BRITISH STANDARD

BS 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

The European Standard EN 1946-2:1999 has the status of a British Standard

ICS 91.100.01; 91.120.10

National foreword

This British Standard is the English language version of EN 1946-2:1999.

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 international/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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Summary of pages

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English version

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

Performance thermique des produits et composants pour le bâtiment — Critères particuliers pour l'évaluation des laboratoires measurant les propriétés de transmission thermique — Partie 2: Mesurages selon la méthode de la plaque chaude gardée

Wärmetechnisches Verhalten von Bauprodukten und Bauteilen Technische Kriterien zur Begutachtung von Laboratorien bei der Durchführung der Messungen von Wärmeübertragungseigenschaften — Teil 2: Messung nach Verfahren mit dem Plattengerät

This European Standard was approved by CEN on 13 December 1998.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CEN

European Committee for Standardization

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Foreword

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

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 1999, and conflicting national standards shall be withdrawn at the latest by July 1999

This European Standard is divided into parts. The first part covers common criteria applicable to all heat transfer property measurements; each subsequent part covers the specific technical criteria applicable to each heat transfer property measurement method described in appropriate standards.

The following parts have been developed:

Part 1: *Common criteria*

Part 2: *Measurements by guarded hot plate method*

Part 3: *Measurements by heat flow meter method*

Part 4: *Measurements by hot box methods*

Part 5: *Measurements by pipe test methods*

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.

Contents

1 Scope

This part 2 of this standard provides specific technical criteria for the assessment of laboratories to undertake steady-state heat transfer property measurements by the guarded hot plate method according to prEN 12667 and prEN 12664.

It complements the common criteria in part 1. Guidance is given on the organization and contents of the equipment manual, the calibration and maintenance files and the measurement procedure document.

It provides information on mandatory equipment performance specifications, equipment description and on calculations for the equipment design and error analysis.

It provides information on experimental procedures suitable for the assessment of equipment accuracy.

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 to applies.

EN 1946-1:1999, *Thermal performance of building products and components — Specific criteria for the assessment of laboratories measuring heat transfer properties — Part 1: Common criteria.*

prEN 12664:1996, *Building materials — 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.*

prEN 12667:1996, *Building materials — Determination of thermal resistance by means of guarded hot plate and heat flow meter methods — Products of high and medium thermal resistance.*

prEN 12939, *Building materials — Determination of thermal resistance by means of guarded hot plate and heat flow meter methods — Thick products of high and medium thermal resistance.*

ISO 8302:1991, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Guarded hot plate apparatus.*

3 Definitions

The definitions in EN 1946-1 and in ISO 8302:1991 also apply to this part of the standard.

4 Equipment manual

4.1 General

The equipment manual shall provide the information specified in **5.2.2** to **5.2.5** of EN 1946-1:1999 and the information specified in this clause.

NOTE Information common to more than one piece of equipment need not be duplicated, e.g. the principle, details of the design and operation of two pieces of equipment built to a common design.

Annex B of prEN 12664:1996 or prEN 12667:1996, which indicates all limiting values for apparatus performance and testing conditions, shall be used as a check-list during the assessment process by the parties concerned to ensure compliance with all the requirements of those standards.

4.2 Equipment performance specifications

According to **2.3.1** of ISO 8302:1991, the upper and lower limits for the following relevant tested properties and testing conditions, including possible interactions among them, shall be specified:

- — specimen thickness;
- — thermal resistance;
- — temperature difference across the specimen;
- — heating and cooling unit temperature;
- — surrounding environment (temperature, relative humidity) at the edge of the specimen during the test.

4.3 Equipment description

The following information shall be documented and shall be available for examination during the assessment:

- — principle of operation (see **1.6.1** of ISO 8302:1991);
- — type of apparatus (see **1.6.2.1**, **1.6.2.2** and **1.6.4** of ISO 8302:1991);
- — principal dimensions of apparatus, in particular heating unit width, guard width and gap width;
- — simple diagrams illustrating the design of the equipment with special attention to the gap design (see **2.1.1.5** of ISO 8302:1991), the cooling unit piping (see **2.1.2** of ISO 8302:1991) and edge insulation (see **2.1.3** of ISO 8302:1991);
- — position, connections and numbering of temperature sensors (see **2.1.4.1** of ISO 8302:1991);
- — electrical components/instruments, apparatus enclosure and main ancillary equipment;
- — details of data acquisition system and related computer programs for data analysis.

To avoid duplication, reference can be made to manuals supplied by the instrument manufacturers or to relevant clauses of ISO 8302:1991.

4.4 Equipment design and error analysis

4.4.1 *General*

With reference to the performance specification given in **4.2**, details shall be given of the design guidelines followed, and the error analysis based on **2.2** of ISO 8302:1991, as summarized in **4.4.2** to **4.4.11**.

Some guidelines on error analysis are given in this subclause; more specific information on some errors is supplied in annex B, while error calculations are supplied in annex C for some typical cases. Examples of equipment conforming to annex C are supplied in **D.2** of prEN 12664:1996 and in **D.2** of prEN 12667:1996. For equipment having characteristics exactly as indicated in this subclause or design details as indicated in annex C of this part and in **D.2** of prEN 12664:1996 or in **D.2** of prEN 12667:1996, no further calculations are needed. In other circumstances similar calculations can be performed by analogy.

4.4.2 ***Edge heat losses and maximum specimen thickness***

According to **3.2.1** of ISO 8302:1991, the sum of the imbalance error and edge heat loss error shall be kept within 0,5 %. In a good equipment design, the two errors will be of the same order of magnitude, hence a 0,25 % limit can be suggested for both. Table 1 shows for some apparatus dimensions the maximum allowed specimen thickness according to **2.2.1** of ISO 8302:1991, when there is no edge insulation and when the edge temperature ratio, e, is 0,25; e is defined as $(T_e - T_2)/(T_1 - T_2)$, where T_1 and T_2 are respectively the temperatures of the hot and cold surfaces of the specimen, and T_e is the temperature at the edge of the specimen, assumed to be uniform.

EXAMPLE: e = 0,25 corresponds to a temperature of the edge of the specimen 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 absolute value of the edge heat loss error increases almost symmetrically when e deviates on either side from 0,5. In the range $0{,}25 \leq e \leq 0{,}75$, this error is maximum for e = 0,25.

Larger specimen thicknesses can be used for some specimens if edge insulation or edge temperature control is used, if auxiliary or gradient guards are installed, or medium and high conductivity specimens are tested. See annex B for additional information.

When the maximum specimen thickness to be specified according to **4.2** exceeds the appropriate value given in Table 1, lateral losses shall be calculated. If, according to these calculations, they exceed those permitted by ISO 8302:1991, the performance check data shall be examined and, if no experimental evidence exists to justify the claimed maximum specimen thickness, the maximum specimen thickness to be specified according to **4.2** shall be reduced.

4.4.3 ***Maximum gap width and minimum specimen thickness***

According to **2.1.1.3** of ISO 8302:1991 the gap width, g, shall be such that the gap area is less than 5 % of the metering area, i.e. the gap width, g, shall not be greater than 1,25 % of the metering area side, L. The maximum gap width resulting from this requirement is given in the seventh column of Table 1. The minimum specimen thickness, d_m, is related to the gap width. d_m shall be at least ten times the gap width, see **1.7.6** of ISO 8302:1991. Thus, when the gap width reaches its maximum allowed value according to the above criteria, the minimum specimen thickness shall not be less than 12,5 % of the side L of the metering section. The minimum specimen thickness resulting from these requirements is given in the eighth column of Table 1. When the minimum specimen thickness to be specified according to **4.2** is less than those of the eighth column of Table 1, the actual gap width, g, shall be used to compute $d_m = 10\,g$, see also **4.4.6**. If this requirement is not met, then the minimum specified specimen thickness shall be increased to meet this requirement.

Minimum specimen thickness shall also be checked against maximum allowed flatness tolerances, see **4.4.9**, **4.4.10** and **4.4.11**.

4.4.4 ***Imbalance error***

According to **2.2.1** of ISO 8302:1991, an error heat flow rate Φ_g can be expressed as follows:

$$\Phi_g = (\Phi_o + \lambda c)\Delta T_g \qquad (1)$$

Table 1 — Minimum and maximum allowed specimen thickness

Dimensions in millimetres

Overall size	Metering section	Guard width	Maximum thickness (edge limit for e = 0,25)	Flatness tolerance (0,025%)	Minimum thickness (flat. tol.)	Max. gap	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
1000	500	250	150	0,25	50,0	6,25	62,5

1) Thicknesses applicable for gap widths according to the seventh column of Table 1; for thinner gaps see **4.4.3**.

where ΔT_g is the actual gap temperature imbalance through the apparatus and Φ_o, representing the heat flow rate for a 1 K gap imbalance through the apparatus itself, is the sum of:

- Φ_a through the air in the gap;
- Φ_r by radiation through the gap;
- Φ_m through the mechanical connections through the gap;
- Φ_c through copper wires;
- Φ_w through metal wires (excluding copper).

To calculate these terms, the elementary equations of heat transfer through a plane layer can be used.

λc is the heat flow rate through both specimens due to a 1 K gap imbalance with c expressed by the following equation:

$$c = (16\, l/\pi)\ \ln[4/(1 - \exp(-\pi g/d)] \qquad (2)$$

In this equation $2l = L$ is the side of the metering area (centre gap to centre gap), g is the gap width and d is the maximum expected specimen thickness.

If the edge heat loss error is 0,25 %, (see **4.4.2** of this standard and **3.2.1** of ISO 8302:1991), ΔT_g shall be such that Φ_g is smaller than 0,25 % of the heat flow rate through the metering section of both specimens.

This calculation changes according to the gap design and is the most critical part of the evaluation of guarded hot plate accuracy. Some calculations are offered as an example in annex C of this standard.

Because the balancing thermopile detects a temperature difference that does not correspond exactly with the actual temperature imbalance through the surfaces of the metering section and guard ring metal plates facing the gap, the maximum acceptable value for ΔT_g shall be larger than the uncertainty in the imbalance detection. A discussion on the imbalance detection through the gap is given in **2.1.1.5** of ISO 8302:1991.

When the balancing thermopile is placed directly within the central section and guard ring metal plates, see Figure 4b) of ISO 8302:1991, the density of heat flow rate crossing them during the tests shall be evaluated and the corresponding temperature drop through the metal plates computed. If this temperature difference is smaller than ΔT_g, the gap design is acceptable without further checks, otherwise the tolerances for the positions of thermopile junctions within the metal plates shall be checked.

When the balancing thermopile is embedded in plastic sheets either placed between the metal plates and the heaters or between the metal plates and the specimen, the effect of the resistances between the metal plates and the thermopile junctions due to the plastic sheets and possible air pockets shall be evaluated as a temperature difference equal to the product of the relevant thermal resistance and the density of heat flow rate crossing it.

The sum of imbalance and edge heat losses shall not be larger than 0,5 %.

The electrical instrumentation used for the imbalance detection shall be capable of detecting voltages less than ΔT_g multiplied by the number of elements of the balancing thermopile and by the thermoelectric power of each element.

The electrical balance maintained during the tests shall therefore be better than the voltage computed in this way. If this requirement is not met, the measured data of the performance check shall be verified and if the sensitivity of the instrumentation for the imbalance detection is still not satisfactory, this shall be rectified. Particular care shall also be taken to ascertain that the quality of the electrical connections and the switches (with reference, in particular, to thermal electromotive forces) is compatible with the level of imbalance to be detected.

4.4.5 *Error in measured electrical power*

The uncertainty in the measurement of electrical power shall be within 0,1 % to comply with **B.1** of prEN 12667:1996 and **B.1** of prEN 12664:1996.

4.4.6 *Error in the definition of the metering area*

The metering area is defined as the area enclosed by the line defining the centre of the gap (see **1.7.6** of ISO 8302:1991; see also **3.1** of ISO 8302:1991 for some special applications). This area is not equal in all testing conditions to the actual metering area of the specimen crossed by the heat flow rate supplied by the metering section of the heating unit; to this uncertainty shall be added the uncertainty in the measurement of the dimensions of the apparatus. An uncertainty due to mechanical tolerances in the measurement of the centre-gap to centre-gap distance up to 0,1 % can be accepted.

NOTE The distance between the line defining the actual metering area of the specimen and the line defining the centre of the gap can be estimated to be within 5 % of the gap width.

4.4.7 *Error in the temperature difference between the heating and cooling units of the apparatus*

According to **2.1.4.1.2** of ISO 8302:1991, the total error in the temperature difference measured by the temperature sensors permanently mounted in the apparatus shall not exceed 1 %, made up as follows:

— calibration of thermocouples (or other temperature sensors): less than 0,4 %;

— accuracy of measuring instruments: less than 0,2 %;

— uncertainty in the definition of the point where the temperature is measured by the sensor: less than 0,4 %.

NOTE 1 When special grade thermocouples (see annex B of ISO 8302:1991) mounted differentially are used, as in Figure 6 b) or 6 c) of ISO 8302:1991, and no additional wire connections between the junctions are made, no calibration is required, and the uncertainty of 0,4 % at room temperature can be achieved for type T thermocouples.

NOTE 2 The absence of additional wire connections between two thermocouple junctions and the care taken to correctly fabricate these junctions and to keep them as isothermal as possible during the tests, are more important than the thermocouple calibration itself. Bad thermocouple connections can induce errors which change with changing test conditions, so derating the accuracy of the calibrations.

NOTE 3 The uncertainty in the definition of the point where the temperature is measured can be assumed to cause an error in the temperature reading not greater than the temperature drop through the metal plates when thermocouples are mounted in grooves in the apparatus metal plates. When thermocouples are mounted in thin sheets, the uncertainty becomes critical and can be assumed to be equal to the temperature drop through a layer of sheet of thickness equal to the diameter of the thermocouple junction.

NOTE 4 Additional errors occur due to contact thermal resistances or due to mounting techniques of the thermocouples on specimen surfaces, see **4.4.10** and **4.4.11**.

4.4.8 *Error in the measurement of the specimen thickness*

The error of the measuring devices shall not exceed 0,5 %, see **2.1.4.2** of ISO 8302:1991, and the additional error resulting from the departures from a true plane of the apparatus and specimen surfaces shall not exceed 0,5 %, see **A.3.3** of prEN 12667:1996 or prEN 12664:1996.

4.4.9 *Non-rigid specimens: error in specimen thickness and minimum specimen thickness*

This error in specimen thickness applies only when testing non-rigid specimens in good contact with the guarded hot plate apparatus and whose thermal resistance is 0,3 $m^2 \cdot IK/W$ or more, e.g. mineral wool boards or elastomeric cellular boards. This error is the consequence of departures from a true plane of the specimen surfaces resulting from departures from a true plane of the apparatus surfaces. According to **A.3.3** of prEN 12667:1996 or prEN 12664:1996, this error shall not exceed 0,5 %.

The worst case condition resulting from flatness tolerances is at the minimum measurable thickness, d_m, when both hot and cold surfaces are either dished or bowing, see Figure 1. If p is the flatness tolerance expressed as the maximum distance of one apparatus surface from a true plane, the average thickness error for each apparatus surface is $p/2$. Considering then both apparatus surfaces in contact with the specimen, the thickness error is p.

According to ISO 8302:1991, if G is the overall size of the apparatus, i.e. the external side of the guard, the maximum allowed flatness tolerance, p, should not exceed 0,025 % of G , i.e. $100\ p/G = 0{,}025$, see the fifth column of Table 1. The limit on thickness error also requires that $100\ p/d_m < 0{,}5$. Thus the minimum specimen thickness, d_m, is limited by flatness tolerances and shall be not less than 5 % of G, see the sixth column of Table 1.

When the equipment to be assessed is intended for measurements on non-rigid specimens, other combinations of minimum specimen thickness and flatness tolerances are permitted, provided the flatness tolerances do not exceed 0,5 % of the minimum thickness. In the case of non-compliance the minimum specimen thickness to be indicated according to **4.2** shall be amended accordingly or the non-compliance shall be rectified.

NOTE The minimum specimen thickness is also affected by the gap width, see **4.4.3**.

4.4.10 *Rigid specimens tested without contact sheets: error due to contact resistances and flatness tolerances*

When testing rigid specimens without contact sheets, specimen thermal resistance being larger than 0,3 $m^2 \cdot K/W$ according to **B.4** of prEN 12667:1996 or prEN 12664:1996 (e.g. polystyrene, rigid polyurethane or aerated concrete boards), the maximum allowed thermal resistance due to the air pockets (on both sides of the specimen as in Figure 2 in worst case conditions) created by departures from a plane (contact resistance), shall, according to **A.3.5.2** of prEN 12664:1996, not exceed 0,5 % of the specimen thermal resistance. Around room temperature (the thermal conductivity of air is close to 0,025 W/(m·K)) the maximum allowed 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 is given in Table 2.

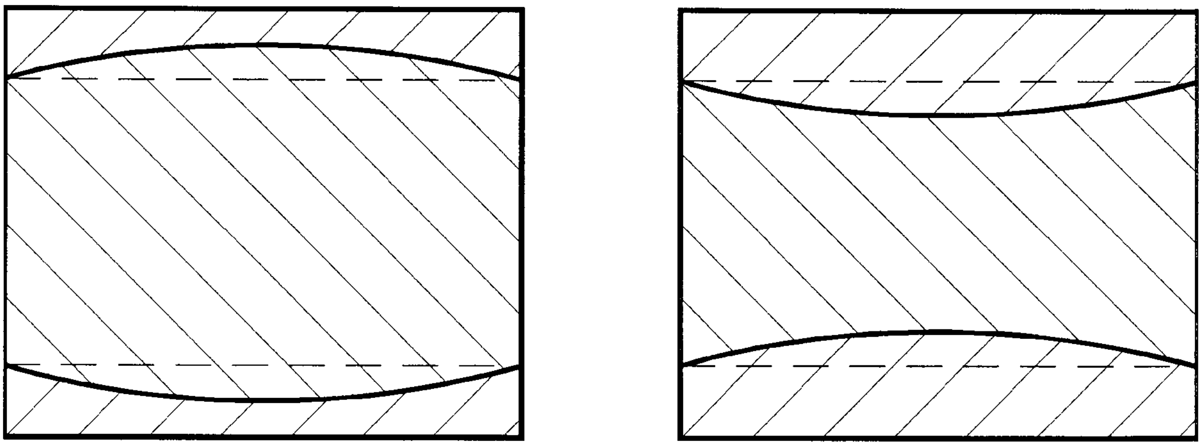

Figure 1 — Non-rigid specimens

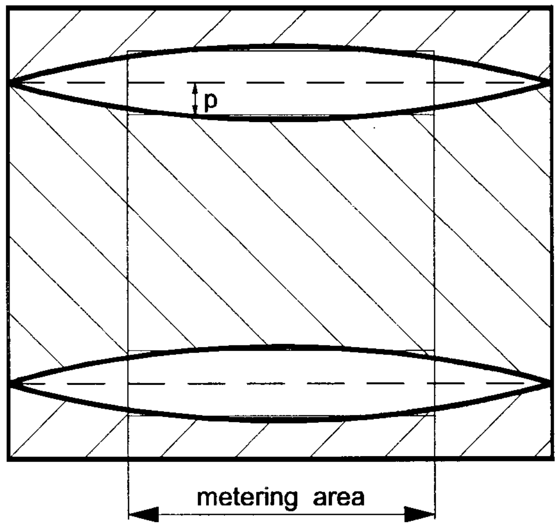

Figure 2 — Rigid specimens

NOTE 1 Table 2 shows that the required levels of flatness for both the specimen and apparatus surfaces are stringent, so that the use of contact sheets can be suggested even for specimens having a thermal resistance greater than 0,3 m²·K/W.

If the equipment to be assessed is intended for measurements on rigid specimens and the flatness tolerances indicated in Table 2 are not met, either amend the testing procedures to require the use of contact sheets (see **4.4.11**) or increase the minimum measurable thermal resistance.

NOTE 2 The minimum specimen thickness is also affected by the gap width, see **4.4.3**.

4.4.11 ***Rigid specimens tested with contact sheets***

Contact sheets are made of an adequately compressible material to eliminate air pockets between specimen and apparatus surfaces. The errors resulting from the use of contact sheets are dependent on the characteristics of the specimen and contact sheets and on the characteristics of the thermocouples mounted on the surfaces of the specimens. Consequently, when the equipment to be assessed is intended for measurements on rigid specimens with contact sheets, directions for their use shall be found in the measurement procedure document, see clause **6**.

4.5 Equipment performance check

4.5.1 ***Requirements applicable to each piece of equipment***

The equipment performance check shall include the following:

— planeness (see **2.4.1** of ISO 8302:1991);

— electrical connections and automatic controllers (see **2.4.2** of ISO 8302:1991);

— temperature measurements (see **2.4.3** of ISO 8302:1991);

— imbalance errors (see **2.4.4** of ISO 8302:1991);

— edge heat losses (see **2.4.5** of ISO 8302:1991);

— emissivity of apparatus surfaces (see below and annex A, which is an expansion of **2.4.6** of ISO 8302:1991);

— linearity test (see **2.4.7** of ISO 8302:1991);

— proven performance check (see **2.4.8** of ISO 8302:1991).

For measurements on low density materials according to prEN 12939, where the thickness effect can be relevant, the emissivity of apparatus surfaces in contact with the specimen shall be determined according to annex A. For other materials, the apparatus emissivity need not be measured if the apparatus surfaces are painted with non-metallic paint, because the limit of 0,8 stated in **2.1.1.2** of ISO 8302:1991 is thus met.

The results of the performance checks shall be incorporated in the equipment manual. They shall comply with the requirements stated in ISO 8302:1991 and should confirm the calculations described in **4.4** of this standard within the accuracy of the assumptions for such calculations.

4.5.2 ***Additional requirements applicable to equipment intended to test thick high thermal resistance specimens***

When the equipment is particularly intended to test thick high thermal resistance specimens according to prEN 12939, beside tests on edge heat losses, described in **2.4.5** of ISO 8302:1991, particular care shall be devoted to the evaluation of the linearity test described in **2.4.7** of ISO 8302:1991.

Table 2 — Flatness tolerances related to the specimen thermal resistance

Specimen thermal resistance m²·K/W	Maximum allowed contact thermal resistance m²·K/W	Maximum equivalent air layer thickness mm
0,3	0,0015	0,037
0,4	0,0020	0,050
0,5	0,0025	0,063
0,6	0,0030	0,075
0,8	0,0040	0,100
1,0	0,0050	0,125
1,5	0,0075	0,188

The smallest temperature difference shall be such as to correspond to the minimum density of heat flow rate expected during all possible testing conditions. Mean test temperatures shall span over the whole temperature range of the equipment. If the linearity test results deviate even by a small fraction of a percentage point from the expected density of heat flow rate in the range of densities of heat flow rate expected during the measurements, a bad placement of imbalance sensors is the most probable reason. The imbalance error detected by the linearity test depends on the particular testing conditions used and cannot be estimated for other testing conditions. If the deviations of the results of the linearity test exceed those acceptable for imbalance errors, the equipment shall not be approved for procedures intended to measure the relevance of the thickness effect, even though meeting the ISO 8302:1991 requirements.

If stacks of two, three, ...*n* specimens suitable for the linearity tests and identical in thermal resistance within 1 % are mounted in the apparatus, and the linearity test is repeated on these stacks, the sensitivity of the apparatus to edge heat losses can be checked experimentally. This set of experiments allows the experimental evaluation of edge heat losses for materials where the heat transfer is almost entirely due to conduction like those suitable for the linearity tests, but is optimistic for low density materials where radiation heat transfer can play a determinant role. For such materials, having determined the maximum specimen thickness through the aforementioned tests, it shall be determined up to what thickness the thermal resistance is a linear function of specimen thickness with a suitable low density reference material[1)].

5 Calibration and maintenance files

Calibration and maintenance files shall be kept containing records of maintenance, repair or modification to the equipment and all periodic calibration data, as indicated in this clause and of calibrations indicated in **5.3** of EN 1946-1:1999.

NOTE Temperature sensors include thermocouples, thermopiles and resistance thermometers.

The ancillary equipment requiring periodic calibration checks include: digital voltmeters, power supplies, voltage and current transducers, standard resistances, thickness transducers, etc.

Appropriate periodic maintenance may be required for some ancillary devices. When applicable, the nature of any such maintenance shall be described, together with its schedule and the annotation to be made on the calibration and maintenance files.

As the guarded hot plate apparatus is an absolute apparatus, its results shall never be corrected using the results of measurements on reference materials. Rather, the equipment design and all the associated instrumentation shall be checked until the cause of disagreement has been identified and rectified. Nevertheless, it is highly recommended that a verification with one or more reference materials be performed not only after the initial performance check required by **2.4** of ISO 8302:1991 but also at regular intervals, e.g. once a year.

6 Measurement procedure document

6.1 General

A measurement procedure document shall be compiled in accordance with **5.4** of EN 1946-1:1999. Specific information on specimen handling and conditioning, measurement procedures and data reporting are described in **3.1** to **3.6** of ISO 8302:1991.

The measurement procedure document shall include, for a given guarded hot plate apparatus, the criteria for the assessment of the attainment of steady state conditions and for the definition of the measurement interval, as described in **3.3.8** of ISO 8302:1991.

Measurement procedures described in a product standard for a specific material shall over-ride the general requirements indicated in ISO 8302:1991.

6.2 Rigid specimens tested with contact sheets

The measurement procedure document shall contain appropriate guidance on the use of contact sheets and resulting errors.

Contact sheets are always required when the specimen thermal resistance is smaller than 0,3 $m^2 \cdot K/W$.

NOTE 1 The use of the thermal contact sheets and surface-mounted thermocouples is also recommended for specimens having a thermal resistance up to 0,5 $m^2 \cdot K/W$.

NOTE 2 The lowest measurable thermal resistance according to ISO 8302:1991, is 0,02 $m^2 \cdot K/W$ (e.g. 0,04 m of structural concrete), but the overall accuracy of 2 % around room temperature can be achieved only when specimen thermal resistance is equal to or greater than 0,1 $m^2 \cdot K/W$.

The use of contact sheets introduces errors in the measurement of the temperature difference through the specimens. A detailed discussion of this procedure, including error analysis, can be found in **A.3.5.3** of prEN 12664:1996.

Errors resulting from the penetration into the contact sheets of the thermocouple junctions mounted on the surfaces of the specimens are not considered here.

Consideration is given here only to the temperature non-uniformity on the surfaces of the specimens resulting from the non-uniform thickness of the contact sheets due to flatness tolerances of both the apparatus and the specimen or local non-homogeneities both in the specimen and in the contact sheets. This is the bounding condition for flatness when testing very low thermal resistance specimens.

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1) One example of a low density reference material is BCR polyester fibre boards CRM 124 supplied by Institute for Reference Materials and Measurements (IRMM), Retieseweg, B-2440 Geel, Belgium. This information is given for the convenience of users of this Standard and does not constitute an endorsement by CEN/CENELEC of this product.

Considering a specimen not perfectly plane, as the one of Figure 2, the relative error, E, in temperature difference resulting from specimen surfaces that are not perfectly plane can be estimated from:

$$E = \frac{p/d_c + 2p/d}{R/R_c + 2}$$

where

- p is the deviation of the specimen surface from a true plane at the point where a thermocouple junction is placed, in mm;
- d is the thickness of the specimen, in mm;
- d_c is the thickness of a single contact sheet, in mm;
- R_c is the thermal resistance of a single contact sheet, in $m^2 \cdot K/W$;
- R is the thermal resistance of the specimen, in $m^2 \cdot K/W$.

When the equipment to be assessed is intended for measurements on rigid specimens with contact sheets and the required accuracy is not met, the testing procedures shall be reviewed to increase the minimum measurable thermal resistance.

NOTE The minimum specimen thickness also depends on the gap width as indicated in **4.4.3**.

7 Assessment

The assessment shall be implemented in accordance with **4** of EN 1946-1:1999.

Particular care shall be taken during the assessment in the verification of the design, error analysis and performance check data contained in the equipment manual.

NOTE This is essential to ensure that the prescribed accuracies are met in all testing conditions for which the approval is sought. Supplementary calculations or experimental performance checks may be required before the on-site assessment.

If the design is not adequate to reach the specified accuracy level in the intended test conditions, the laboratory shall either revise the equipment design and construction or reduce the range of testing conditions. If it is impossible to find a suitable range of testing conditions in which the equipment reaches the needed level of accuracy, then, clearly, the equipment fails to meet the requirements for approval.

It would be advisable to ask for one or more of the performance checks indicated in **4.5** to be repeated.

The approval shall not be granted without proficiency tests.

Annex A (normative)
Determination of apparatus emissivity

The emissivity, ε, of the apparatus surfaces is one of the parameters affecting the measurement of the thermal resistance of low density insulating materials. When measuring such materials, this parameter shall be known. The following procedure is an expansion of what is summarized in **2.4.6** of ISO 8302:1991. Other procedures can be used if they reach at least the same accuracy of the one given here.

The total hemispherical emissivity of a guarded hot plate apparatus can be determined if the heat transfer between the hot and cold surfaces of the apparatus can be assumed as the steady-state heat transfer in a transparent conducting medium bounded by two parallel, flat, infinite isothermal surfaces. The experimental conditions to satisfy these assumptions are shown later in this annex. Under such an assumption the total density of heat flow rate, q_t, can be written as:

$$q_t = q_r + \frac{\lambda}{d}\Delta T \qquad \text{(A.1)}$$

where

$$q_r = \frac{4\sigma_n T_m{}^3 \Delta T}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} \qquad \text{(A.2)}$$

d is the distance between the two surfaces, in m;

λ is the thermal conductivity of the medium separating the two surfaces, in W/(m·K);

ΔT is the temperature difference between the two surfaces, in K;

T_m is the mean temperature of the two surfaces, in K;

σ_n is the Stefan Boltzmann's constant ($5{,}67 \times 10^{-8}$ W/($m^2 \cdot K^4$));

ε_1, ε_2 are the emissivities of the two surfaces.

If $q_t/\Delta T$ is measured at various values of d, the graph of $q_t/\Delta T$ versus $1/d$ is a straight line of slope λ and intercept $q_r/\Delta T$. With air between the plane surfaces, λ is λ_{air}. Values accurate to 0,6 % between θ = 10 °C and θ = 70 °C are given, in W/(m·K), by equation (A.3)[2)], where $\theta = T_m - 273{,}15$:

$$\lambda_{air} = 0{,}0242396(1 + 0{,}0030520\theta - 1{,}282 \times 10^{-6}\theta^2 \qquad \text{(A.3)}$$

Equation (A.1) may be applied to guarded hot plate apparatus when no natural convection takes place between their hot and cold surfaces. This last condition is met in horizontal apparatus when the hot side is the uppermost or, for any other surface layout, when temperature differences are very small. Also, the distance, d, between the apparatus surfaces shall be kept small compared with their width, so that equation (A.2) is a reasonable approximation to the radiation heat transfer.

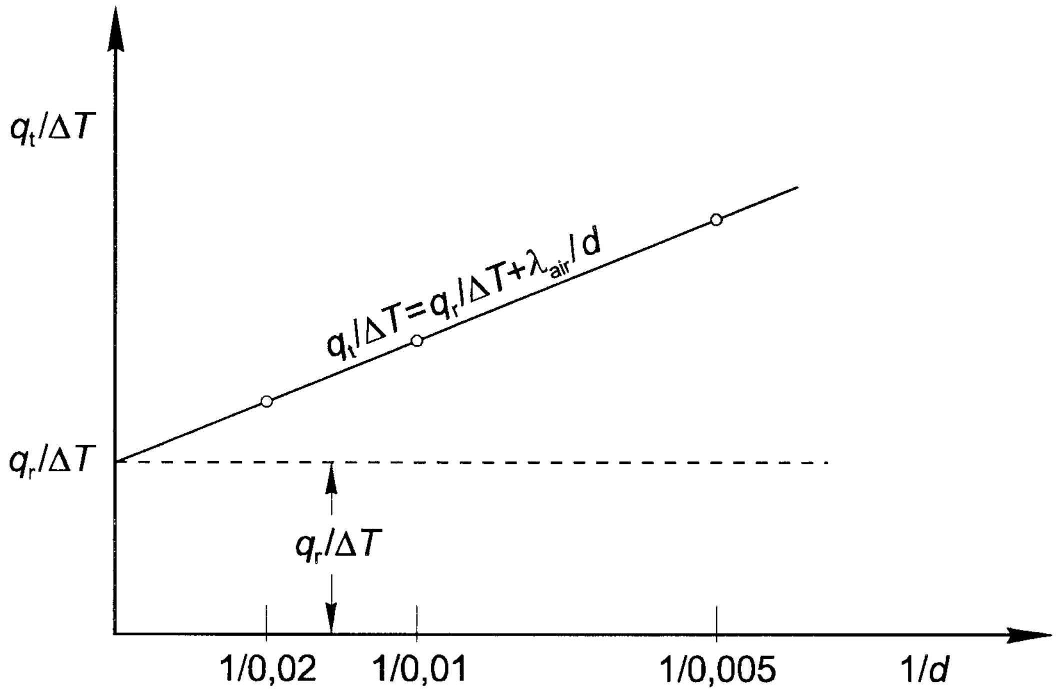

Figure A.1 — Density of heat flow rate (divided by ΔT) in a conducting transparent layer

[2)] Equation (A.3) has been obtained by regression of the data contained in Encyclopaedia of Gases, Elsevier/Air Liquide, Elsevier Scientific Publishing Company, Amsterdam, 1976.

NOTE 1 The experimental evidence of the absence of natural convection is that the plot of $q_t/\Delta T$ versus $1/d$ is a straight line.

Consider first a single-specimen guarded hot plate apparatus with the hot side up and with different sets of spacers to create air spaces.

NOTE 2 Spacers of 5 mm, 10 mm and 20 mm and a temperature difference of a few kelvins are recommended.

The quantity q_r can be derived in three different ways.

a) The best fit of experimental data by least squares regression is used to derive both $q_r/\Delta T$ and λ. As λ is the thermal conductivity of the air at the mean test temperature, its value shall agree with literature data (around room temperature the equation (A.3) may be used).

b) A constant offset is added or subtracted to each test thickness to obtain the best correlation of experimental data with a straight line (correlation parameter as close as possible to unity). The unknowns of the regression are again $q_r/\Delta T$ and λ.

NOTE 3 This allows for apparatus surfaces not being perfectly flat or for devices to measure the air space thickness having a systematic error; flatness tolerances of less than 0,1 mm can be detected by this method.

Again, a good agreement with literature data shall exist for the thermal conductivity of the air.

c) The thermal conductivity of the air is taken from literature data, e.g. equation (A.3), and the term λ/d is subtracted from $q_t/\Delta T$. The average of the experimental values of $q_r/\Delta T$ at different test thicknesses is then computed.

Once obtained $q_r/\Delta T$, the following quantity, derived by equation (A.2), is known:

$$\frac{4\sigma_n T_m{}^3}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}-1} \qquad \text{(A.4)}$$

As also the quantity $4\sigma_n T_m{}^3$ is known, the total hemispherical emissivity can be derived from the expression (A.4) only when ε_1 and ε_2 are equal. In this case the three above procedures shall give results in agreement with each other within 0,02.

When the value of the emissivity of each apparatus surface is of interest, the apparatus surfaces shall first be coated to have the same emissivity ε, which is determined by a first set of measurements as those just described. Then a second set of measurements shall be made at the same mean temperature T_m, having removed the coating just from the surfaces of emissivity ε_1: in the expression (A.4) ε is now known and hence ε_1 can be derived. Finally, a third set of measurements shall be made again at the same mean temperature T_m, having removed the coating just from the surfaces of emissivity ε_2: in the expression (A.4) ε is now known and hence ε_2 can be derived.

When the emissivity of a two-specimen guarded hot plate apparatus is to be measured, a high-thermal-resistance specimen shall be placed on the upper side of the guarded hot plate (where natural convection can take place). The specimen thermal resistance shall be known and the density of heat flow rate that crosses it during the emissivity test shall be subtracted from q_t.

NOTE 4 The mean temperature and temperature difference through the specimen may differ widely, during the same test, from those through the air space; this is due to the large difference in thermal resistance between the specimen and the air space.

Evaluate the density of heat flow rate through the specimen from the data pertaining to it (mean test temperature, temperature difference and specimen thermal resistance), and make emissivity computations with the data pertaining to the air space.

NOTE 5 The final accuracy in the determination of the apparatus emissivity is now limited also by the accuracy in the evaluation of the density of heat flow rate crossing the specimen.

Annex B (normative)

Edge heat losses and maximum specimen thickness

Considering that according to **3.2.1** of ISO 8302:1991, the sum of the imbalance and the edge heat loss error shall be kept within 0,5 %, it is recommended that the edge heat loss error is not more than 0,25 %. Table B.1 shows for some apparatus dimensions and specimen thicknesses the edge heat loss error according to **2.2.1** of ISO 8302:1991, when there is no edge insulation and when the edge temperature ratio e, see **4.4.2**, is taken to be 0,25 as suggested in ISO 8302:1991.

If, for the same apparatus and testing conditions, the temperature of the edge of the specimen is such that $0,40 \le e \le 0,60$, the specimen thickness may be increased by some 20 % (while keeping the error less than 0,25 %): compare the first two sets of data in Table B.2.

Larger specimen thicknesses can be used if edge insulation, auxiliary guards or gradient guards are used.

When an additional outer plane guard is used, calculate the edge heat loss error using a guard width equal to the sum of the width of the principal and additional guards.

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

When edge insulation is used, in no case can the edge heat loss error be lower than that of an apparatus having the same metering section size and the guard width increased by the thickness of the edge insulation. The effect of edge insulation can roughly be assessed from the data in Table B.1 by increasing the guard width by one third of the thickness of the edge insulation, provided that the apparatus and its edge insulation are enclosed in a conditioned cabinet with the air temperature, assumed as edge temperature, meeting the conditions for $e = 0,25$.

Table B.1 — Percentage errors due to edge heat losses in the case of no edge insulation and edge temperature ratio *e* = 0,25

Dimensions in millimetres

Overall size	Metering section	Guard width	Specimen thickness							
			40	50	60	80	100	120	160	200
200	100	50	**1,01** %	**2,77** %	—	—	—	—	—	—
300	200	50	**0,51** %	**1,44** %	—	—	—	—	—	—
300	150	75	0,09 %	**0,38** %	**1,01** %	**3,61** %	—	—	—	—
400	200	100	0,01 %	0,06 %	0,20 %	**1,01** %	**2,77** %	—	—	—
400	100	150	0,00 %	0,00 %	0,03 %	0,24 %	**0,92** %	**2,27** %	—	—
500	300	100	0,01 %	0,04 %	0,14 %	**0,68** %	**1,91** %	—	—	—
500	250	125	0,00 %	0,01 %	0,04 %	**0,30** %	**1,01** %	**2,33** %	—	—
500	200	150	0,00 %	0,00 %	0,01 %	0,14 %	**0,55** %	**1,43** %	**4,95** %	—
600	300	150	0,00 %	0,00 %	0,01 %	0,09 %	**0,38** %	**1,01** %	**3,61** %	—
800	500	150	0,00 %	0,00 %	0,01 %	0,06 %	0,23 %	**0,61** %	**2,25** %	**5,27** %
800	400	200	0,00 %	0,00 %	0,00 %	0,01 %	0,06 %	0,20 %	**1,01** %	**2,77** %
1 000	500	250	0,00 %	0,00 %	0,00 %	0,00 %	0,01 %	0,04 %	**0,30** %	**1,01** %

NOTE Values in bold characters are those exceeding 0,25 %.

Table B.2 — Percentage errors due to edge heat losses — Special cases

Dimensions in millimetres

Overall size	Metering section	Guard width	Specimen thickness							
			40	50	60	80	100	120	160	200
pure conduction, *e* = 0,25										
500	300	100	0,01 %	0,04 %	0,14 %	**0,68** %	**1,91** %	—	—	—
500	250	125	0,00 %	0,01 %	0,04 %	**0,30** %	**1,01** %	**2,33** %	—	—
500	200	150	0,00 %	0,00 %	0,01 %	0,14 %	**0,55** %	**1,43** %	**4,95** %	—
pure conduction, *e* = 0,40500										
500	300	100	0,00 %	0,02 %	0,05 %	**0,28** %	**0,81** %	**1,74** %	—	—
500	250	125	0,00 %	0,00 %	0,02 %	0,12 %	**0,41** %	**0,98** %	**3,19** %	—
500	200	150	0,00 %	0,00 %	0,01 %	0,06 %	0,22 %	**0,59** %	**2,13** %	—
pure conduction, *e* = −1										
500	300	100	0,04 %	0,24 %	**0,82** %	**4,06** %	—	—	—	—
500	250	125	0,01 %	0,06 %	**0,26** %	**1,80** %	**6,01** %	—	—	—
500	200	150	0,00 %	0,02 %	0,09 %	**0,83** %	**3,32** %	—	—	—
pure conduction, *e* = 0										
500	300	100	0,01 %	0,08 %	**0,27** %	**1,35** %	**3,75** %	—	—	—
500	200	150	0,00 %	0,01 %	0,03 %	**0,28** %	**1,10** %	**2,84** %	**9,72** %	—
pure radiation, *e* = 0										
500	300	100	3,3 %	5,1 %	—	—	—	—	—	—
500	200	150	2,5 %	3,8 %	5,5 %	—	—	—	—	—

NOTE Values in bold characters are those exceeding 0,25 %.

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 from 0,25 to 0,75.

EXAMPLE: a mean test temperature of 50 °C, a temperature difference of 20 °C and a laboratory temperature of 20 °C give *e* = −1; the resulting edge heat loss error is given in the third set of data of Table B.2.

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 B.1, unless the calculations of edge heat loss errors include coupled conduction and radiation heat transfer. The adverse effect of radiation heat transfer on edge heat loss error can be understood by comparing the last two sets of data of Table B.2: they correspond to the two extremes of pure conduction in the specimen and pure radiation if the space occupied by the specimen was left void. The value $e = 0$ corresponds to the minimum edge heat loss error for pure radiation (as e close to 0,5 corresponds to the minimum edge heat loss error for pure conduction in the specimen).

The information given in this annex is based on an assumption of isotropic specimens, and it is not suitable to assess the performance of equipment intended to test non-isotropic or layered specimens.

When testing medium and high conductivity specimens, edge heat losses have a reduced impact on test accuracy. When no additional edge insulation is used, the indications of Table B.I can be used as a guidance for specimens having a thermal conductivity less than 0,4 W/(m·K); the maximum thicknesses allowed from the data of Table B.1 can be increased by 20 % for specimens having a thermal conductivity of 0,8 W/(m·K) and by 40 % for specimens having a thermal conductivity of 1,6 W/(m·K) or greater. For intermediate values of the thermal conductivity, maximum specimen thicknesses can be derived by linear interpolation.

Annex C (informative)
Calculations of some guarded hot plate errors

C.1 General

Error analyses are supplied here for common sizes etc. of equipment. Examples of equipment conforming to this error analysis are supplied in **D.2** of prEN 12664:1996 and in **D.2** of prEN 12667:1996. If the equipment to be considered corresponds to the design indicated, no further calculations need be made. Otherwise, analogous calculations can be done for the specific equipment. The main apparatus characteristics and testing conditions, for three pieces of equipment (named here as equipment A, B and C), are assumed.

	EQUIPMENT		
	A	**B**	**C**
— overall apparatus size in millimetres	300	500	800
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
— minimum gap width in millimetres	2	3	4
Minimum specimen thickness is 10 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
— maximum specimen conductivity in W/(m·K)	1,5	1,5	1,5
— maximum specimen thickness in mm (see **C.2** and **4.4.2**, Table 1)	45	75	100
— maximum thickness in mm of the heating unit metal plate (aluminium, 150 W/(m·K))	5	8	12
— maximum total heater thickness in mm	3	3	3
— maximum total section in mm^2 of copper wires (400 W/(m·K)) crossing the gap	6	6	6
— maximum total section in mm^2 of non-copper wires (100 W/(m·K)) crossing the gap	6	6	6
— 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 equipment, in millimetres)	832 (8 × 13)	1520 (10 × 19)	3240 (15 × 27)

C.2 Maximum specimen thickness

	EQUIPMENT		
	A	**B**	**C**
Maximum specimen thickness in mm for the apparatus sizes of **C.1**, according to **4.4.2**	45	75	100

C.3 Imbalance error

	EQUIPMENT		
	A	B	C
The value of c in m, according to **4.4.4**, is:	1,31	2,24	4,49
This corresponds to the products λc in W/K:			
— for the minimum specimen thermal conductivity λ = 0,015 W/(m·K), see **C.1**	0,0197	0,0336	0,0674
— for the maximum specimen thermal conductivity λ = 1,5 W/(m·K), see **C.1**	1,97	3,36	6,74
The term Φ_0 is the sum of:			
Φ_a through the air in the gap (λ_{air} = 0,025 W/(m·K) at 20 °C);			
Φ_r by radiation through the gap (at 20 °C);			
Φ_m through the mechanical connections through the gap;			
Φ_c through copper wires;			
Φ_w through metal wires (excluding copper).			
The term Φ_a in W/K is:	0,098	0,158	0,338
The term Φ_r in W/K is:	0,074	0,109	0,154
The term Φ_m in W/K is:	0,125	0,152	0,243
The term Φ_c in W/K is:	1,200	0,800	0,600
The term Φ_w in W/K is:	0,300	0,200	0,150
The term Φ_0 in W/K is the sum of the listed terms:	1,798	1,419	1,486
by adding λc, the sum ($\Phi_0 + \lambda c$) in W/K is:			
— for the specimen conductivity 0,015 W/(m·K)	1,818	1,453	1,553
— for the specimen conductivity 1,5 W/(m·K)	3,768	4,779	8,226

Assuming a temperature difference through the specimen of 20 K for the specimen conductivity 0,015 W/(m·K) and a temperature difference through the specimen of 10 K for the specimen conductivity of 1,5 W/(m·K), the corresponding densities of heat flow rates at the maximum specimen thickness are in W/m^2:

	EQUIPMENT		
	A	B	C
— for the specimen conductivity 0,015 W/(m·K)	6.67	4,00	3,00
— for the specimen conductivity 1,5 W/(m·K)	333	200	150
and the heat flow rates in W through the metering section of both specimens are:			
— for the specimen conductivity 0,015 W/(m·K)	0,30	1,50	1,50
— for the specimen conductivity 1,5 W/(m·K)	15,00	25,00	75,00
To get the suggested error of 0,25 %, see **4.4.2**, the value of ΔT_g in mK shall be smaller than:			
— for the specimen conductivity 0,015 W/(m·K)	0,4	0,9	2,4
— for the specimen conductivity 1,5 W/(m·K)	10,0	13,1	22,8
Assuming a balancing thermopile of 32 elements with a thermoelectric power of 40 µV/K per element, the electrical balance in µV shall be better than:			
— for the specimen conductivity 0,015 W/(m·K)	0,5	1,1	3,1
— for the specimen conductivity 1,5 W/(m·K)	12,7	16,7	29,2
The maximum acceptable value for ΔT_g shall be compared with the accuracy of the balancing thermopile in detecting the temperature imbalance through the gap. Considering the above calculated densities of heat flow rates crossing the metal plates of the heating unit (aluminium, 150 W/(m·K)), the temperature differences, in mK, across these plates are:			
— for the specimen conductivity 0,015 W/(m·K)	0,22	0,21	0,24
— for the specimen conductivity 1,5 W/(m·K)	11	11	12

These values are less than the maximum acceptable values for ΔT_g and hence any position along the thickness of the heating unit metal plates is satisfactory. Consequently, the gap design of Figure 4b) of ISO 8302:1991, under the above assumptions, does not require further checks, while all other solutions require the analysis of the uniformity of the thermal resistance between the metal plate and the thermopile junction. For thermopiles imbedded in plastic sheets (see Figure 4a) of ISO 8302:1991), the effect of an air pocket 0,01 mm thick (air conductivity of 0,025 W/(m·K)) or the effect of a 0,1 mm difference in thickness of the plastic layer (plastic conductivity of 0,25 W/(m·K)) between the junctions on each side of the gap and the metal plate result in the following temperature differences in mK with the above calculated densities of heat flow rates:

	EQUIPMENT		
	A	**B**	**C**
— for the specimen conductivity 0,015 W/(m·K)	2,67	1,60	1,20
— for the specimen conductivity 1,5 W/(m·K)	133	80	60

It appears then that the gap design of Figure 4a) of ISO 8302:1991 can be acceptable only for low conductivity specimens when particular care has been put to avoid air pockets and local non-uniformities in the mounting of thermopile junctions.

C.4 Error in measured electrical power

This error shall be limited to 0,1 % according to **B.1** of prEN 12667:1996 and **B.1** of prEN 12664:1996.

C.5 Error in the definition of the metering area

The metering area is defined as the area enclosed by the line through the centre of the gap. An uncertainty equal to 5 % of the gap width can be accepted plus 0,1 % due to mechanical tolerances, i.e.:

	EQUIPMENT	
A	**B**	**C**
0,37 %	0,34 %	0,26 %

C.6 Error in the temperature difference

Differential connections are assumed for special grade type T thermocouples operated around room temperature. According to **4.4.7** a 0,4 % uncertainty in the calibration can be assumed.

The accuracy of the measuring instrument shall be within 0,2 %. The remaining 0,4 % allowed by **2.1.4.1.2** of ISO 8302:1991 to stay within the prescribed limit of 1 % shall be the maximum value resulting from the uncertainty in the definition of the point where the temperature is measured by the sensor.

C.7 Error in the specimen thickness

This error depends mainly on the finishing of the specimen surfaces and becomes critical with low thickness specimens. The minimum specimen thickness is 10 times the gap width, according to **1.7.6** of ISO 8302:1991, i.e. in mm:

	EQUIPMENT	
A	**B**	**C**
20	30	40

According to **2.1.4.2** of ISO 8302:1991, the error in the measurement of the thickness is limited to 0,5 %, which, applied to the above minimum thicknesses, gives the following absolute errors in mm:

	EQUIPMENT	
A	**B**	**C**
0,10	0,15	0,20

C.8 Error due to imperfect contact between apparatus and specimen

Contact resistance between specimens and temperature sensors becomes critical at low specimen thermal resistances and is related to the surface finishing and the method used to measure the temperature difference, see **2.1.4.1** of ISO 8302:1991. It is the most important source of error that derates expected guarded hot plate apparatus accuracy when testing low resistance specimens (below 0,1 $m^2 \cdot K/W$, according to **1.5.3** of ISO 8302:1991).

Considering that the maximum specimen conductivity to be measured is 1,5 W/(m·K), even at the maximum specimen thicknesses (45 mm, 75 mm and 100 mm for equipment A, B and C respectively), the minimum thermal resistance in $m^2 \cdot K/W$ is:

EQUIPMENT		
A	**B**	**C**
0,030	0,050	0,067

These values are all below 0,30 $m^2 \cdot K/W$, i.e. the error due to imperfect contact between apparatus and specimen can be larger than 0,5 % and the use of contact sheets becomes mandatory for minimum measurable thermal resistances. As this error is dependent on the specimen and does not qualify the equipment, the value 0,5 %, applicable down to thermal resistances of 0,10 $m^2 \cdot K/W$ is assumed in the evaluation of the maximum probable error, see **C.10**. For the indicated minimum measurable thermal resistances, the error calculated by linear interpolation of the acceptable errors 0,5 % and 4 % at the thermal conductances 1/0,10 $W/(m^2 \cdot K)$ and 1/0,02 $W/(m^2 \cdot K)$ is:

EQUIPMENT		
A	**B**	**C**
2,04 %	0,88 %	0,44 %

This error can therefore be the most important one for low resistance specimens.

C.9 Error due to non-symmetrical conditions

According to **2.2.2** of ISO 8302:1991 this error should be less than 0,1 %

C.10 Maximum probable error

The maximum probable error in percent is obtained from the individual components calculated in **C.2** to **C.9**:

	EQUIPMENT		
	A	**B**	**C**
Imbalance and edge heat loss error	0,5 %	0,5 %	0,5 %
Error in measured electrical power	0,1 %	0,1 %	0,1 %
Error in the definition of the metering area	0,37 %	0,34 %	0,26 %
Error in the temperature difference	1,0 %	1,0 %	1,0 %
Error in the specimen thickness	0,5 %	0,5 %	0,5 %
Error due to imperfect contact	0,5 %	0,5 %	0,5 %
Error due to non-symmetrical conditions	0,1 %	0,1 %	0,1 %
By summing, the maximum error is:	3,07 %	3,04 %	2,96 %
If the above errors are added in quadrature, the maximum probable error is:	1,38 %	1,37 %	1,36 %

Random errors due to random drifts of measurement instrumentation and automatic control systems, which can be minimized by averaging many measurements, have not been included in this error analysis.

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