of heat flow rate.

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:

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

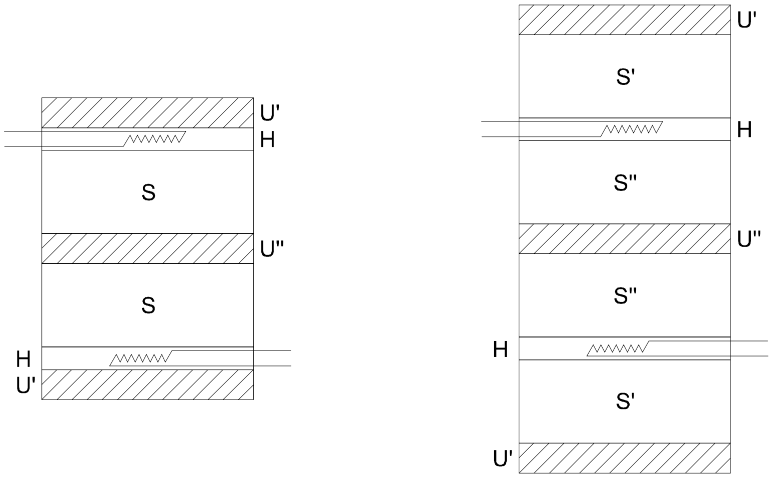
Calibration procedures are given in ISO 8301:1991.



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

5.3.4 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 1946-3:1999. 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 ±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 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 measurements, 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

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

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 parallel over the total surface area within 2 % of the specimen thickness and shall be made as flat as the apparatus surfaces and so that the accuracy in the measurement of the specimen thickness be within 0,5 % (see A.3.6 and Table A.2).

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 $(A_d/A_m)(R_a/R) < 0{,}0005$ the effect may be ignored;

— if $0{,}0005 \leq (A_d/A_m)(R_a/R) \leq 0{,}005$ the test may be undertaken, but the presence of the defects 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.

If contact sheets are used or thermocouples are mounted on the surface of the specimen, then the relevant product standards and EN 12664 shall be consulted.

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. The specimen(s) shall be prepared according to procedures appropriate to the material, in conformity with relevant product standards.

NOTE These product standard procedures cover such matters as mounting frames, covering sheets, specific precautions on specimen mounting, handling and conditioning, on how to get one (two) specimen(s) of the desired density during the test and how to check it, and on how to get a mass before and after conditioning, where applicable.

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

After the determination of the mass of the specimen(s), they shall be conditioned to constant mass according to relevant product standards.

NOTE Conditioning is e.g. drying in a ventilated oven or drying and then bringing into equilibrium with the laboratory air; to prevent moisture migration to or from the specimen during the test, the specimen itself may be enclosed in a vapour-tight envelope.

A relative loss of mass is calculated from the mass determined before and after the drying.

To reduce testing time, the specimen(s) may be conditioned to the mean test temperature immediately prior to being placed in the apparatus.

7.3 Measurements

7.3.1 Mass

Just before mounting the specimen(s) in the apparatus, determine its mass with an accuracy better than 0,5 %.

7.3.2 Thickness and density

The specimen thickness is either the thickness imposed by positioning the heating and the cooling unit or the thickness of the specimen(s) as measured at the beginning of the test, as stated by relevant product standards.

NOTE For roll- or mat-type materials, product standards usually specify the thickness to be used for testing.

Specimen(s) thickness can be measured either in the apparatus at the existing test temperature and compression conditions or outside the apparatus with instrumentation that will reproduce the pressure on the specimen during the test, as stated by relevant product standards.

For thickness measurements in the apparatus, gauging points, or measuring studs mounted on purpose at the outer four corners of the cooling unit (or the heating and cooling units for a single specimen apparatus) or along the axes perpendicular to the units, at their centres, shall be used. The specimen thickness is determined from the average difference in the distance between the gauging points when the specimen(s) is (are) in place in the apparatus and when it is not in place, and the same force is used to press the apparatus units towards each other.

From the specimen dimensions, the thickness measured as above and the mass of the conditioned specimen determined as in 7.3.1 the as-tested density can be computed.

7.3.3 Temperature difference selection

Select the temperature difference to be in accordance with A.3.8 and the relevant product standard.

7.3.4 Ambient conditions

When heat transfer properties are desired for the situation in which the specimen is surrounded by air (or some other gas), adjust the humidity of the atmosphere surrounding the apparatus units during a test to a dew-point temperature at least 5 K below the cooling unit temperature.

When enclosing the specimen in a vapour-tight envelope to prevent moisture migration to or from the specimen, the testing conditions shall be such that no water condensation will take place on the portion of the envelope in contact with the cold side of the specimen.

7.3.5 Heat flow rate measurements

7.3.5.1 Heat flow rate in the guarded hot plate apparatus

Measure the average electrical power supplied to the metering area to within ±0,1 %.

Fluctuations or changes in the temperatures of the heating unit surfaces during the test period, due to random fluctuations or changes in their input power, shall not exceed 0,3 % of the temperature difference between the heating and cooling units.

Adjust and maintain the power input to the guard section, preferably by automatic control, to obtain the degree of temperature balance between the metering and guard section that is required to keep the sum of the imbalance and edge heat loss errors within 0,5 % (see 6.2).

7.3.5.2 Heat flow rate in the heat flow meter apparatus

Observe the mean temperature and the electromotive force output of the heat flow meter, the mean temperature and the temperature drop across the specimen(s) to check when they are stabilized.

Ensure that the temperature fluctuations (as a function of time) at the surface of the heat flow meter do not cause fluctuations in its electrical output greater than 2 % during the test period.

Ensure that the density of heat flow rate is in a range such that the accuracy of the calibration factor, f, and of the electrical instrumentation to read the heat flow meter output are in accordance with 5.3.5 and relevant requirements given in annex C.

7.3.6 Cold surface control (for two-specimen guarded hot plate apparatus)

When a two specimen apparatus is used, adjust the cooling units or cold surface heaters so that the temperature differences through the two specimens do not differ by more than 2 %.

7.3.7 Temperature difference detection

Determine the heating and cooling unit temperatures and the centre-to-guard temperature balance (for guarded hot plate apparatus only) by methods having sufficient repeatability and accuracy to meet all relevant requirements given in annex B for guarded hot plate apparatus, or relevant requirements given in annex C for heat flow meter apparatus.

7.3.8 Settling time and measurement interval

Make sets of observations as in 7.3.5 and 7.3.7 at measurement intervals as recommended in A.3.11 until, during a period equal to or larger than four times the time interval Δt defined in A.3.11, successive sets of observations give thermal resistance values which do not differ by more than 1 % and are not changing monotonically.

When an accurate estimate of settling time is not possible or if there is no test experience on similar specimens in the same equipment at the same testing conditions (e.g. when starting routine testing on a new product), continue these observations until at least 24 hours have elapsed since the beginning of the steady state conditions so defined.

NOTE To check, at a glance, the attainment of steady state conditions, it may be helpful to record graphically the relevant measured quantities.

7.3.9 Final mass and thickness measurements

Upon completion of the observations in 7.3.8, measure the mass of the specimen(s) immediately. Repeat the thickness measurement and report any specimen change in volume.

8 Calculations

8.1 Density and mass changes

8.1.1 Densities

Calculate the density ρ_0 and/or ρ_c of the conditioned specimen as tested, as follows:

$$\rho_0 = m_2/V$$

$$\rho_c = m_3/V$$

where:

ρ_0 is the density of the dry material as tested;

ρ_c is the density of the material after a more complex conditioning procedure (very frequently up to the equilibrium with the standard laboratory atmosphere);

m_2 is the mass of the material after drying;

m_3 is the mass of the material after a more complex conditioning procedure;

V is the volume occupied by the material after drying or conditioning.

8.1.2 Mass changes

Calculate the relative mass change of the material as received due to drying, Δm_r, or due to a more complex conditioning procedure, Δm_c :

$$\Delta m_r = (m_1 - m_2)/m_2$$

$$\Delta m_c = (m_1 - m_3)/m_3$$

where:

m_1 is the mass of the material in as-received condition;

m_2 and m_3 are as defined in 8.1.1.

When required by the product standards, or when it is considered useful to evaluate the test conditions correctly, beside Δm_c, calculate the following relative mass change, Δm_d, due to the conditioning after the drying:

$$\Delta m_d = (m_3 - m_2)/m_2$$

Calculate the relative mass regain, Δm_w, of the specimen during the test, in relation to the mass immediately before the test, with the equation:

$$\Delta m_w = (m_4 - m_5)/m_5$$

where:

m_4 is the mass of material in the specimen immediately after the test;

m_5 is the mass of dried or conditioned material in the specimen immediately before the test (it is either $m_5 = m_2$ or $m_5 = m_3$).

8.2 Heat transfer properties

8.2.1 General

To make all the computations, use average values of the observed steady state data. The sets of observations described in 7.3.8 shall be used in the computations; other sets of observations during the steady state can be used as long as the heat transfer properties derived from each of these sets do not differ by more than 1 % from those derived from the sets described in 7.3.8.

8.2.2 Guarded hot plate apparatus measurements

Compute the thermal resistance R, using the following equation:

$$R = \frac{T_1 - T_2}{\Phi} A$$

or the transfer factor $\mathcal{T}$, using the following equation:

$$\mathcal{T} = \frac{\Phi\, d}{A(T_1 - T_2)}$$

where:

Φ is the average power supplied to the metering section of the heating unit;

T_1 is the average specimen(s) hot side temperature;

T_2 is the average specimen(s) cold side temperature;

A is the metering area as defined in 5.2.5; for two specimen apparatus the metering area defined in 5.2.5 shall be multiplied by two;

d is the average specimen(s) thickness.

If the conditions described in A.3.2 and A.4.3 are applicable, compute either the thermal transmissivity, λ_t, or the thermal conductivity, λ, (or thermal resistivity, $r = 1/\lambda$), using the following equation:

$$\lambda_t \text{ or } \lambda = \frac{\Phi\, d}{A(T_1 - T_2)}$$

where Φ, A, T_1, T_2 and d are as defined above.

8.2.3 Heat flow meter apparatus measurements

8.2.3.1 Single specimen configuration

8.2.3.1.1 Single heat flow meter configuration

Compute the thermal resistance, R, using the following equation:

$$R = \frac{T_1 - T_2}{f\, e_\mathrm{h}}$$

where:

f	is the calibration factor of the heat flow meter;
e_h	is the heat flow meter output;
T_1 and T_2	are as defined in 8.2.2;

or compute the transfer factor, T, using the following equation:

$$T = \frac{f\, e_\mathrm{h}\, d}{T_1 - T_2}$$

where T_1, T_2 and d are as defined in 8.2.2.

If the conditions described in A.3.2 and A.4.3 are applicable, compute either the thermal transmissivity, λ_t or the thermal conductivity, λ, (or thermal resistivity, $r = 1/\lambda$), using the following equation:

$$\lambda_\mathrm{t} \text{ or } \lambda = \frac{f\, e_\mathrm{h}\, d}{T_1 - T_2}$$

where f, e_h, T_1, T_2 and d are as defined above.

8.2.3.1.2 Two heat flow meter configuration

All the requirements of 8.2.3.1.1 are applicable to this configuration, with $f\,e_\mathrm{h}$ replaced by 0,5 $(f_1 e_{\mathrm{h}1} + f_2 e_{\mathrm{h}2})$ where the indexes 1 and 2 refer to the first and second heat flow meter respectively (of which the surface temperatures are respectively T_1 and T_2).

8.2.3.2 Two-specimen configuration

Compute the total thermal resistance, R_t, as follows:

$$R_\mathrm{t} = \frac{(T'_1 - T'_2) + (T''_1 - T''_2)}{f\, e_\mathrm{h}}$$

and, if the conditions described in A.3.2 and A.4.3 are applicable, compute the average thermal transmissivity, λ_tm , or the average thermal conductivity, λ_m, (or thermal resistivity, $r_\mathrm{m} = 1/\lambda_\mathrm{m}$), using the following equation:

$$\lambda_\mathrm{tm} \text{ or } \lambda_\mathrm{m} = \frac{f\, e_\mathrm{h}}{2}\left(\frac{d'}{(T'_1 - T'_2)} + \frac{d''}{(T''_1 - T''_2)}\right)$$

where the symbols are as in 8.2.3.1.1 and ' and " refer to the two specimens (' for the first specimen and " for the second specimen).

9 Test report

If results are to be reported according to this standard, all requirements laid down shall be met; for allowed exceptions see r).

The report of the results of each test shall include the following (the numerical values reported shall represent the average values for the two specimens as-tested or the value of a specimen for single specimen apparatus).

a) Test method used (guarded hot plate or heat flow meter conforming to this standard), type of apparatus used (with one or two specimens, see 5.2.2, 5.2.3 or 5.3.1) and the identification of the equipment. Method to reduce edge heat losses. Ambient temperature of the environment surrounding the apparatus during the test. Product standard applicable to the tested specimen(s).

b) Name and any other pertinent identification of the material, including a physical description supplied by the manufacturer.

c) Description of the specimen and reference to the product standard according to which sampling and specimen preparation was carried out.

d) Thickness of the specimens in metres, specifying if either imposed or measured. Reference to a specific test method used, if imposed by a product standard. Criteria from the relevant product standard to define the imposed thickness.

e) Method and temperatures of conditioning.

f) Densities of the conditioned material as tested.

g) Relative mass changes during drying and/or conditioning (see 8.1).

h) Relative mass change during the test (see 8.1). Observed thickness (and volume) changes during the test (see 7.3.9).

i) Average temperature difference across the specimen(s) during the test, see 7.3.7, in K.

j) Mean temperature of test, in K or °C.

k) Density of heat flow rate through the specimen during test ($q = \Phi/A$ for guarded hot plate apparatus or $q = f\,e_h$ for heat flow meter apparatus, see 8.2).

l) Thermal resistance or transfer factor of the specimen(s). Where applicable, the thermal resistivity, thermal conductivity, or thermal transmissivity, and, if required by the relevant product standard, range of thickness for which these values have been measured or are known to apply, see EN 12939.

m) Date of completion of the test; duration of the full test and of the steady state part of the test, if such information is required by the relevant product standard.
For heat flow meter apparatus only: date of last heat flow meter calibration. Type or types of the calibration specimens used, their thermal resistance, date of specimen certification, source of certification, expiration date of calibration, and the certification test number.

n) Orientation of the apparatus; vertical, horizontal, or any other orientation. In the case of single specimen apparatus, the position of the hot side of the specimen when not vertical: top, bottom or any other position.

o) For tests made using water-vapour tight envelopes, information shall be given on the nature and thickness of the envelope.

p) A graphical representation of the results in the report shall be given when required by the relevant product standard. This shall consist of a plot of each value of the thermal properties obtained versus the corresponding mean temperature of the test, plotted as ordinates and abscissae respectively. Plots of thermal resistance or transfer factor as a function of specimen thickness shall be given when required by the relevant product standard.

q) When all the requirements stated in this standard and in EN 1946-2:1999 or EN 1946-3:1999 are fulfilled, the maximum expected error in a measured property is within 2 % for guarded hot plate apparatus and within 2 % plus calibration specimen traceability added in quadrature for heat flow meter apparatus; a statement providing these figures shall be included in the report; when one or more of the requirements stated in this standard or in EN 1946-2:1999 or EN 1946-3:1999 are not fulfilled by the specimen(s) (see also r) on the statement of non-compliance) it is recommended that a complete estimation of the error or errors in measured property be included in the report.

r) Where circumstances or requirements preclude complete compliance with the procedure of the test described in this standard, exceptions allowed by the relevant product standard may be made, but shall be specifically explained in the report. A suggested wording is: “This test conformed with all requirements of EN 12667, *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*, with the exception of .... (a complete list of the exceptions follows)”.

s) Name of the operator who carried out the test.

Annex A
(normative)

Limitations to the implementation of the measurement principle and on measurable properties

A.1 Introduction: heat transfer and measured properties

When testing high and medium thermal resistance products, the actual heat transfer within them can involve a complex combination of different contributions of:

— radiation;
— conduction both in the solid and in the gas phase;
— convection (in some operating conditions);

plus their interactions together with mass transfer, especially in moist materials. For such materials the heat transfer property, very often improperly called “thermal conductivity”, calculated for a specimen by applying a defined formula to the measured heat flow rate, temperature difference and dimensions, may be not an intrinsic property of the material itself, as it may depend on the testing conditions. This property should therefore be called “transfer factor” (the transfer factor is often referred to elsewhere as “apparent” or “effective thermal conductivity”). The transfer factor may have a significant dependence on the thickness of the specimen and/or on the temperature difference for the same mean test temperature and on the radiative characteristics of the surfaces adjoining those of the specimen.

NOTE The specific problem of testing thick specimens exceeding apparatus capabilities and/or exhibiting the so-called thickness effect is addressed in EN 12939.

For all the above reasons the thermal resistance, as the transfer factor, is a property that properly describes the thermal behaviour of the specimen in its specific testing conditions. If there is the possibility of the onset of convection within the test specimen (e.g. in light mineral wool), the apparatus orientation, the thickness and the temperature difference can influence both the transfer factor and the thermal resistance.

If a heat transfer property of many specimens of the same material is measured, this property may:

1) vary due to variability of composition of the material or samples of it;
2) be affected by moisture or other factors;
3) change with time;
4) change with mean temperature;
5) depend upon the prior thermal history.

It shall be recognized, therefore, that the selection of a typical value of heat transfer properties representative of a material in a particular application, shall be based on appropriate sampling schemes, testing conditions and conversion rules, see also A.4.

A.2 Definitions

A.2.1 thermal conductivity, λ, at a point P: Quantity defined in each point P of a purely conducting medium by the following relation between the vectors $\boldsymbol{q}$ and grad(T):

$$\boldsymbol{q} = - \lambda \, \mathrm{grad}(T)$$

NOTE In the most general case the thermal conductivity is a nine element tensor and not a constant.

A.2.2 thermally homogeneous medium: Medium in which the thermal conductivity is not a function of the position within the medium but may be a function of the direction, time and temperature.

A.2.3 porosity, ξ: Total volume of the voids within a porous medium (a porous medium is one which is heterogeneous due to the presence of e.g. fibres, cell walls, grains) divided by the total volume of the medium. The local porosity, ξ_P, at the point P is the porosity within a specimen when the volume of an elementary part of the specimen is small with respect of the specimen, but large enough to evaluate a meaningful average.

A.2.4 homogeneous porous medium: Medium in which the local porosity is independent of the point where the value is computed [EN ISO 9251:1995].

NOTE Most high and medium thermal resistance specimens are homogeneous porous, i.e. not homogeneous (see the definition of porosity) and hence not thermally homogeneous.

A.2.5 thermally isotropic medium: Medium in which the thermal conductivity is not a function of the direction but may be a function of the position within the medium, of time and temperature.

NOTE The thermal conductivity of an isotropic medium is defined through a single value in each point, instead of a matrix of values.

A.2.6 thermally stable medium: Medium in which the thermal conductivity is not a function of time, but may be a function of the co-ordinates, of temperature and, when applicable, of direction.

A.2.7 mean thermal conductivity of a specimen: Property defined in steady state conditions in a body that has the form of a slab bounded by two parallel, flat isothermal faces and by adiabatic edges perpendicular to the faces, that is made of a material thermally homogeneous, isotropic (or anisotropic with a symmetry axis perpendicular to the faces), stable only within the precision of a measurement and the time required to execute it, and with the thermal conductivity constant or a linear function of temperature.

A.2.8 transfer factor of a specimen: Defined by

$$T = \frac{q\ d}{\Delta T} = \frac{d}{R}$$

NOTE This definition is applicable to any steady state test with a guarded hot plate or heat flow meter apparatus on specimens where conduction, convection and radiation take place together. It depends on experimental conditions, e.g. temperature difference, apparatus emissivity and specimen thickness, and in these conditions characterizes a **specimen** in relation to the combined conduction and radiation heat transfer. It is often referred to elsewhere as measured, equivalent, apparent or effective thermal conductivity of a **specimen**.

A.2.9 thermal transmissivity of a material: Defined by:

$$\lambda_{\mathrm{t}} = \frac{\Delta d}{\Delta R}$$

when $\Delta d/\Delta R$ is independent of the thickness d.

NOTE The thermal transmissivity is independent of experimental conditions and characterizes an insulating **material** in relation with combined conduction and radiation heat transfer. The thermal transmissivity can be seen as the limit reached by the transfer factor in thick layers where combined conduction and radiation heat transfer takes place. It is often referred to elsewhere as equivalent, apparent or effective thermal conductivity of a **material**.

A.2.10 steady state heat transfer property: Generic term to identify one of the following properties: thermal resistance, transfer factor, thermal conductivity, thermal resistivity, thermal transmissivity, thermal conductance, mean thermal conductivity.

A.2.11 settling time: Time needed for a measurement to reach steady state conditions within 1 %.

A.2.12 rigid specimen: A specimen of a material too hard and unyielding to be appreciably altered in shape by the pressure of the heating and cooling unit, so as to achieve uniform thermal contact over the entire heating and cooling unit surfaces facing the specimen.

A.2.13 room temperature: Generic term to identify a mean test temperature of a measurement such that a person in a room would regard it comfortable if it were the temperature of that room.

A.2.14 ambient temperature: Generic term to identify the temperature in the vicinity of the edge of the specimen or in the vicinity of the whole apparatus.

NOTE This temperature is the temperature within the cabinet where the apparatus is enclosed or that of the laboratory for non-enclosed apparatus.

A.2.15 operator: Person responsible for carrying out the test and for the presentation through a report of the measured results.

A.2.16 data user: Person involved in the application and interpretation of measured results to judge material or system performance.

A.2.17 designer: Person who develops the constructional details of an equipment in order to meet predefined performance limits for the apparatus in assigned testing conditions and who identifies the test procedures to verify the predicted apparatus accuracy.

A.3 Limitations due to the implementation of the principle

A.3.1 General

The implementation of the measurement principle outlined in clause 4 through the apparatus described in this standard implies some limitations.

A.3.2 Specimen homogeneity

A.3.2.1 General criteria

The test principle outlined in clause 4 assumes homogeneous specimens: most high and medium thermal resistance products fall within the definition of a homogeneous porous medium, see A.2. Such products may be tested, provided that the largest size of pores, grains or any other non-homogeneity has dimensions smaller than one-tenth of the specimen thickness. For any other non-homogeneity, with the exception of layered specimens, see A.3.2.2, ISO 8302:1991 shall be consulted.

A.3.2.2 Layered specimens

For layered inhomogeneous composite specimens, the mean measurable thermal conductivity of each layer should be less than twice that of any other layer. This shall be regarded as a rough rule of the thumb asking only for an estimate made by the operator, that does not necessarily imply the measurement of the conductivity of each layer. It is expected that in this situation the accuracy will remain close to the one predictable for tests on homogeneous specimens. No guidelines can be supplied to assess measurement accuracy when this requirement is not met.

A.3.2.3 Anisotropic specimens

Some specimens, while meeting the homogeneity criteria, are anisotropic in that the value of the thermal conductivity measured in a direction parallel to the surfaces is different to that measured in a direction normal to the surfaces. For such specimens this can result in larger imbalance and edge loss errors. If the ratio between these two measurable values is larger than two, ISO 8302:1991 shall be consulted.

A.3.3 Maximum specimen thickness

The boundary conditions at the edges of the specimens due to the effects of edge insulation, of auxiliary guard heaters and of surrounding ambient temperature will affect the edge heat loss error and hence will limit the maximum thickness of specimen for any one configuration, as described in EN 1946-2:1999, annex B.

In this standard, the edge temperature ratio, e, is defined by:

$$e = (T_e - T_2)/(T_1 - T_2)$$

where T_e is the temperature of the edge of the specimen (supposed uniform) and T_1 and T_2 are respectively the temperatures of the hot and cold side of the specimen. When there is no edge insulation and $0{,}25 \le e \le 0{,}75$, the maximum specimen thickness should not exceed those indicated, for some common apparatus sizes, in column 4 of Table A.1. column 4 data are according to the expression given in 2.2.1 of ISO 8302:1991.

> EXAMPLE 1 $e = 0{,}25$ corresponds to a temperature of the edge of the specimen kept 5 K below the mean test temperature, when the temperature difference between the hot and cold side of the specimen is 20 K.

NOTE The edge heat loss error is zero for homogeneous isotropic specimens when e is close to 0,5. The error for $e = 0{,}25$ gives the maximum error for $0{,}25 \le e \le 0{,}75$. Then for any other value of e up to 0,75, the edge heat loss error is smaller.

Table A.1 — Minimum and maximum allowed specimen thickness

Dimensions in millimetres

Overall size	Metering section	Guard width	Maximum thickness (edge limit)	Flatness tolerance (0,025 %)	Minimum thickness (flatness tolerance)	Max. gap width	Minimum thickness[1)] (gap limit)
200	100	50	30	0,05	10,0	1,25	12,5
300	200	50	35	0,08	15,0	2,50	25,0
300	150	75	45	0,08	15,0	1,88	18,8
400	200	100	60	0,10	20,0	2,50	25,0
400	100	150	80	0,10	20,0	1,25	12,5
500	300	100	65	0,13	25,0	3,75	37,5
500	250	125	75	0,13	25,0	3,13	31,3
500	200	150	85	0,13	25,0	2,50	25,0
600	300	150	90	0,15	30,0	3,75	37,5
800	500	150	100	0,20	40,0	6,25	62,5
800	400	200	120	0,20	40,0	5,00	50,0
1 000	500	250	150	0,25	50,0	6,25	62,5

1) Thicknesses applicable for gap widths according to the seventh column of Table A.1; for thinner gaps see 5.2.5.

When edge insulation is interposed between the specimen edge and the walls of a cabinet directly in contact with the laboratory air, the laboratory temperature is the edge temperature. When the laboratory temperature differs significantly from the mean test temperature, e can be markedly outside the range 0,25 to 0,75.

EXAMPLE 2 A mean test temperature of 50 °C, a temperature difference of 20 °C and a laboratory temperature of 20 °C gives $e = -1$. In this case the data in Table A.1 are no longer applicable.

For guarded hot plate apparatus only, when an additional outer plane guard is used, the maximum specimen thickness can be evaluated as if the guard were extended up to the edge of the additional plane guard.

For a gradient guard or for edge insulation either undertake numerical calculations or carry out systematic experimental investigations on apparatus of similar design to determine the edge heat loss error.

When using a heat flow meter apparatus in the single specimen symmetrical configuration, see 5.3.1, the maximum specimen thickness indicated in Table A.1 may be increased by 50 % when the requirements of 4.4 and 4.6 of EN 1946-3:1999 are met.

The above information is based on purely conductive models. For low density materials (e.g. less than 20 kg/m^3), where a considerable amount of radiation heat transfer takes place, it is advisable not to exceed the thicknesses allowed from the data of Table A.1, see EN 12939.

A.3.4 Minimum specimen thickness

The minimum specimen thickness is limited by contact resistances given in A.3.6. Where thermal conductivity or thermal resistivity is required, the minimum specimen thickness is also limited by the accuracy of the instrumentation for measuring the thickness.

When testing **non-rigid specimens**, the maximum departure of apparatus surfaces from a plane (which shall not exceed 0,025 % of the overall apparatus size, see the fifth column of Table A.1) shall under no circumstance induce an uncertainty in the measured specimen thickness greater than 0,5 %: corresponding minimum specimen thicknesses are supplied in the sixth column of Table A.1.

For guarded hot plate apparatus the minimum specimen thickness shall also be at least ten times the heating unit gap width, see 5.2.5. The gap, in turn, shall have an area not exceeding 5 % of the metering area: the maximum gap width resulting from this requirement is given in the seventh column of Table A.1, and the corresponding minimum specimen thickness is given in the eighth column of Table A 1.

A.3.5 Maximum limits for the thermal resistance

The upper limit of thermal resistance that can be measured is limited by the stability of the power supplied to the heating unit, the ability of the instrumentation to measure power level and the extent of the heat losses or gains due to temperature imbalance errors (analysed in EN 1946-2:1999) between the central metering and guard sections of the specimens and of the heating unit.

A.3.6 Flatness and contact resistances

When testing a specimen (in particular one of high thermal conductance and rigid, see the definition of “rigid specimen” in A.2), even small non-uniformities of the surface of both the specimen and the apparatus (surfaces not perfectly flat) will allow contact resistances not uniformly distributed between the specimens and the plates of the heating and of the cooling units.

NOTE These will cause non-uniform heat flow rate distribution and thermal field distortion within the specimens; moreover, they will make accurate surface temperature measurements difficult to undertake and also create an uncertainty in the determination of the specimen thickness.

When testing **rigid specimens**, the maximum departure of apparatus surfaces from a plane shall under no circumstance induce errors associated with the total added thermal resistance (on both sides of the specimen), due to imperfect contact of rigid specimens, exceeding 0,5 % of the specimen thermal resistance. This error is independent of apparatus sizes: Table A.2 shows, for some thermal resistances of the specimen, the resulting maximum allowed contact resistances. From these, the maximum equivalent air layer thickness resulting from the air pockets on both sides of the specimen, and inclusive of the effect of both apparatus and specimen departures from a true plane, has been derived when the thermal conductivity of the air is close to 0,025 W/(m·K), i.e. around room temperature, see the third column of Table A.2.

A.3.7 Parallelism

Parallelism is not as critical as flatness for the procedures described in this standard; the maximum deviation from parallelism for specimen surfaces is defined by the requirement that the specimen thickness shall not differ from the mean value by more than 2 %, see B.5 in annex B.

A.3.8 Limits to temperature difference

It is recommended that temperature differences in the range of 10 K to 50 K are used in order to minimize temperature-difference measurement errors.

Table A.2 — Flatness tolerances related to the specimen thermal resistance

Specimen thermal resistance $m^2·K/W$	**Maximum allowed contact thermal resistance** $m^2·K/W$	**Maximum equivalent air layer thickness (apparatus + specimen)** mm
0,3	0,0015	0,04
0,4	0,0020	0,05
0,5	0,0025	0,06
0,6	0,0030	0,08
0,8	0,0040	0,10
1,0	0,0050	0,13
1,5	0,0075	0,19

In the unlikely event that lower or higher temperature differences are required by a product standard, ISO 8302:1991 shall be consulted.

A.3.9 Maximum operating temperature

The maximum operating temperature of the heating and cooling units may be limited by oxidation, thermal stress or other factors which degrade the flatness and uniformity of the surface plate and by changes of electrical resistivity of electrical insulations which may affect accuracy of all electrical measurements.

A.3.10 Warping

Special care should be exercized with specimens with large coefficients of thermal expansion that warp excessively when subjected to a temperature gradient. The warping may damage the apparatus or may cause additional contact resistance that may lead to serious errors in the measurement. Specially designed equipment may be necessary to measure such materials.

A.3.11 Settling time and measurement interval

As the principle of the method assumes steady state conditions, to attain a correct value for properties, it is essential to allow sufficient time (i.e. the settling time, see A.2.11 for its definition) for the apparatus and specimen to attain thermal equilibrium.

NOTE 1 In measurements on good insulators having low thermal capacity and for cases where there is moisture absorption or desorption with consequent latent heat exchange, the internal temperatures (and therefore moisture contents) of the specimen can require a very long time to attain thermal equilibrium. The time required to reach equilibrium will depend on the apparatus, on the specimen, and on their interactions and can vary from 10 minutes (e.g. when testing in a well controlled heat flow meter apparatus a thin specimen of insulating material already in equilibrium in a laboratory kept at the mean test temperature) to more than one day (e.g. when testing a thick specimen of insulation material in a guarded hot plate apparatus without automatic control of the heating unit or when testing specimens where a moisture redistribution has to take place during the measurements).

The following items shall be critically considered to evaluate this time:

a) thermal capacities and control system of the cooling unit(s) for guarded hot plate apparatus or heating and cooling units for heat flow meter apparatus;
b) thermal capacities and control system of the heating unit metering section, and heating unit guard section (for the guarded hot plate apparatus only);
c) insulation of the apparatus;
d) thermal diffusivity, water vapour permeability and thickness of the specimen;
e) test temperatures and environment during test;
f) temperature and moisture contents of the specimen(s) at the beginning of the test.

NOTE 2 As a general guideline, control systems can strongly reduce the time to reach thermal equilibrium, but little can be done to reduce the time to reach moisture content equilibrium.

Where a more accurate estimate of settling time is not possible, or where there is no testing experience on similar specimens in the same apparatus at the same testing conditions, compute the following time interval Δt:

$$\Delta t = (\rho_p c_p d_p + \rho_s c_s d) R$$

where:

ρ_p is the density;
c_p is the specific heat;
d_p is the thickness;

all related to the heating unit metal plate for guarded hot plate apparatus or either metal plate (of the heating or cooling unit) for heat flow meter apparatus (the effect of the term $\rho_p c_p d_p$ is minimized by effective automatic control of the heating and cooling unit temperatures in a heat flow meter apparatus);

ρ_s is the density of the specimen;
c_s is the specific heat of the specimen;
d is thickness of the specimen;
R thermal resistance of the specimen.

If automatic controllers are used, in particular to feed the electrical heaters of the heating unit, Δt shall be reduced according to automatic control theory to take into due account the presence of such controllers.

The settling time is related to Δt, typically five times to reach steady state within less than 1 %. The measurement interval is recommended not to be more than 0,25 % of Δt, so that the values obtained represent average values.

A.4 Limitations on measurable heat transfer properties

A.4.1 General

The heat transfer property measured on one individual specimen may characterize the test specimen in its test condition only, may be an intrinsic property of the specimen or may be a property which characterizes the product from which the test specimen has been sampled. Keeping in mind the following clauses, guidance shall be found in relevant product standards on the significance of test results.

A.4.2 Thermal resistance, thermal conductance or transfer factor

Either the thermal resistance, the thermal conductance or the transfer factor may be given as a result of one measurement on one specimen under given testing conditions, provided that the homogeneity criteria of A.3.2 are met.

The thermal resistance, thermal conductance or transfer factor are often a function of temperature differences across the specimen. The temperature differences shall be indicated in the test report.

A.4.3 Mean thermal conductivity or thermal transmissivity of a specimen

In order to determine the mean thermal conductivity or thermal transmissivity of a specimen (when applicable) the homogeneity criteria of A.3.2.1 shall be met, and in addition, at any one mean temperature, the thermal resistance shall also be independent of the temperature difference established across the specimen. If this last criterion is not met, only the thermal resistance of the specimen at the given testing conditions shall be reported.

A.4.4 Thermal conductivity or thermal transmissivity of a material

A.4.4.1 General

In order to determine the thermal conductivity or thermal transmissivity of a material (when applicable), the criteria of A.4.3 shall be fulfilled. In addition adequate sampling shall be performed to ensure that the material is homogeneous or homogeneous porous, and that the measurements are representative of the whole material, product or system; guidance on these matters is to be found in the relevant product standard applicable to the specimen tested. The thickness of the specimens shall be greater than that for which the transfer factor of the material, product or system does not change by more than 2 % with further increase in thickness.

A.4.4.2 Dependence on specimen thickness

To assess the relevance of the effect of specimen thickness on the transfer factor, EN 12939 shall be consulted, in conjunction with the relevant product standards.

A.5 Preliminary decisions

Having ascertained that valid measurements are possible in accordance with a product standard and the limitations described in this annex, before any measurement are undertaken with guarded hot plate apparatus or heat flow meter apparatus available in the laboratory, a number of decisions have to be made, which relate to the specific property desired or needed as a result of any direct measurement (e.g. thermal conductivity or thermal resistance), or to any correlation desired or needed among measured properties (e.g. thermal conductivity as a function of temperature, or as a function of density at a given temperature).

In particular these decisions will be influenced by:

a) The size and form of apparatus either available or necessary. A particular apparatus of one size may not be sufficient to carry out measurements on all specimen thicknesses.

   Similarly the range of both temperature and environmental conditions either available or necessary shall be checked.

b) The size and number of specimens needed according to relevant product standards.

c) The need or desirability of enclosing the specimen in thin water-vapour tight envelopes, according to relevant product standards.

NOTE 1 These techniques are intended to prevent either moisture adsorption after drying or change in moisture content after conditioning.

d) The need for either specimen thickness spacers or applied pressure on the specimen.

NOTE 2 When a person submits a particular specimen or sample for test according to a product standard or requires specific information on measured heat transfer properties, it is assumed that the operator can discuss the impact on the measurements of the basic principles of heat transfer in high and medium thermal resistance products and those of the design and operation of the guarded hot plate or heat flow meter.

NOTE 3 There is a difference between a measurement the goal of which is to determine one of the steady state heat transfer properties defined in A.2, and a measurement required by a product standard. The latter may be required by a sampling plan on specimens that do not conform to all the requirements stated in this standard. A typical situation is that of specimens not flat enough to ensure good contact with the apparatus, or not parallel, as required in 6.3.2.1, or tested at a thickness far from the end use of the material. The numerical results of such tests can therefore be regarded merely as a convenient basis for the acceptance or rejection of lots of a particular material, and not necessarily as a meaningful thermal property.

Annex B
(normative)

Limits for equipment performance and test conditions — Guarded hot plate

B.1 General

This annex defines mandatory limits for equipment performance check and test conditions. All references to clauses of ISO 8302:1991 are for information only; clause numbers followed by an asterisk (*) give amended values compared to ISO 8302:1991.

B.2 Accuracy and repeatability, stability, uniformity

Clause in ISO 8302:1991	Description	Value
1.5.3	expected guarded hot plate method accuracy (at room temperature)	2 %
1.5.3	expected guarded hot plate method accuracy (full temperature range)	5 %
1.5.3	expected repeatability (specimen removed and mounted again)	1 %
2.1.4.1.1	maximum allowed imbalance error	0,5 %
3.2.1	maximum value for the sum of imbalance and edge heat loss errors	0,5 %
2.1.1.2	required heating unit temperature uniformity related to temperature difference through the specimen	2 %
2.1.1.2	maximum temperature difference between the average temperature of the opposite surfaces of the heating unit	0,2 K
3.3.5	maximum allowed temperature fluctuations of the heating unit (related to the temperature difference between heating and cooling units) due to fluctuations of input power	0,3 %
2.1.2 *	required long-term stability of the cooling unit temperature related to the temperature difference across the specimen	0,5 %
2.1.2 *	required upper limit of fluctuations of the cooling unit temperature related to the temperature difference across the specimen	2 %
2.1.2 *	required stability of the cooling unit temperature related to the temperature difference across the specimen	2 %
2.1.4.1.2	required accuracy in the measurement of temperature difference between heating and cooling unit	1 %
3.3.6	maximum difference between the temperature differences through the two specimens in a two-specimen apparatus	2 %
2.1.4.1.4	suggested standard errors for thermocouples	see Table B.1 of ISO 8302:1991
2.1.4.1.4	suggested standard error for thermocouples between 21 K and 170 K	1 %
2.1.4.1.4 *	error in the measurement of temperature difference due to distortion	deleted

Clause in ISO 8302:1991	Description	Value
2.1.4.2	required accuracy in the measurement of specimen thickness	0,5 %
3.2.1	maximum thickness difference for two specimens to be mounted in a two specimen apparatus	2 %
2.1.1.1 *	maximum uncertainty in measured specimen thickness for non-rigid specimens due to departures from a plane	0,5 %
2.1.1.1	maximum departure from a plane of an apparatus surface or of the surfaces of rigid specimens	0,025 %
2.1.4.3	required accuracy of electrical measurements on temperature sensors, related to the temperature difference across the specimen	0,2 %
3.3.5 *	required accuracy in the measurement of average electrical power supplied to the metering section	0,1 %
2.1.4.3	required accuracy in the measurement of electrical power	0,1 %
3.3.1	required accuracy in the determination of specimen mass	0,5 %
2.2.4	maximum probable error as percentage of total error	50 % to 75 %

B.3 Suggested apparatus sizes

Clause in ISO 8302:1991	Description	Value
1.7.9	suggested apparatus sizes	0,3 m; 0,5 m
1.7.9	suggested apparatus size (only for homogeneous materials)	0,2 m
1.7.9	suggested apparatus size (only to assess thickness effect)	1 m

B.4 Equipment design requirements

Clause in ISO 8302:1991	Description	Value
2.1.1.2; 2.3.6; 3.2.2.3.3	minimum total hemispherical emissivity for any surface in contact with the specimen	0,8
2.1.1.1	maximum departure from a plane of an apparatus surface or of the surfaces of rigid specimens	0,025 %
2.1.1.3	maximum gap area related to the metering section area	5 %
2.1.1.5	maximum distance of imbalance sensors from the gap, related to the side or diameter of the metering section	5 %
2.1.3	maximum heat flow rate through the wires, related to heat flow rate through the specimen	10 %
2.1.1.2	required heating unit temperature uniformity related to temperature difference through the specimen	2 %
2.1.1.2	maximum temperature difference between the average temperature of the opposite surfaces of the heating unit	0,2 K

Clause in ISO 8302:1991	Description	Value
3.3.5	maximum allowed temperature fluctuations of the heating unit (related to the temperature difference between heating and cooling units) due to fluctuations of input power	0,3 %
2.1.2 *	required long-term stability of the cooling unit temperature related to the temperature difference across the specimen	0,5 %
2.1.2 *	required stability of the cooling unit temperature related to the temperature difference across the specimen	2 %
2.1.2 *	required upper limit of fluctuations of the cooling unit temperature related to the temperature difference across the specimen	2 %
2.4.2 *	maximum allowed temperature difference, as percentage of minimum temperature difference through the specimen, during isothermal tests	1 %
2.4.5	maximum ratio between the edge to mean specimen temperature difference and temperature difference through the specimen (for best accuracy)	0,1 (0,02)
2.1.4.1.4	maximum thermocouple diameter when mounted in the surface of the plates to measure temperature differences between heating and cooling units	0,6 mm
2.1.4.1.4 *	suggested maximum thermocouple diameter when mounted as above in the surface of an apparatus smaller than 0,5 m in side or diameter	0,2 mm
2.1.4.1.1	suggested maximum diameter for thermocouples to detect imbalance	0,3 mm
2.1.4.1.2	minimum number of temperature sensors on each side of the metering section (whichever is greater)	$10\sqrt{A}$ or 2
2.1.4.1.2	minimum electrical resistance between unshielded temperature sensors and apparatus metal plates	100 MΩ
3.3.4.1	minimum required difference between air dew point and cooling unit temperature	5 K
3.3.4.1	suggested range for the above difference in inter-laboratory comparisons	5 K to 10 K
2.1.5	maximum suggested apparatus pressure on the specimen for most insulating materials	2,5 kPa

B.5 Acceptable specimen characteristics

Clause in ISO 8302:1991	Description	Value
1.1	minimum measurable thermal resistance in a guarded hot plate apparatus	0,1 $m^2 \cdot K/W$
1.1	minimum measurable thermal resistance in a guarded hot plate apparatus accepting derated accuracy	0,02 $m^2 \cdot K/W$
1.7.1 *	maximum thermal resistance for rigid specimens requiring special techniques to measure surface temperatures	0,3 $m^2 \cdot K/W$

Clause in ISO 8302:1991	Description	Value
2.1.4.1.3	minimum thermal resistance for non rigid specimens to use permanently mounted temperature sensors to measure the temperature difference across the specimen	0,5 $m^2 \cdot K/W$
2.1.4.1.3 *	maximum resulting thermal resistance (on both sides of the specimen) due to imperfect contact of rigid specimens, expressed as percentage of the specimen thermal resistance	0,5 %
3.2.2.2.1 *	minimum resistance for rigid specimens to measure temperature difference through apparatus thermocouples	0,3 $m^2 \cdot K/W$
2.1.4.1.3 *	additional uncertainty in the temperature difference across a rigid specimen of thermal resistance greater than 0,1 $m^2 \cdot K/W$ when using contact sheets and/or temperature sensors mounted on the surface of the specimen	0,5 %
2.1.4.1.3 *	additional uncertainty in the temperature difference across a rigid specimen of thermal resistance between 0,1 $m^2 \cdot K/W$ and 0,02 $m^2 \cdot K/W$ when using contact sheets and/or temperature sensors mounted on the specimen surface	from 0,5 % to 4 %
1.7.6	minimum specimen thickness related to gap width minimum	10 times
3.2.1	maximum thickness difference for two specimens to be mounted in a two specimen apparatus	2 %
2.1.1.1	maximum departure from a plane of an apparatus surface or of the surfaces of rigid specimens	0,025 %
2.1.1.1 *	maximum uncertainty in measured specimen thickness for non-rigid specimens due to departures from a plane	0,5 %
3.2.2.2.1 *	maximum value of $(A_d/A_m)(R_a/R)$ to ignore the effect of defects on the surface of the specimen	0,000 5
3.2.2.2.1	maximum deviation from parallel planes for specimen surfaces, related to specimen thickness	2 %
1.8.2	maximum size for inhomogeneities related to specimen thickness	1/10
3.2.2.3.1 *	minimum suggested ratio between specimen thickness and mean dimension of beads, grains, flakes, etc.	10
3.4.1	change in thermal resistance in specimens containing short circuits requiring measurements with thicker sheets	1 %
3.4.1	minimum difference in measured properties to consider a specimen as non-homogeneous	2 %
1.7.4	maximum ratio of thermal conductivity of any two layers in layered specimens	2
1.8.2	maximum ratio of thermal conductivity in the directions perpendicular and parallel to specimen thickness in anisotropic specimens	2
1.8.3.1	limit for transfer factor changes with thickness to assign thermal transmissivity to the material	2 %
3.4.2	maximum difference for transfer factor at different thicknesses to be assumed as thermal transmissivity	2 %
3.4.2	maximum acceptable difference from a linear relationship versus thickness for thermal resistance to compute the interpolating line slope	1 %

Clause in ISO 8302:1991	Description	Value
3.2.2.3.3	maximum specimen thickness for plastic sheets in method B for loose-fill materials	50 µm
3.4.1	minimum thickness requested for the sheets made of finely ground cork to break thermal paths	0,002 m

B.6 Acceptable testing conditions

Clause in ISO 8302:1991	Description	Value
1.1	minimum measurable thermal resistance in a guarded hot plate apparatus	0,1 $m^2 \cdot K/W$
1.1	minimum measurable thermal resistance in a guarded hot plate apparatus accepting derated accuracy	0,02 $m^2 \cdot K/W$
1.7.1 *	maximum thermal resistance for rigid specimens requiring special techniques to measure surface temperatures	0,3 $m^2 \cdot K/W$
1.7.3	lower limit for temperature differences measured differentially	5 K
1.7.3	lower recommended limit for temperature differences through the specimen	10 K
3.3.3	lower limit for temperature differences across the specimen when determining an unknown relationship between temperature and heat transfer properties	5 K
3.3.3	upper recommended limit for temperature difference across the specimen when determining an unknown relationship between temperature and heat transfer properties	10 K
3.3.6	maximum difference between the temperature differences through the two specimens in a two-specimen apparatus	2 %
3.2.2.2.1	minimum number of thermocouples on each side of the specimen (whichever is greater of the two criteria)	$10\sqrt{A}$ or 2
3.3.4.1	minimum required difference between air dew point and cooling unit temperature	5 K
3.3.4.1	suggested range for the above difference in inter-laboratory comparisons	5 K to 10 K
3.2.1	maximum value for the sum of imbalance and edge heat loss errors	0,5 %
2.4.5	maximum ratio between the edge to mean specimen temperature difference and temperature difference through the specimen (for best accuracy)	0,1 (0,02)
1.7.6	minimum specimen thickness related to gap width	10 times
3.2.1	maximum thickness difference for two specimens to be mounted in a two specimen apparatus	2 %
2.1.5	maximum recommended apparatus pressure on the specimen for most insulating materials	2,5 kPa
3.2.2.2.1 *	maximum resistance of interposed sheets	lowest compatible
3.2.2.2.2	suggested standard laboratory temperature in which the specimen is left to reach equilibrium with room air	(296 ± 1) K

3.2.2.2.2	suggested standard laboratory relative humidity in which the specimen is left to reach equilibrium	(50 ± 10) % RH
3.3.8	maximum resistance change in four successive sets of observations to assess steady state attainment	1 %
3.3.8	minimum time elapsed since steady state beginning, for unknown testing conditions, to complete observations	24 h

Annex C
(normative)

Limits for equipment performance and test conditions — Heat flow meter

C.1 General

This annex defines mandatory limits for equipment performance check and test conditions. All references to clauses of ISO 8301:1991 are for information only; clause numbers followed by an asterisk (*) give amended values compared to ISO 8301:1991.

C.2 Accuracy and repeatability, stability, uniformity

Clause in ISO 8301:1991	Description	Value
1.5.3.3	expected heat flow meter method accuracy (when the mean temperature of the test is near the room temperature)	±3 %
1.5.3.1	expected repeatability with specimen maintained within the apparatus	better than ±1 %
1.5.3.1	expected repeatability with specimen removed and mounted again after long time intervals	better than ±1 %
1.5.3.2	expected accuracy of the calibration of heat flow meter method (when mean temperature of the test is near the room temperature)	±2 %
1.5.4.2	upper acceptable limit in calibration stability	±1 %
1.5.4.2	suggested calibration time intervals for the heat flow meter method	24 h before or after the test
1.5.4.2	calibration intervals if short and long-term stabilities of the heat flow meter have been proved to be better than ±1 %	15 d to 30 d
1.5.4.1	suggested time limit to check the stability of calibration standards	5 years
2.2.5.3	maximum value for the edge heat loss error	0,5 %
2.2.1.2	required temperature uniformity of the working surface of the heating and cooling units, related to the temperature difference across the specimen	1 %
2.2.1.2	required temperature stability of the working surface of the heating and cooling units during the test period, related to the temperature difference across the specimen	0,5 %
2.2.1.2	required temperature stability of the face of the heat flow meter in contact with the specimen, related to the temperature difference across the specimen	less than 0,5 %
2.2.3.1.1	required accuracy in the measurement of temperature difference between heating and cooling units in contact with specimen	1 %
2.2.3.1.3 *	error in the measurement of temperature difference due to distortion	deleted

Clause in ISO 8301:1991	Description	Value
2.2.1.2	maximum error in measured heat flow rate when the heat flow meter is placed in contact with the working surface of the heating or cooling unit, due to their temperature non-uniformity	0,5 %
2.2.1.2	maximum allowed fluctuations in the electrical output of the heat flow meter related to the temperature fluctuations at the surface of the heat flow meter	2 %
2.2.3.3	required accuracy in the measurement of specimen thickness	0,5 %
2.1.1.1 *	maximum uncertainty in measured specimen thickness for non-rigid specimens due to departures from a plane	0,5 %
2.2.1.1	maximum departure from a plane of working surfaces of heating and cooling units	0,025 %
2.2.3.2.2	required accuracy of electrical measurements of temperature differences across the specimen(s)	±0,5 %
2.2.3.2.2	required accuracy of electrical measurements of the output from the thermopile	±0,6 %
2.2.3.2.2	minimum requested sensitivity of electrical instruments at the minimum output of the temperature difference detector	0,15 %
2.2.3.2.2	maximum allowed error due to the instrument non-linearity at all expected outputs of the temperature-difference detector	0,1 %
2.2.3.2.2	maximum allowed error on electrical signals due to input impedance under any possible condition	0,1 %
2.2.3.2.2	maximum allowed error to any electrical reading during a normal period between calibrations, or 30 days, whichever is greater	0,2 %
2.2.3.2.2	maximum allowed root mean square noise that occurs in the values of temperature difference and thermopile output, resulting from noise immunity	0,1 %
3.3.1	required accuracy in the determination of specimen mass	0,5 %

C.3 Equipment design requirements

Clause in ISO 8301:1991	Description	Value
2.2; 2.3.5	minimum total hemispherical emissivity for any surface in contact with the specimen	0,8
3.2.2.3.2	minimum total hemispherical emissivity of the surfaces seen from the specimen at operating temperature	0,8
2.2.1.1	maximum departure from a plane of working surfaces of heating and cooling units	0,025 %
2.2.2.4	maximum departure from a plane of the metering area of the heat flow meter	0,025 %
3.2.2.2.1	maximum departure from a plane of an apparatus surface or of the surface of rigid specimens	0,025 %
2.2.2.3	required ratio between metering area and the total surface of the heat flow meter	10 % ≤ A ≤ 40 %

Clause in ISO 8301:1991	Description	Value
2.3.2	suggested ratio between the side of the heat flow meter metering area and the maximum specimen thickness	4
2.3.2	suggested ratio between the external side of the heat flow meter and the maximum specimen thickness	8
2.2.1.2	required temperature uniformity of the working surface of the heating and cooling units, related to the temperature difference across the specimen	1 %
2.2.1.2	required temperature stability of the working surface of the heating and cooling units during the test period, related to the temperature difference across the specimen	0,5 %
2.2.1.2	required temperature stability of the face of the heat flow meter in contact with the specimen, related to the temperature difference across the specimen	less than 0,5 %
2.2.1.2	maximum error in measured heat flow rate when heat flow meter is placed in contact with the working surface of the heating or cooling unit, due to their temperature non-uniformity	0,5 %
2.2.1.2	maximum allowed fluctuations in the electrical output of the heat flow meter related to the temperature fluctuations at the surface of the heat flow meter	2 %
3.3.5.3	upper acceptable variation as a function of time of the heat flow meter output in respect of its mean value	1,5 %
2.2.2.5	suggested diameter for thermocouples used as surface temperature sensors of the heat flow meter	0,2 mm
2.2.3.1.3	maximum thermocouple diameter when mounted in the surface of the heating and cooling units to measure the temperature differences between heating and cooling units	0,6 mm
2.2.3.1.3 *	suggested maximum thermocouple diameter when mounted as above in the surface of an apparatus smaller than 0,5 m in side or diameter	0,2 mm
2.2.3.1.1	minimum number of temperature sensors on each side of the working surfaces of heating and cooling units	$10\sqrt{A}$ or 2
2.2.3.1.1	maximum surface area in which one thermocouple only may be placed	0,04 m^2
2.2.2.3	percentage of the most central area of the heat flow meter in which the temperature difference detectors shall be concentrated	40 %
2.2.3.1.1	minimum electrical resistance of the insulation between thermocouples and apparatus metal plates	1 MΩ
2.2.2.3	suggested maximum diameter for the cross-sectional area of the conductors in the thermopile	0,2 mm
2.2.2.3	minimum heat flow meter output without use of special techniques to prevent extraneous thermal electromotive forces in the leads, the measuring circuits and the heat flow meter itself	0,000 2 V
2.2.2.5	suggested thickness of a metal or non-metal foil to be used to cover the metering area	80 µm

Clause in ISO 8301:1991	Description	Value
2.2.5.1	minimum required difference between air dew point and cooling unit temperature	5 K
2.2.4.2	maximum suggested apparatus pressure on the specimen for most insulating materials	2,5 kPa

C.4 Acceptable specimen characteristics

Clause in ISO 8301:1991	Description	Value
1.1.1	minimum measurable thermal resistance in a heat flow meter apparatus	0,1 $m^2 \cdot K/W$
1.7.2.2	maximum increment of specimen thickness in the single specimen configuration to that corresponding to the two specimen symmetrical configuration	50 %
1.7.3 *	maximum thermal resistance for rigid specimens requiring special techniques to measure surface temperatures	0,3 $m^2 \cdot K/W$
2.2.3.1.2.1	minimum thermal resistance for non-rigid specimens to use permanently mounted temperature sensors in the working surfaces of cooling and heating units	0,5 $m^2 \cdot K/W$
2.2.3.1.2.2 *	maximum resulting thermal resistance (on both sides of the specimen) due to imperfect contact of rigid specimens, expressed as percentage of the specimen thermal resistance	0,5 %
3.2.2.2.1 *	minimum thermal resistance of rigid specimens not requiring the use of thin sheets or temperature sensors mounted on the specimen to measure temperature difference across the specimen	0,3 $m^2 \cdot K/W$
2.2.3.1.2.2 *	additional uncertainty in the temperature difference across a rigid specimen when using contact sheets and/or temperature sensors mounted on the surface of the specimen	0,5 %
2.3.2	suggested ratio between the external side of the heat flow meter and the maximum specimen thickness	8
3.2.1	maximum thickness difference for two specimens to be mounted in a two-specimen apparatus	2 %
3.2.2.2.1	maximum departure from a plane of an apparatus surface or of the surface of rigid specimens	0,025 %
2.1.1.1 *	maximum uncertainty in measured specimen thickness for non-rigid specimens due to departures from a plane	0,5 %
3.2.2.2.1 *	maximum value of $(A_d/A_m)(R_a/R)$ to ignore the effect of defects on the surface of the specimen	0,000 5
3.2.2.2.1	maximum deviation from parallel planes for specimen surfaces, related to specimen thicknesses	2 %
1.8.2	upper acceptable dimension limit of any non-homogeneity of the specimen	1/10 d
3.2.2.3 *	minimum suggested ratio between specimen thickness and mean dimensions of beads, grains, flakes, etc.	10

Clause in ISO 8301:1991	Description	Value
3.4.1	change in thermal resistance, in specimens containing short circuits, requiring measurements with thicker sheets	1 %
3.4.1	minimum difference in measured properties to consider a specimen as non-homogeneous	2 %
1.8.3.1	upper acceptable limit for transfer factor changes with thickness to assign thermal conductivity or thermal transmissivity to the material	2 %
3.4.2	maximum difference for transfer factor at different thicknesses to be assumed as thermal transmissivity	2 %
3.4.2	maximum acceptable difference from a linear relationship versus thickness for thermal resistance to compute the interpolating line slope	1 %
3.2.2.3.2	maximum thickness for plastic sheets in method B for loose-fill materials	50 µm

C.5 Acceptable testing conditions

Clause in ISO 8301:1991	Description	Value
1.1.1	minimum measurable thermal resistance in a heat flow meter apparatus	0,1 $m^2 \cdot K/W$
1.7.3 *	maximum thermal resistance for rigid specimens requiring special techniques to measure surface temperatures	0,3 $m^2 \cdot K/W$
3.3.3	lower limit for temperature differences across the specimen when determining an unknown relationship between temperature and heat transfer properties	5 K
3.3.3	upper recommended limit for temperature difference across the specimen as above	10 K
2.4.1	maximum allowed temperature difference between cold and hot surfaces while testing calibration specimens	20 K to 40 K
2.2.3.1.3	suggested maximum thermocouple diameter when placed against or set into the surface of the specimens	0,2 mm
3.2.2.2.1	minimum number of thermocouples on each side of the specimen (whichever is greater of the two criteria)	$10\sqrt{A}$ or 2
2.2.5.1	minimum required difference between air dew point and cooling unit temperature	5 K
2.2.5.3	maximum value for the edge heat loss error	0,5 %
1.7.2.2	maximum increment of specimen thickness in the single specimen configuration to that corresponding to the two specimen symmetrical configuration	50 %
3.2.1	maximum thickness difference for two specimens to be mounted in a two-specimen apparatus	2 %
2.2.4.2	maximum suggested apparatus pressure on the specimen for most insulating materials	2,5 kPa
3.2.2.2.1 *	maximum resistance of interposed sheets	lowest compatible

Clause in ISO 8301:1991	Description	Value
3.2.2.2.2	suggested standard laboratory temperature in which the specimen is left to reach equilibrium with room air	(296 ± 1) K
3.2.2.2.2	suggested standard laboratory relative humidity in which the specimen is left to reach equilibrium	(50 ± 10) % RH
3.3.5.2	maximum thermal resistance change in five successive sets of observations to assess steady state attainment	1 %
3.3.5.3	upper acceptable variation as a function of time of the heat flow meter output in respect of its mean value	1,5 %
3.4.1	minimum thickness requested for the sheets made of finely ground cork to break thermal paths	0,002 m

Annex D
(normative)

Equipment design

D.1 General

Equipment shall conform with the requirements given in this standard and EN 1946-2:1999 or EN 1946-3:1999. One way of achieving that is to make use of equipment design in D.2 or D.3. In that case the error analysis need not be performed; only the performance checks described in EN 1946-2:1999 or EN 1946-3:1999 need be undertaken.

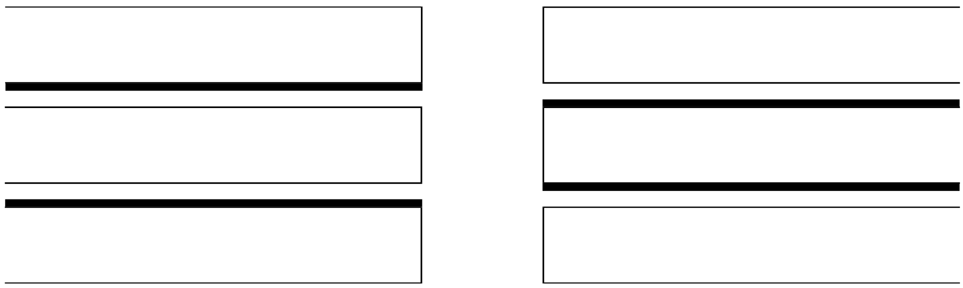
NOTE Annex C of EN 1946-2:1999 and annex C of EN 1946-3:1999 contain error analyses for the designs in this annex.

Only guarded hot plate apparatus C, see D.2, and heat flow meter apparatus B, see D.3, may be used in the full range of testing conditions expected in document EN 12939.

D.2 Guarded hot plate apparatus

Three pieces of equipment are described (named as equipment A, B and C). Main guarded hot plate apparatus characteristics and test conditions shall be as follows.

	EQUIPMENT		
	A	**B**	**C**
— overall apparatus size in millimetres	300	500	800
NOTE 1 Overall apparatus size may be increased to 600 mm for equipment B, all other dimensions being unchanged, with the only effect of increasing maximum specimen thickness to 100 mm. The widening of the overall apparatus size to 600 mm may also be obtained through a secondary guard, separated from the main guard by a gap 5 mm wide.			
— metering section width in millimetres (centre gap to centre gap)	150	250	500
— guard width in millimetres (centre gap to guard external edge)	75	125	150
— gap width in millimetres	2	3	4
NOTE 2 Minimum specimen thickness is ten times the gap width; if the designer tries to reduce gap width, imbalance errors are increased.			
— minimum specimen conductivity in W/(m·K)	0,015	0,015	0,015



NOTE The bold lines are the strips of the photoetched boards.

Figure D.1 — Heating unit heater

	EQUIPMENT A	EQUIPMENT B	EQUIPMENT C
— maximum specimen conductivity in W/(m·K)	0,5	0,5	0,5
— minimum specimen thermal resistance in m^2·K/W	0,3	0,3	0,3
NOTE 3 Minimum specimen thermal resistance according to this standard is 0,5 m^2·K/W; minimum specimen thermal resistance of 0,3 m^2·K/W makes equipment C suitable for tests according to EN 12939.			
— maximum specimen thermal resistance in m^2·K/W	3,0	5,0	6,7
— maximum specimen thickness in millimetres	45	75	100
— minimum specimen thickness in millimetres	20	30	40
— flatness tolerances in millimetres	0,08	0,13	0,20
NOTE 4 The above flatness tolerances ensure accurate measurements of the specimen thickness at the minimum allowed values listed above for non-rigid specimens ensuring perfect contact with the apparatus surfaces. For rigid specimens the above tolerances ensure the required limitation of contact thermal resistances for specimen thermal resistances greater than 0,6 m^2·K/W for equipment A, greater than 1,0 m^2·K/W for equipment B and greater than 1,6 m^2·K/W for equipment C.			
— thickness, in mm, of the heating unit metal plate (aluminium, 150 W/(m·K))	5	8	12
— total heater thickness in millimetres	3	3	3

The heater can be either two photoetched boards approximately 1 mm thick with the conducting layer, see bold lines of Figure D.1, of each board separated by an electrical insulating board approximately 1 mm thick, see Figure D.1a), or a two sided heating board approximately 1 mm thick, insulated from the heating unit metal plates by two electrical insulating boards approximately 1 mm thick, see Figure D.1b). Silicon grease or other heat conducting compounds shall be used between the heating unit metal plates and the photoetched boards to avoid any air pocket. The solution of Figure D.1a) is preferred because it allows an easier assembling and disassembling of the heating unit. Gluing of the heater boards and heating unit metal plates ensures maximum mechanical strength and an easier way to meet flatness tolerances (if the heating unit is compressed between two flat metal plates during gluing). Gluing does not allow heating unit servicing in case of faults. The heating unit may also be fastened with screws; their number shall be kept to an absolute minimum (e.g. along the axes and diagonals) and their surfaces shall be finished after fastening, to obtain a flat surface in contact with the specimens.

	EQUIPMENT		
	A	**B**	**C**
— maximum total section, in mm^2, of copper wires (400 W/(m·K)) crossing the gap	6	6	6

NOTE 5 The above section results e.g. from 32 pairs of junctions for a copper-constantane balancing thermopile of wire 0,25 mm in diameter (1,6 mm^2), no more than 6 copper-constantane thermocouples 0,55 mm in diameter on each surface in contact with the specimen (2,8 mm^2), 2 current wires (1,5 mm^2) for the central section heater and 2 potentiometric wires (0,1 mm^2) for the central section heater.

The junctions of the balancing thermopiles shall be located in the gap as in Figure D.2. Points A and C are at a distance $0,2\ l \pm 0,05\ l$ and $0,7\ l \pm 0,05\ l$ from the heating unit axis, where l is the half width of the metering section. The thermopile wires shall run parallel to the gap in an appropriate groove in the heater metal plates, see the gap design in Figure D.3, for at least 15 mm from the junction.

	EQUIPMENT		
	A	**B**	**C**
— maximum total section, in mm^2, of non copper wires (100 W/(m·K)) crossing the gap	6	6	6

If photoetched boards cross the gap, the figures for current and potentiometric copper wires shall not be included in the calculation (explained in note 3), but the cross-section on non-copper wires may exceed 6 mm^2. In this case the total thermal conductance of copper and non-copper wires shall be checked.

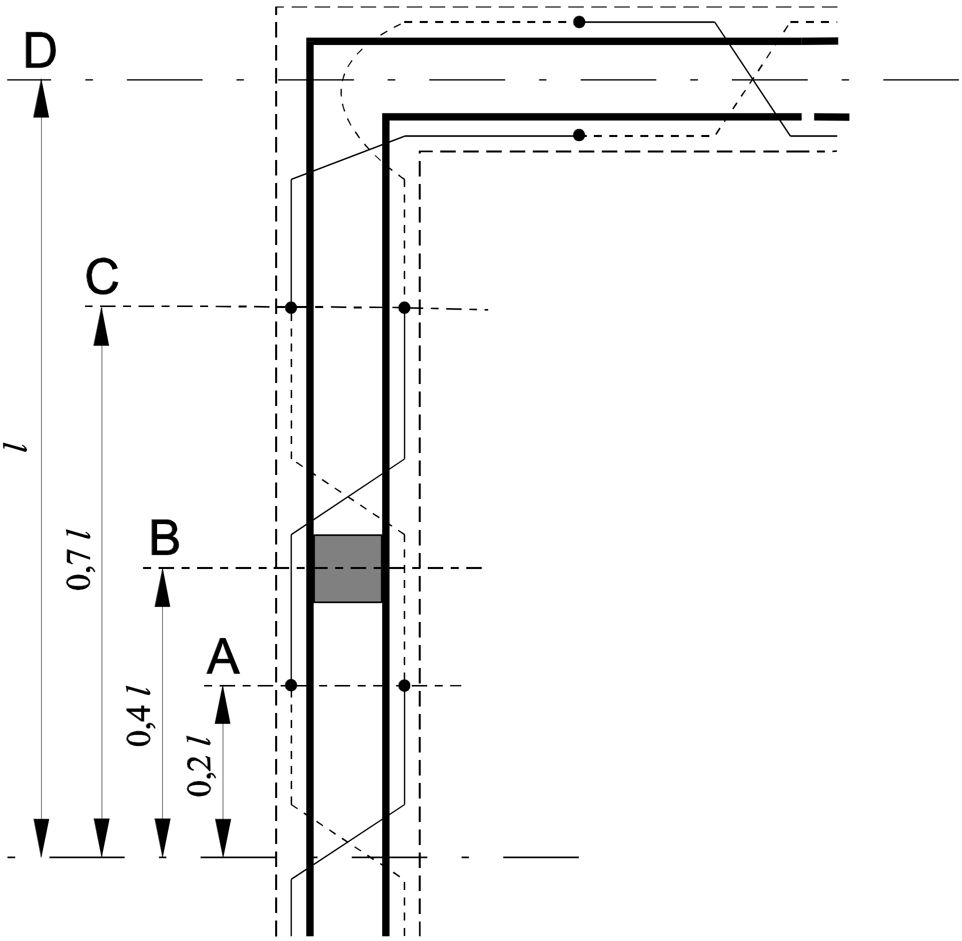
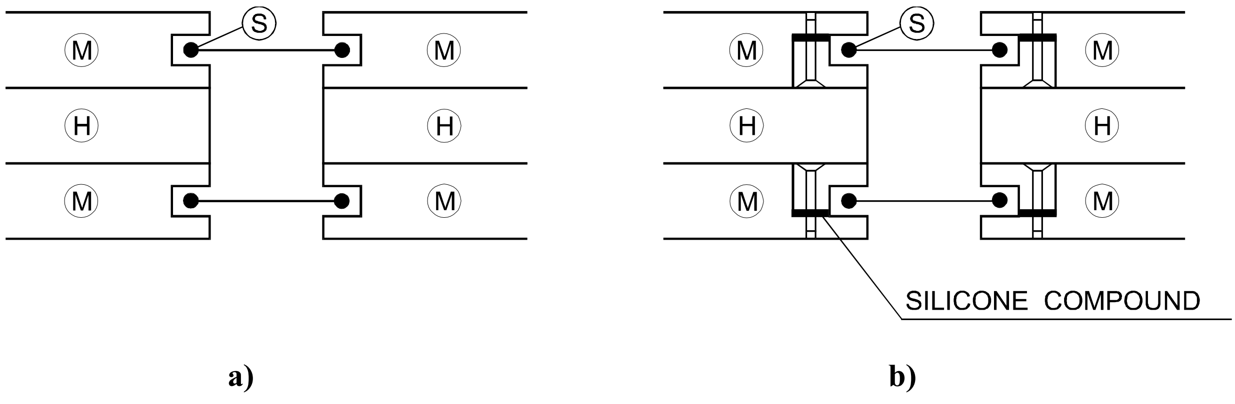


Figure D.2 — Position of the spacers and junctions of balancing thermopile



Key

H	Heater
M	Heating unit metal plate
S	Sensing element

Figure D.3 — Details of the gap design

	EQUIPMENT A	EQUIPMENT B	EQUIPMENT C
— maximum total section, in mm^2, of mechanical connections (0,3 W/(m·K)) in the gap (eight blocks of the dimensions indicated in brackets for each piece of equipment, in millimetres)	832 (8 × 13)	1520 (10 × 19)	3240 (15 × 27)

The approximate position of the mechanical connections is shown in Figure D.2 by point B. The distance of this point from the heating unit axis is 0,4 l ± 0,05 l, where l is the half width of the metering section.

	EQUIPMENT A	EQUIPMENT B	EQUIPMENT C
— minimum temperature difference through the specimen in K (for thermal resistances of less than 1 m^2·K/W)	10	10	10
— normal temperature difference through the specimen, in K	20	20	20
— maximum temperature difference through the specimen, in K	40	40	40
— maximum heat flow rates, in W. through the metering section of both specimens (at the maximum temperature difference and minimum thermal resistance of the specimen)	6	17	67
— minimum sensitivity of the null detector for the balancing thermopile of 32 elements with a thermo-electric power of 40 μV/K per element, in μV	0,5	1,1	3,1

The gap design of Figure D.3a) is acceptable for thermal conductivities of the specimen up to 1,5 W/(m·K), while the gap design of Figure D.3b) is acceptable for thermal conductivities of the specimen up to 0,5 W/(m·K) only if a contact compound with a thermal conductivity 0,4 W/(m·K) or higher and not thicker than 0,02 mm is interposed between the heating unit metal plate and the screwed aluminium strip.

	EQUIPMENT A	EQUIPMENT B	EQUIPMENT C
— maximum error in measured electrical power, in %	0,2	0,2	0,2
— mechanical tolerances on the metering area side, in %	0,1	0,1	0,1
— accuracy of thermocouple calibration in % of the temperature difference	0,4	0,4	0,4
— accuracy in thermocouple reading of the digital voltmeter, in %	0,2	0,2	0,2

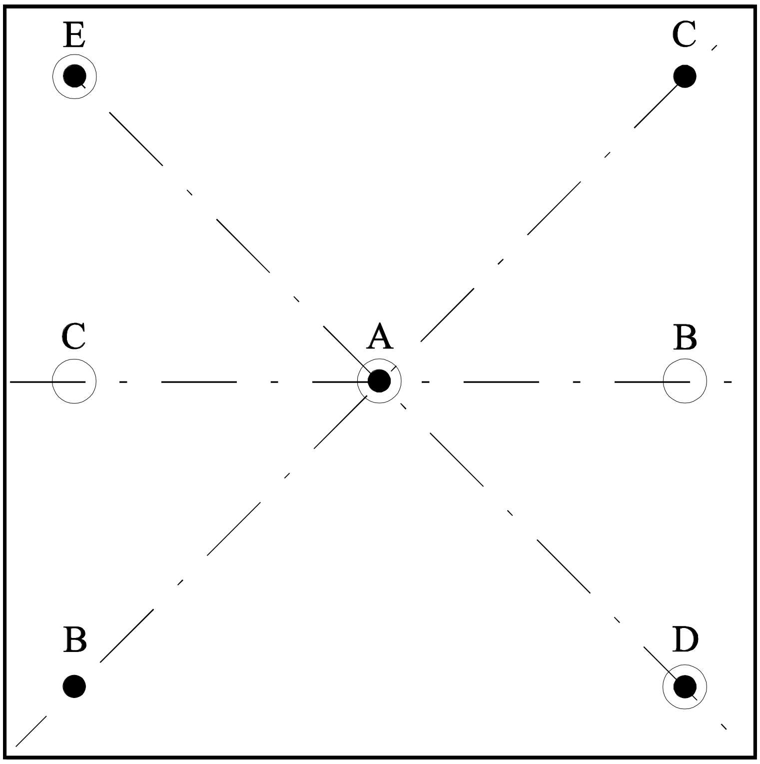
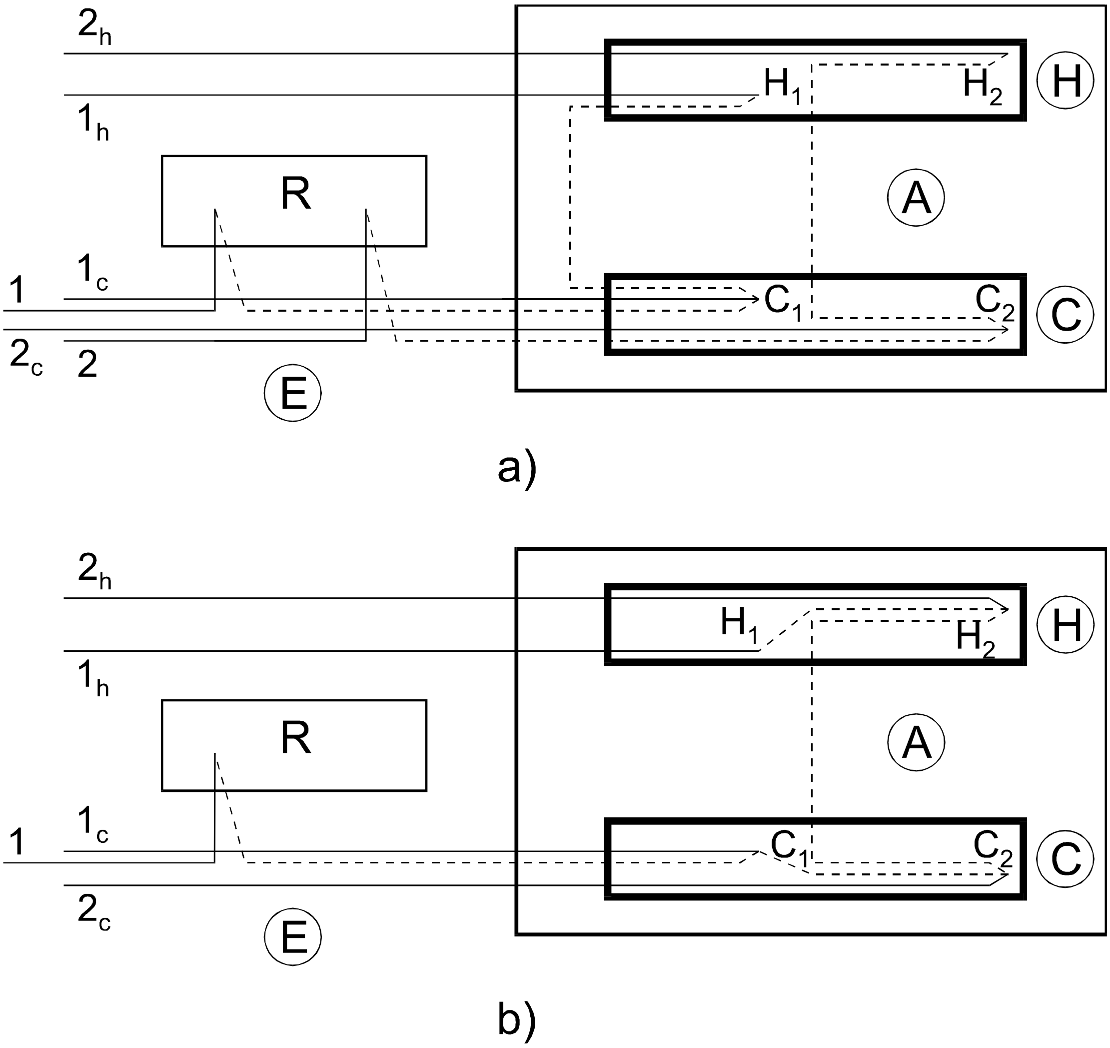


Figure D.4 — Position of the thermocouples on the heating and cooling unit

Thermocouples shall be special-grade type T thermocouples. They shall be mounted in grooves in the heating and cooling unit metal plates as indicated in Figure D.4, locations A and B for equipment A, locations A, B and C for equipment B and all indicated locations for equipment C. Dots in Figure D.4 indicate the approximate position on one surface of the heating unit and on the surface of the cooling unit facing it; circles indicate the approximate position on the opposite surfaces.

The border of the figure indicates the portion corresponding to the metering area section. Additional thermocouples installed in the portion corresponding to the guard section are optional. The electrical connection of the thermocouples of the heating and cooling units shall be as in Figure D.5a) or D.5b)

The cooling units shall be made of an aluminium metal plate chilled by liquid circulation in a pipe glued with metal-loaded epoxy resin on the surface not in contact with the specimen.



Key

H	Heating unit
H_1, H_2	Thermocouple junctions on the heating unit
C	Cooling unit
C_1, C_2	Thermocouple junctions on the cooling unit
R	Reference bath (ice point)
A	Apparatus cabinet
E	Environment (laboratory)

Figure D.5 — Thermocouple connections

The preferred layout of the cooling pipe is that of Figure D.6c), which, by appropriate dimensioning, allows reduced mass flow rates if compared with those indicated below.

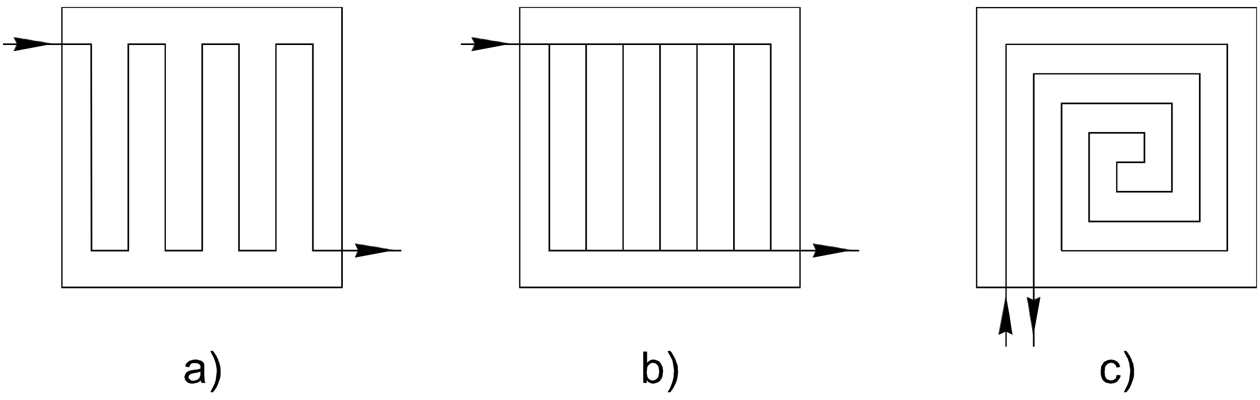


Figure D.6 — Layout of the cooling pipes of the cooling units

The characteristics of the cooling units shall be as follows.

	EQUIPMENT		
	A	**B**	**C**
— thickness of the aluminium cooling plate in mm	15	25	40
— thickness of the insulating layer on the surface of the cooling unit not in contact with the specimen (thermal conductivity of 0,04 W/(m·K) or less), in mm	30	50	80
— required mass flow rate for a fluid with a specific heat of 3 300 J/(kg·K) or greater, in kg/s	0,023	0,059	0,14

The cabinet enclosing the apparatus shall be water vapour tight; the internal air temperature shall be kept at the mean test temperature within 2,5 K. This is only possible through appropriate air conditioning of the inside of the cabinet. The dew point of the air shall be at least 5 K lower than the cold plate temperature.

All the wires (power supply, thermocouples, thermopile output, etc.) coming from the heating unit shall by clamped, at a distance of nearly 100 mm from the edge of the heating unit, with a metal block at least 100 mm long and with a diameter of at least 30 mm and kept at the same temperature of the heating unit within 0,5 K through electric heating. This is not required for equipment B if its overall apparatus size is increased to 600 mm through a secondary guard, see note 1 at the beginning of this clause D.2.

D.3 Heat flow meter apparatus

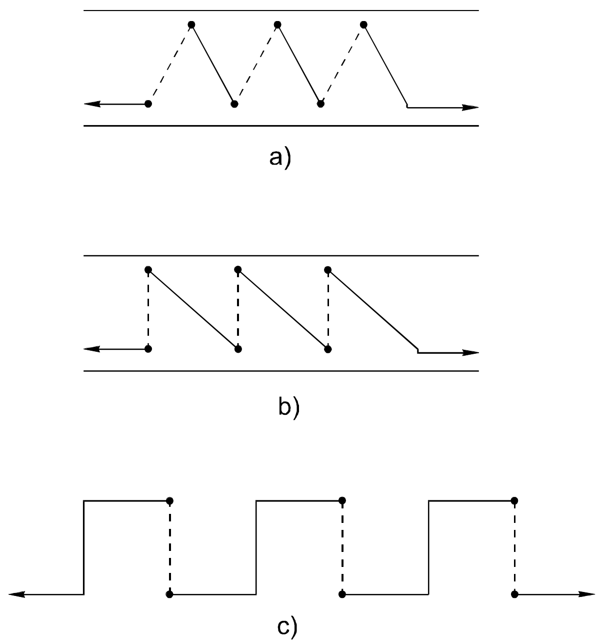
Three pieces of equipment are described, (named as equipment A, B and C). Main heat flow meter apparatus characteristics and test conditions shall be as follows.

— apparatus configuration:

equipment A	single-specimen asymmetrical
equipment B	single-specimen symmetrical
equipment C	single-specimen asymmetrical

	EQUIPMENT A	EQUIPMENT B	EQUIPMENT C
— overall apparatus size in mm	300	500	600
— metering section width in mm	150	200	300

The heat flow meter shall be made of a vulcanized rubber sheet 5 mm to 8 mm thick. In the portion of the sheet corresponding to the metering area the thermopile shall be mounted with the junctions lying on the opposite surfaces of the sheet. The minimum number of couples of junctions for the thermopile shall be 64 for equipment A, 100 for equipment B and 144 for equipment C. Junction layout shall be as in Figure D.7c) or D.7b), but never as in Figure D.7a). The external surfaces of the sheet shall be protected with thin rubber layers not thicker than 1 mm.



Key

----- Metal A
—— Metal B
• Junctions

Figure D.7 — Examples of schematic design of thermopile junction layouts

	EQUIPMENT A	B	C
— minimum specimen conductivity, in W/(m·K)	0,015	0,015	0,015
— maximum specimen conductivity, in W/(m·K)	0,4	0,4	0,4
— minimum specimen thermal resistance, in m^2·K/W	0,1	0,1	0,1

NOTE 1 Minimum specimen thermal resistance according to this standard is 0,5 m^2·K/W; minimum specimen thermal resistance according to EN 12939 is 0,3 m^2·K/W; the limit here indicated, and proposed in EN 1946-3:1999, makes these pieces of equipment suitable for some tests according to EN 12664.

	A	B	C
— maximum specimen thermal resistance in m^2·K/W	3,0	5,0	6,7
— maximum specimen thickness in mm	50	140	100

NOTE 2 Equipment B only is suitable to be used in the full range of testing conditions expected in document EN 12939; for this application its maximum specimen thickness shall be reduced from 140 mm to 125 mm.

NOTE 3 The metering section width of equipment B may be alternatively of 250 mm; the only effect is that maximum specimen thicknesses shall be changed from 140 mm to 130 mm and from 125 mm to 115 mm.

	A	B	C
— minimum specimen thickness in mm	15	25	30
— flatness tolerances in mm	0,08	0,13	0,15

NOTE 4 The above flatness tolerances ensure accurate measurements of the specimen thickness at the minimum allowed values listed above for non-rigid specimens ensuring perfect contact with the apparatus surfaces. For rigid specimens the above tolerances ensure the required limitation of contact thermal resistances for specimen thermal resistances greater than 0,6 m^2·K/W for equipment A, greater than 1,0 m^2·K/W for equipment B and greater than 1,2 m^2·K/W for equipment C.

	A	B	C
— minimum temperature difference through the specimen in K (for thermal resistances of less than 1 m^2·K/W)	10	10	10
— normal temperature difference through the specimen in K	20	20	20
— minimum density of heat flow rate (at the normal temperature difference and maximum specimen thermal resistance), in W/m^2	6,67	4,0	3,0

	EQUIPMENT A	B	C
— minimum thermopile output at the minimum density of heat flow rate (for a thermo-electric power 40 µV/K per element), in µV	430	400	430
— accuracy of thermocouple calibration in % of the temperature difference	0,4	0,4	0,4
— accuracy in thermocouple reading of the digital voltmeter, in %	0,2	0,2	0,2

Thermocouples shall be special-grade type T thermocouples of diameter not exceeding 0,55 mm. They shall be mounted in grooves in the heating or cooling unit metal plates in contact with the specimen or in grooves in an additional rubber sheet no more than 2 mm thick on the surface of the heat flow meter in contact with the specimen. For thermocouples mounted in rubber sheets, the junctions shall be welded on the surface not in contact with the specimen of a thin copper plate mounted flush with the surface of the rubber sheet in contact with the specimen. The copper plates shall have a surface of 250 mm^2 to 400 mm^2. The location of the thermocouple junctions in contact with the specimen shall be as indicated by the dots only in Figure D.4, locations A and B for equipment A, locations A, B and C for equipment B and equipment C. The border of the figure indicates the portion corresponding to the metering area section; additional thermocouples installed in the portion corresponding to the guard section are optional. At least two additional thermocouples shall be mounted, in the same way as above, on the surface of the heat flow meter not in contact with the specimen, to measure the mean heat flow meter temperature.

The electrical connection of all thermocouples of the heating and cooling units (in contact or not in contact with the specimen) shall be as in Figure D.5a) or D.5b).

The cooling units shall be made of an aluminium metal plate chilled by liquid circulation in a pipe glued with metal-loaded epoxy resin on the surface not in contact with the specimen. The preferred layout of the cooling pipe is that of Figure D.6c), which, by appropriate dimensioning, allows reduced mass flow rates if compared with those indicated below.

	EQUIPMENT A	B	C
— thickness of the insulating layer on the surface of the heating or cooling unit not in contact with the specimen (thermal conductivity of 0,04 W/(m·K) or less), in mm	30	50	60

The cooling and heating units shall be able to provide the following heat flow rates:

	EQUIPMENT A	B	C
— maximum heat flow rate in W through the specimen (at the normal temperature difference of 20 K andminimum thermal resistance of the specimen)	18	50	72
— heat flow rate through the insulating layer of the heating or cooling unit, in W	1,8	3,0	3,6

The characteristics of the cooling units shall be as follows:

	EQUIPMENT		
	A	**B**	**C**
— thickness of the aluminium cooling plate, in mm	15	25	40
— required mass flow rate for a fluid with a specific heat of 3300 J/(kg·K) or greater, in kg/s	0,030	0,080	0,12

The cabinet enclosing the apparatus shall be water vapour tight; the internal air temperature shall be kept at the mean test temperature within 2,5 K. This is only possible through appropriate air conditioning of the inside of the cabinet. The dew point of the air shall be at least 5 K lower than the cold plate temperature.

All the wires (thermocouples, thermopile output, etc.) coming from the heating and heating unit heat flow meter (if applicable) shall by clamped at the heating unit along its edge for at least 20 cm, before leaving the apparatus. The same applies for the cooling unit and cooling unit heat flow meter (if applicable).

NOTE 5 Single-specimen asymmetrical equipment, having the overall apparatus size between the 300 mm of equipment A and 600 mm of equipment C, is still conforming with the requirements of this standard and EN 1946-3:1999 provided that the overall apparatus size, metering section width, maximum specimen thickness, flatness tolerances, thickness of insulating layer on the surface of the heating or cooling unit, all interpolate the data related to equipment A and equipment C with the same ratio; provided that the minimum number of couples of junctions for the thermopile is 100, provided that the maximum specimen thermal resistance does not exceed the ratio of the maximum specimen thickness and the minimum specimen conductivity, and provided that the mass flow rate of the cooling or heating fluid is scaled according to the overall apparatus surface.

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