BRITISH STANDARD

BS 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

The European Standard EN 1946-3:1999 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 1946-3:1999.

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

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 16, an inside back cover and a back cover.

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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 3: Measurements by heat flow meter method

Performance thermique des produits et composants pour le bâtiment — Critères particuliers pour l'évaluation des laboratoires mesurant les propriétés de transmission thermique — Partie 3: Mesurages selon la méthode fluxmétrique

Wärmetechnisches Verhalten von Bauprodukten und Bauteilen — Technische Kriterien zur Begutachtung von Laboratorien bei der Durchführung der Messungen von Wärmeübertragungseigenschaften — Teil 3: Messung nach dem Verfahren mit dem Wärmestrommeßplatten-Gerät

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.

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CEN

European Committee for Standardization

Comité Européen de Normalisation

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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 3 of this standard provides specific technical criteria for the assessment of laboratories to undertake steady-state heat transfer property measurements by the heat flow meter 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 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

The definitions in EN 1946-1:1999 and in ISO 8301:1991 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 checklist 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 8301:1991, 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;

— sensitivity coefficient of the heat flow meter.

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** of ISO 8301:1991);

— type of configuration of the apparatus (see **2.1** of ISO 8301:1991);

— principal dimensions of apparatus, in particular heating and cooling unit width, central metering area and guard width;

— simple diagrams illustrating the design of the equipment with special attention to the thermopile design (see **2.2.2.3** of ISO 8301:1991), the heating and cooling unit piping (see **2.2.1.1** of ISO 8301:1991) and edge insulation (see **2.2.5.1** of ISO 8301:1991);

— position, connections and numbering of temperature sensors (see **2.2.3.1** of ISO 8301:1991);

— 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 8301:1991.

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 as summarized in **4.4.2** to **4.4.9**, considering also, when applicable, **2.2** of ISO 8302:1991 on the guarded hot plate apparatus.

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 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 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 **2.2.5.3** of ISO 8301:1991, the edge heat loss error shall be kept within 0,5 %.

For single-specimen asymmetrical configurations, see Figure 1a), provided that the heat flow meter thickness is within 2 % of the overall apparatus size, see **1.7.2.2** and **2.2.5.2.1** of ISO 8301:1991 for guidance, the fourth column of Table 1 gives for some apparatus dimensions the maximum allowed specimen thickness according to **2.2.1** of ISO 8302:1991 on the guarded hot plate, 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 $0,25 \le e \le 0,75$, this error is maximum for e = 0,25.

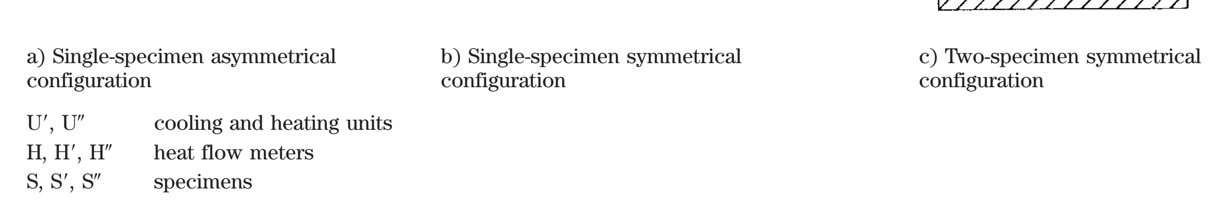
When the heat flow meter thickness exceeds the above quoted 2 %, the sum of specimen and heat flow meter thickness should conform with Table 1 data.

For single-specimen symmetrical configurations, see Figure 1b), the specimen thickness can be up to 50 % higher than that of the single-specimen asymmetrical configuration, see **1.7.2.2** and **2.2.5.2.3** of ISO 8301:1991 and the fifth column of Table 1.

For two-specimen symmetrical configurations, see Figure 1c), the specimen thickness shall be smaller than that of the single-specimen asymmetrical configuration, see **2.2.5.2.2** of ISO 8301:1991; calculation can be made for the edge temperature ratio e = 0, see the sixth column of Table 1.

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 8301:1991, 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.



a) Single-specimen asymmetrical configuration

b) Single-specimen symmetrical configuration

c) Two-specimen symmetrical configuration

U′, U″ cooling and heating units
H, H′, H″ heat flow meters
S, S′, S″ specimens

Figure 1 — Typical layouts of heat flow meter apparatus configurations

Table 1 — Minimum and maximum allowed specimen thickness

Dimensions in millimetres

Overall size	Metering section	Guard width	Maximum thickness			Flatness tolerance (0,025%)	Minimum thickness (flat. tol.)
			sing. sp. asymmetric for e = 0,25	sing. sp. symmetric for e = 0,25	two sp. symmetric for e = 0		
200	100	50	35	50	30	0,05	10,0
300	200	50	40	60	35	0,08	15,0
300	150	75	50	75	45	0,08	15,0
400	200	100	70	100	60	0,10	20,0
400	100	150	90	130	80	0,10	20,0
500	300	100	75	110	65	0,13	25,0
500	250	125	85	130	75	0,13	25,0
500	200	150	95	140	85	0,13	25,0
600	300	150	100	150	90	0,15	30,0
800	500	150	110	170	100	0,20	40,0
800	400	200	140	210	120	0,20	40,0
1 000	500	250	170	260	150	0,25	50,0

4.4.3 ***Minimum specimen thickness***

Minimum specimen thickness shall be compatible with flatness tolerance, see **4.4.7** to **4.4.9**.

4.4.4 ***Temperature uniformity of the heating or cooling unit***

According to **2.2.1.2** of ISO 8301:1991, the temperature uniformity of the working surfaces of the apparatus shall be better than 1 % of the temperature difference across the specimen. In addition, if a heat flow meter is placed in contact with the working surface of a heating or cooling unit and is sensitive to the temperature variations along this surface, the variations shall be as small as necessary to maintain an error in measured heat flow rate below 0,5 %. The latter requirement cannot be predicted without an accurate knowledge of the thermopile design.

The 1 % temperature uniformity requirement can be checked by considering the largest expected heat flow rate Φ_s through the specimen and the heat flow rate Φ_e towards the environment surrounding the apparatus through the remaining surfaces of the heating or cooling unit. When the heating or cooling unit is kept at its temperature by liquid flow circulation, the temperature difference ΔT_p between the plate inlet and outlet is defined by the following equation where m_r is the mass flow rate and c is the specific heat of the liquid circulated:

$$\Phi_s + \Phi_e = m_r \, c \, \Delta T_p$$

The value of ΔT_p can be assumed as temperature non-uniformity for most liquid-paths [see Figure 2a) and 2b)]. For helical counter flow paths [see Figure 2c)] the temperature uniformity can in some cases be better, but calculations are more complex (see **2.2.1.1** of ISO 8301:1991).

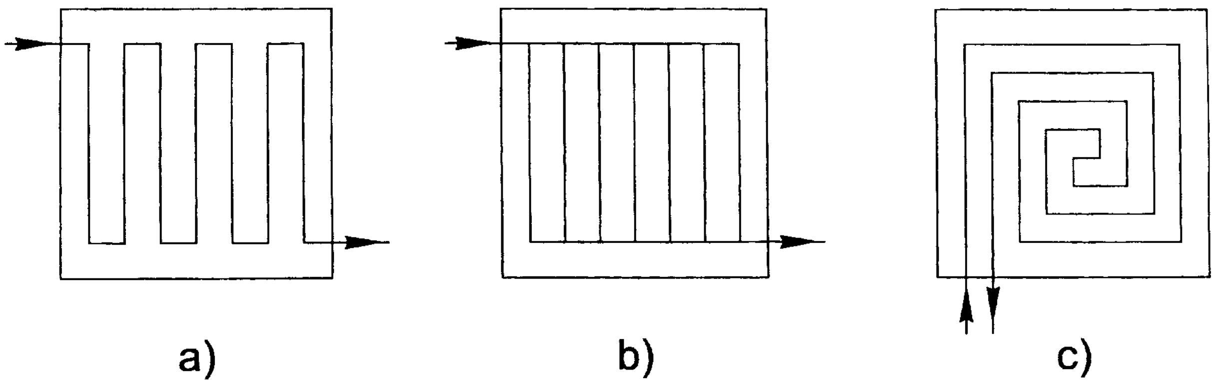


Figure 2 — Examples of schematic design of heating or cooling units in the case of external liquid supply

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

According to **2.2.3.1.1** of ISO 8301:1991, the total error in the temperature difference measured by the temperature sensors permanently mounted in the apparatus shall not exceed 1 %, made up of the terms a) and b) as follows:

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

— linearity of measuring instruments: less than 0,1 %;

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

— noise immunity of measuring instruments: less than 0,1 %;

— these four terms added quadratically give a total uncertainty of 0,5 %;

b) uncertainty in the definition of the point where the temperature is measured by the sensor: less than 0,5 %.

NOTE 1 When special grade thermocouples (see annex D of ISO 8301:1991) mounted differentially are used, as in Figure 6b) or 6c) of ISO 8302:1991 (on the guarded hot plate), 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 **4.4.8** and **4.4.9**.

4.4.6 ***Error in the measurement of the specimen thickness***

The error of the measuring devices, shall not exceed 0,5 %, see **2.2.3.3** of ISO 8301:1991, 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.

4.4.7 ***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 heat flow meter apparatus and whose thermal resistance is 0,3 $m^2 \cdot K/W$ 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.2.3** of prEN 12667:1996, 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 3. If p is the flatness tolerance expressed as 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 8301:1991, 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 seventh column of Table 1. The limit on thickness error also requires that $100\,p/d_m \leq 0{,}5$. Thus, the minimum specimen thickness, d_m, is limited by flatness tolerances and shall be not less than 5 % of G. See the eighth column of Table 1.

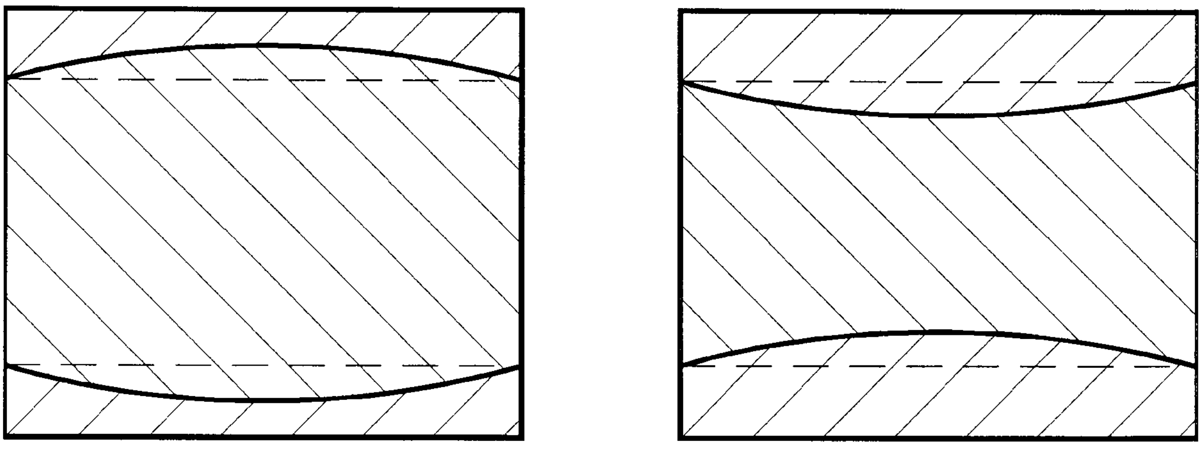


Figure 3 — Non-rigid specimens

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 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.

4.4.8 ***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 **C.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 4 in worst case conditions) created by departures from a plane (contact resistance), shall, according to **A.3.5.1** 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.

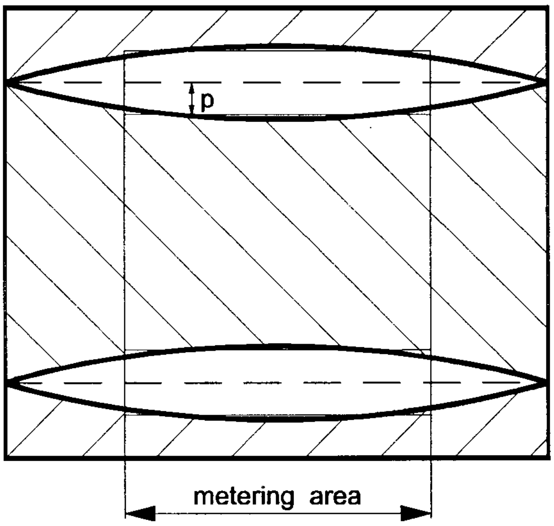


Figure 4 — Rigid specimens

NOTE 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 $m^2 \cdot K/W$.

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 **4.4.9**) or increase the minimum measurable thermal resistance.

4.4.9 ***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**.

The use of contact sheets usually requires pressures of the apparatus on the specimens of typically 10 kPa. It shall be ensured that the heat flow meter can withstand such a pressure without undergoing changes of the calibration factor.

4.5 Calibration of the heat flow meter

The calibration of the heat flow meter shall be in accordance with **2.4** of ISO 8301:1991. For the check of its linearity see also **4.6** on the equipment performance check. The calibration procedure, the calibration specimens to be used, the calibration intervals and the annotations to be made in the calibration and maintenance files shall be described in the equipment manual.

An accurate relationship of the calibration factor with temperature can be obtained only if the mean heat flow meter temperature can be determined (i.e. when the temperatures of both sides of the heat flow meter are known and their average is calculated). If the calibration factor is attributed to the temperature of one of the sides of the heat flow meter, the calibration factor is apparently related to the density of heat flow rate.

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

4.6 Equipment performance check

4.6.1 *Requirements applicable to each piece of equipment*

The equipment performance check shall include the following:

— planeness (see **2.5.1** of ISO 8301:1991);

— computing circuitry, if applicable (see **2.5.2** of ISO 8301:1991);

— heat flow meter zero offset, drifts, non-linearity, etc. (see **2.5.3** and **2.5.4** of ISO 8301:1991);

— electrical connections and automatic controllers (see **2.4.2** of ISO 8302:1991 on the guarded hot plate);

— temperature measurements (see **2.4.3** of ISO 8302:1991 on the guarded hot plate);

— emissivity of apparatus surfaces (see below and annex A);

— linearity test (see **2.4.7** of ISO 8302:1991 on the guarded hot plate);

— proven performance check (see **2.5.5** of ISO 8301:1991).

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 **2.2** of ISO 8301:1991 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 8301:1991 and should confirm the calculations described in **4.4** of this standard within the accuracy of the assumptions for such calculations.

4.6.2 *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, establish first that the calibration factor of the heat flow meter is independent of the density of the heat flow rate within 0,25 %, i.e. acceptable edge heat loss error, by the following procedure.

First mount a sheet of hard plastic a few millimetres thick as a specimen in the apparatus. Adjust the temperature difference through the plastic sheet to several values, giving densities of heat flow rate between zero and the maximum density of heat flow rate expected during normal use of the equipment, keeping the mean temperature of the plastic sheet constant.

The temperature differences during this test are less than 1 K due to the low thermal resistance of the specimen, so that very accurate measurements of temperature differences are required. See the discussion in **2.1.4.1.2** of ISO 8302:1991 on the guarded hot plate apparatus.

Draw a graph of temperature difference versus density of the heat flow rate, which should be a straight line passing through the origin. Any non-linearity in this graph is due to non-uniformities of temperature over the hot and/or cold plates because some heat flow meters are sensitive also to temperature gradients parallel to their main surfaces (see **2.2.2.3** of ISO 8301:1991).

NOTE 1 Non-linearities exceeding 0,25 % cannot be the result of the dependence of the calibration factor on the mean test temperature of the heat flow meter because in this test a range below 1 K is expected.

Next repeat the same experiment with a specimen of material that is suitable for the linearity test described in **2.4.7** of ISO 8302:1991 for the guarded hot plate (specimen for which the conductivity is a linear function of temperature). The non-linearity of the density of heat flow rate over the range of mean heat flow meter temperatures and densities of heat flow rate expected during normal use of the equipment shall not exceed by more than 0,25 % the non-linearity of the specimen.

NOTE 2 This test verifies, besides the linearity of the heat flow meter, the accuracy of the calibration factor versus temperature.

If the equipment does not pass the linearity test, it shall not be approved for measurements according to prEN 12939.

When the equipment is particularly intended to test thick high thermal resistance specimens according to prEN 12939, it is recommended to establish also the sensitivity of the apparatus to edge heat losses by the following experimental procedure.

Using specimens suitable for the linearity test described in **2.4.7** of ISO 8302:1991 on the guarded hot plate and each having the same thermal resistance to within 1 %, measure the thermal resistance of stacks of one, two, three, …*n* specimens, keeping constant the mean test temperature. Repeat the test at the lowest and highest mean test temperature expected during normal use of the equipment. When the line, which interpolates measured thermal resistance versus specimen thickness, deviates from a straight line by more than 0,5 %, the maximum allowed specimen thickness has been reached.

Since the specimens suitable for the linearity test are of materials where the heat transfer is almost entirely due to conduction, the maximum allowed specimen thickness so determined applies when testing specimens of similar materials only, but is too high for low density materials where radiation heat transfer plays a significant role. For such materials it shall further be determined up to what thickness the thermal resistance is a linear function of specimen thickness with a suitable low density reference material[1)] where radiation heat transfer plays a role larger than in specimens to be tested.

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.

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 8301:1991.

The measurement procedure document shall include, for a given heat flow meter apparatus, the criteria for the assessment of the attainment of steady-state conditions and for the definition of the measurement interval, as described in **3.3.5** of ISO 8301:1991.

Measurement procedures described in a product standard for a specific material shall override the general requirements indicated in ISO 8301:1991.

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

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.3.5.2** 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 the 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 4, 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.

7 Assessment

The assessment shall be implemented in accordance with clause **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 can 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 **4.6** 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 on the guarded hot plate. Other procedures can be used if they reach at least the same accuracy of the one given here.

The total hemispherical emissivity of a heat flow meter 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:

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

where:

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

where

- 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 × 10^{-8} W/(m^2·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 $\theta = T_m - 273{,}15$:

$$\lambda_{air} = 0{,}024\,239\,6\,(1 + 0{,}003\,052\,\theta - 1{,}282 \times 10^{-6}\,\theta^2) \qquad (A.3)$$

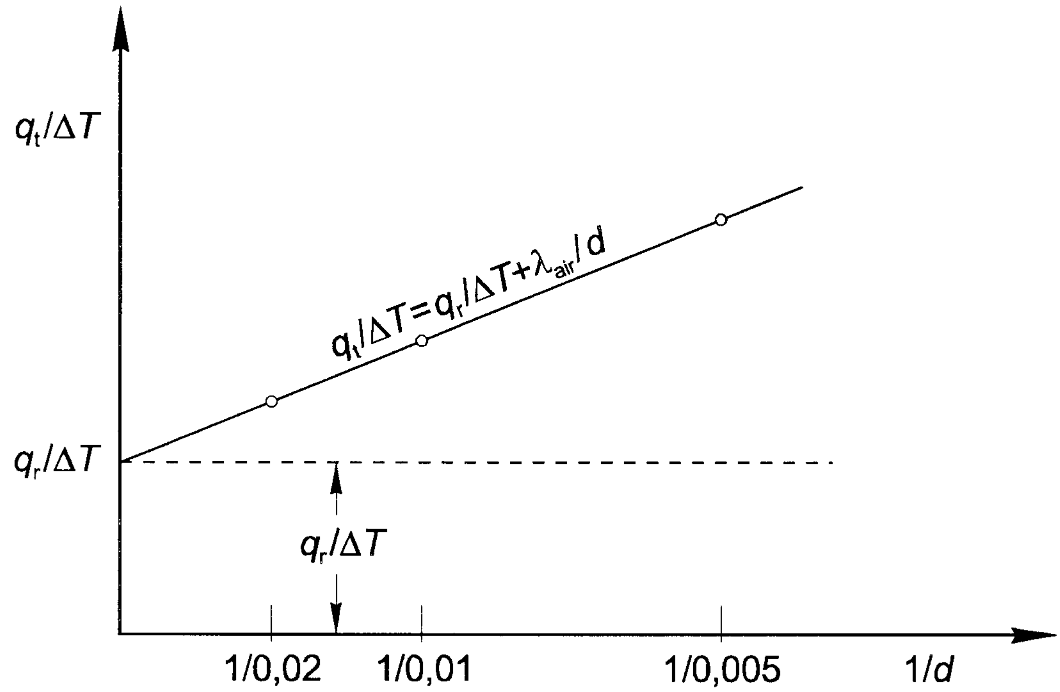

Figure A.1 — Density of heat flow rate (divided by ΔT) in a conducting transparent layer

[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.

Equation (A.1) may be applied to heat flow meter 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.

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 heat flow meter 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:

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

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 symmetrical configuration heat flow meter apparatus is to be measured, the configuration may be modified for this purpose to become a single specimen asymmetrical configuration.

Annex B (normative)

Edge heat losses and maximum specimen thickness

According to **2.2.5.3** of ISO 8301:1991, the edge heat loss error shall be kept within 0,5 %. 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 on the guarded hot plate, 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 on the guarded hot plate.

If, for the same apparatus and testing conditions, the temperature of the edge of the specimen is such that $0,40 \leq e \leq 0,60$, the specimen thickness may be increased by some 20 % (while keeping the error less than 0,5 %): compare the first two sets of data in Table B.2.

Table B.1 — Percentage errors due to edge heat losses in 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 = 0,40										
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 %.

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

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. 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 reduced impact on test accuracy. When no additional edge insulation is used, the indications of Table B.1 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 heat flow meter errors

C.1 General

Error analyses are supplied here for common design and sizes etc. of equipment. Examples of equipment conforming to this error analysis are supplied in **D.3** 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:

— apparatus configuration:

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

	Equipment		
	A	**B**	**C**
— overall apparatus size in millimetres	300	500	600
— metering section width in millimetres	150	200	300
— 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
— maximum specimen thickness in millimetres (see **C.2** and **4.4.2**, Table 1)	50	140	100
— liquid circulated in the heating and cooling unit plates	water	water	water

C.2 Maximum specimen thickness

Maximum specimen thicknesses of Table C.1 are according to Table 1 in **4.4.2**.

C.3 Temperature uniformity

For all three pieces of equipment it is assumed that the maximum temperature difference is 20 K, and that the equipment is enclosed in conditioned cabinets at the mean test temperature. The maximum heat flow rate across the specimen Φ_S, see **4.4.4**, corresponding to the minimum specimen thermal resistance (0,1 m^2·K/W according to ISO 8301) is in watts (W):

Equipment		
A	**B**	**C**
18	50	72

Assuming insulation of thermal resistance of 1 $m^2 \cdot K/W$ between each plate and the cabinet containing the apparatus and conditioned at the mean test temperature, the resulting heat flow rate Φ_e, see **4.4.4**, from the heating or cooling plate towards the cabinet is then in watts (W):

Equipment		
A	**B**	**C**
0,9	2,5	3,6

The product $m_r\ c\ \Delta T_p$, see **4.4.4**, is equal to the sum $\Phi_s + \Phi_e$, i.e., in watts (W):

Equipment		
A	**B**	**C**
18,9	52,5	75,6

The specific heat, c, of liquid water is 4,2 kJ/(kg·K); the maximum allowed temperature non-uniformity for the heating and cooling unit plates is 1 % of the temperature difference across the specimen, i.e. 0,2 K, so the minimum allowed mass flow rate, m_r, is then in kg/s:

Equipment		
A	**B**	**C**
0,022 5	0,062 5	0,090 0

or in litres per hour:

Equipment		
A	**B**	**C**
81	225	324

C.4 Error in the temperature difference

Differential connections are assumed for special grade type T thermocouples operated around room temperature. According to **4.4.5**, a 0,4 % uncertainty in the calibration can be assumed.

The resulting effect of instrument linearity, stability, noise immunity and thermocouple accuracy gives a total uncertainty of 0,5 %, see **4.4.5**. The remaining 0,5 % allowed by **2.2.3.1.1** of ISO 8301:1991 to stay within the prescribed limit of 1 % is the result of the uncertainty ΔT_p due to the uncertainty in the definition of the point where the temperature is measured by the sensor. For 20 K temperature difference, 0,5 % gives $\Delta T_p = 0{,}1$ K.

The maximum expected density of heat flow rate q_m at the minimum thermal resistance of 0,1 $m^2 \cdot K/W$ and maximum temperature difference of 20 K is 200 W/m^2.

The maximum allowed uncertainty in the definition of the point where the temperature is measured by a thermocouple junction is one half of the junction diameter, and since two junctions are needed to measure a temperature difference, the total uncertainty is equal to the junction diameter. If the junctions are imbedded either in the apparatus metal plates, or in sheets protecting the heat flow meter, the resulting error in the measurement of the temperature difference is equal to the temperature drop ΔT_p through a layer of thickness d_p as thick as a thermocouple junction diameter and of the same thermal conductivity λ_p as that of the metal plate or protective sheet under the maximum expected density of heat flow rate. The resulting maximum allowed layer thickness is then:

$$d_p = \Delta T_p\ \lambda_p / q_m = 0{,}1\ \lambda_p/200 = 0{,}000\ 5\ \lambda_p$$

For a metal plate having a thermal conductivity $\lambda_p = 100$ W/(m·K), $d_p = 50$ mm, hence thermocouples imbedded in grooves in apparatus metal plates measure the surface temperature correctly. If the protective sheet has a thermal conductivity $\lambda_p = 0{,}2$ W/(m·K), then the maximum value is $d_p = 0{,}1$ mm. This can be achieved by using very thin thermocouples, or by mounting the thermocouple junctions on thin metal plates having a surface of few square centimetres and mounted flush with the protective sheet surface.

C.5 Error in the specimen thickness

This error depends mainly on the finishing of the specimen surfaces and becomes critical with low thickness specimens. If the 0,025 % flatness tolerance indicated in **3.2.2.2.1** of ISO 8301:1991 is accepted, the resulting flatness tolerances in mm are as follows:

Equipment		
A	**B**	**C**
0,08	0,13	0,15

According to **2.2.3.3** of ISO 8301:1991, the error in the measurement of the thickness is limited to 0,5 %, which, applied to the above flatness tolerances, gives the following minimum specimen thickness in mm:

Equipment		
A	**B**	**C**
15	25	30

C.6 Error due to imperfect contact between apparatus and specimen

Contact resistances between specimens and temperature sensors become critical at low specimen thermal resistances and are related to the surface finishing and the method used to measure the temperature difference, see **2.2.3.1** of ISO 8301:1991. It is an important source of error that derates expected heat flow meter apparatus accuracy when testing low resistance specimens.

Considering that the maximum specimen thermal conductivity to be measured is 0,4 W/(m·K), even at the maximum specimen thicknesses (50 mm, 140 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**
0,11	0,31	0,23

Two values are below 0,30 $m^2 \cdot K/W$, i.e. the error due to imperfect contact between apparatus and specimen may 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.8**.

C.7 Accuracy of the calibration

This accuracy can be split in accuracy of the calibration specimen, non-linearity of the calibration as a function of the density of heat flow rate and calibration drifts.

The accuracy of the calibration specimen is not a characteristic of the equipment and is limited by the accuracy of the guarded hot plate used to measure the thermal resistance of the calibration specimen. When a certified reference material is used, its accuracy is guaranteed by a set of comparative measurements among high level laboratories. The Certified Reference Materials developed by the Community Bureau of Reference of the Commission of the European Communities have an accuracy close to 1,5 %. This uncertainty will be used in these calculations.

The maximum acceptable non-linearity of the calibration not requiring a correction is 1 % according to **2.5.3.2** of ISO 8301:1991.

Acceptable calibration drifts not requiring the determination of a new calibration factor are within 1 %.

C.8 Maximum probable error

The maximum probable error in percent is obtained from the individual components calculated in **C.2** to **C.7**:

Edge heat loss error	0,5 %
Error in the temperature difference	1,0 %
Error in the specimen thickness	0,5 %
Error due to imperfect contact	0,5 %
Accuracy of the calibration specimen	1,5 %
Maximum allowed non-linearity of the calibration	1,0 %
Maximum calibration drift	1,0 %

If these errors are summed, the maximum error is 6 %.

If the errors are added in quadrature, the maximum probable error is 2,4 %.

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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