Thermal performance of buildings — Determination of thermal resistance by hot box method using heat flow meter — Masonry

The European Standard EN 1934:1998 has the status of a British Standard

ICS 91.120.10

National foreword

This British Standard is the English language version of EN 1934:1998.

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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Wärmetechnisches Verhalten von Gebäuden — Messung des Wärmedurchlaßwiderstandes Heizkastenverfahren mit dem Wärmestrommesser — Mauerwerk

This European Standard was approved by CEN on 24 January 1998.

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CEN

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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 is one of a package on measurements with hot box apparatus. The basic principles of the method and the guarded and calibrated implementations are described in EN ISO 8990.

In this European Standard the basic principles of the method and the implementation of a heat flow meter in a hot box for measurements on masonry is described, keeping the style and structure as similar as possible to EN ISO 8990:1996. The numbering of clauses in this European Standard follows the clause numbering in EN ISO 8990:1996.

In the same package of European Standards the procedure to test window panes, window frames, complete windows and doors in a hot box are described.

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 September 1998, and conflicting national standards shall be withdrawn at the latest by September 1998.

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

Introduction

Many masonry elements are such that in practice the heat transfer through them is a complex combination of conduction, convection, radiation and mass transfer. The method described in this standard determines the total amount of heat transferred from one side of the specimen to the other for a given temperature difference in defined testing conditions. However, the heat transfer properties often depend on the specimen itself and on the boundary conditions, specimen dimensions, direction of heat transfer, temperatures, temperature differences, air velocities and relative humidity. In consequence the test conditions either replicate those of the intended application or are convertible to them. For ease of intercomparison of results, conventional testing conditions are adopted during the tests. Tested values are the base used in conversion procedures to get the appropriate design values.

The results obtained from a single specimen are not necessarily representative or applicable to all samples of a masonry wall and product standards should be consulted for appropriate sampling.

The design and operation of the heat flow meter hot box is a very complex subject. It is essential that the designer and user of such apparatus has a thorough background knowledge of heat transfer, and has experience of precision measurement techniques.

For a particular specimen it should be decided whether the method is applicable or whether other measurement methods or calculations are more suitable. For homogeneous specimens the guarded hot plate apparatus (see ISO 8302) or the heat flow meter apparatus (see ISO 8301) should be preferred. For specimens not meeting the homogeneity criteria of **6.2.1** of this standard, or with a possibility of convection within internal cavities, the metering section of a heat flow meter might not cover a representative portion of the specimen: for such specimens the use of a guarded or calibrated hot box apparatus of suitable size should be considered (see EN ISO 8990).

1 Scope

This standard establishes the principles and criteria to be complied with for the determination of the laboratory steady-state heat transfer properties of masonry walls in a hot box by means of a heat flow meter mounted on one face of the masonry wall to be tested (i.e. the test specimen). It describes the apparatus, measurement technique and necessary data reporting. It does not, however, specify a particular apparatus design since requirements vary particularly in terms of size, and also to a lesser extent, in terms of operating conditions.

The property that is measured is the surface-to-surface thermal resistance of the specimen, provided that the metering section of the heat flow meter covers a representative portion of the specimen, and the homogeneity criteria of **6.2.1** are met. From these measurements the thermal resistance for application in buildings is derived. The thermal transmittance of a masonry wall can then be calculated from this value with standardized surface coefficients.

This standard is applicable to measurements on both dry and moist specimens, provided that the conditions indicated in **5.3.3** are met. The influence of moisture content on the thermal properties of masonry can be taken into account by measurements at different moisture contents of the specimen in the range of the practical moisture content including the dry state, which corresponds to the most frequent testing condition.

The method is also suitable for horizontal elements such as ceilings and floors.

2 Normative references

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

EN ISO 6946, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method* (ISO 6946:1996).

EN ISO 7345, *Thermal insulation — Physical quantities and definitions* (ISO 7345:1987).

EN ISO 8990:1996, *Thermal insulation — Determination of steady-state thermal transmission properties — Calibrated and guarded hot box* (ISO 8990:1994).

ISO 8301:1991, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus*.

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

3 Definitions, symbols and units

3.1 Definitions

For the purposes of this standard, the definitions in EN ISO 7345 and EN ISO 8990:1996 and the following definitions apply.

3.1.1

mean radiant temperature[1)]

appropriate weighting of the temperatures of surfaces "seen" by the specimen for the purpose of determining the radiant heat flow rate to or from the surface of the specimen

3.1.2

environmental temperature[1)]

appropriate weighting of air and radiant temperatures, for the purpose of determining the heat flow rate to the surface of the specimen

3.1.3

moderately inhomogeneous specimen

specimen which, when tested, meets temperature uniformity criteria as stated in **5.3.2**

3.2 Symbols and units

Symbol	Quantity	Unit
A	area perpendicular to the density of heat flow rate	m^2
R_s	surface thermal resistance	$m^2 \cdot K/W$
R_t	specimen thermal resistance (surface-to-surface)	$m^2 \cdot K/W$
R_T	total thermal resistance (environment to environment)	$m^2 \cdot K/W$
T_a	air temperature	K
T_n	environmental temperature	K
T_r	mean radiant temperature	K
T_s	surface temperature	K
U	thermal transmittance ($1/R_T$)	$W/(m^2 \cdot K)$
d	specimen thickness	m
f	calibration factor of the heat flow meter	$W/(mV \cdot m^2)$
g	guard width	m
h	surface coefficient of heat transfer ($1/R_{si}$ or $1/R_{se}$)	$W/(m^2 \cdot K)$
l	half-side of the metering section	m
p	metering section perimeter	m
q	density of heat flow rate	W/m^2
ΔT_g	temperature difference between metering and guard section	K
Φ_1	heat flow rate through the metering section of the specimen	W
Φ_2	imbalance heat flow rate between guard section and metering section in the specimen	W
Φ_2'	portion of the imbalance heat flow rate Φ_2 credited to the average temperature imbalance ΔT_g	W
Φ_2''	portion of the imbalance heat flow rate Φ_2 credited to temperature non-uniformity on guard section and metering section	W
Φ_5	heat flow rate at the edge of the specimen	W
λ_f	thermal conductivity of the heat flow meter	$W/(m \cdot K)$
λ_s	thermal conductivity of the material of the specimen in contact with the heat flow meter	$W/(m \cdot K)$

Subscripts

For the purposes of this standard, the following subscripts apply,

i	internal, usually hot side
e	external, usually cold side
*	moist specimen

4 Principle of the method

4.1 Principle of the apparatus

The heat flow meter hot box apparatus is intended to reproduce the boundary conditions of a specimen in steady state conditions between two environments, each at uniform temperature. A specimen is then placed between a hot and a cold chamber in which environmental temperatures are imposed. Heat exchanged at the surfaces of the test specimen involves both convective and radiative contributions. The former depends upon air temperatures and air velocity, and the latter depends upon the temperatures and the total hemispherical emissivities of the specimen surfaces and of surfaces "seen" by the test specimen surfaces. The effect of the heat transfer by convection and radiation are conventionally combined in the concept of an "environmental temperature" and a surface heat transfer coefficient.

For this method it is important to limit non-uniformities of temperature on the surface of the specimen and it is not necessary to reproduce exactly end use surface coefficients of heat transfer and environmental temperatures.

1) For more information see EN ISO 8990:1996, annex A.

4.2 Determination of the density of heat flow rate

On the hot side of the specimen a heat flow meter is mounted to measure the density of heat flow rate, q, passing through the specimen and crossing a surface, of area A, located at its centre, see Figure 1. Over this surface, called hereafter the metering section, it is necessary that the density of heat flow rate is sufficiently uniform. The metering section is also the active or sensing part of the heat flow meter.

In order to provide a uniform thermal resistance between the specimen surface and the hot side environment, a sheet of material is placed on the surface of the specimen not covered by the heat flow meter. The sheet should have a thermal resistance and thickness equal to that of the heat flow meter.

NOTE Some heat flow meters have the sensing elements distributed all over their surface, so that the heat flow meter active or sensing section is equal to the metering section of the specimen and the sheet section is equal to the guard section. Other heat flow meters have the sensing elements distributed only in a central section; that corresponds to the metering section of the specimen and is smaller than the total heat flow meter section.

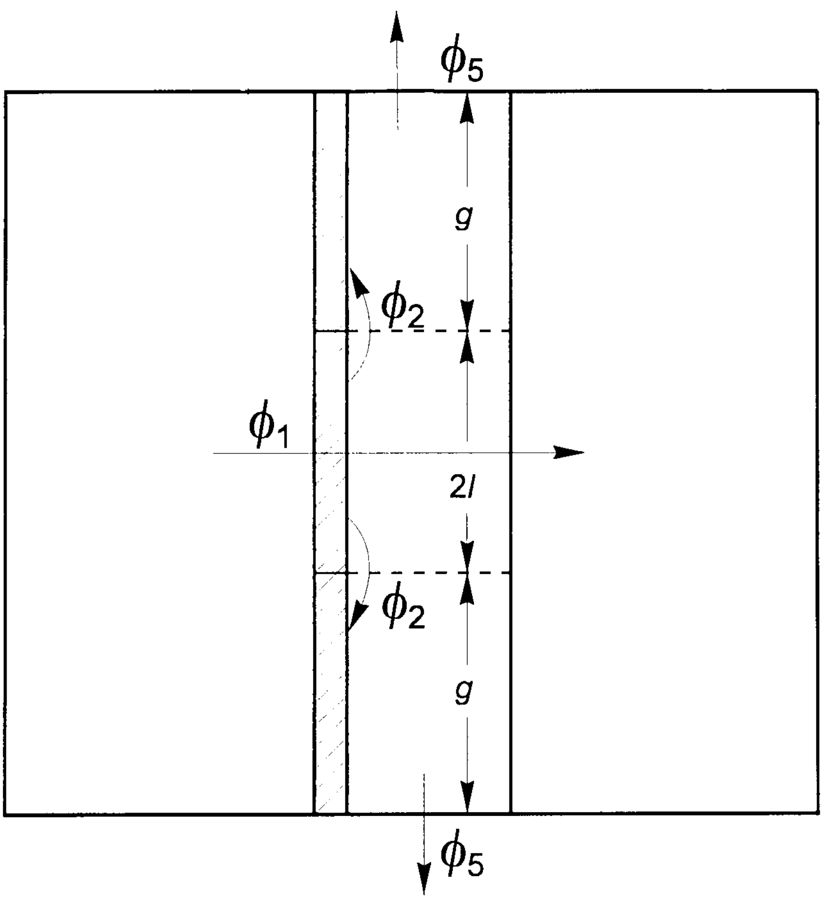
4.3 Determination of the surface-to-surface thermal resistance of the specimen

Steady-state measurements are made of surface temperatures and of the density of heat flow rate through the specimen. From these measurements the surface-to-surface thermal resistance of the specimen is calculated.

4.4 Guarding and guard section

The surface of the specimen surrounding the metering section is called hereafter “guard section”. To ensure a uniform density of heat flow rate in the metering section, the guard section shall be held as close as possible to the same temperature as the metering section, so that the lateral heat flow rate Φ_2 from the metering section to the guard section through the specimen is nearly zero, see Figure 1.

The guard section shall be large enough to ensure that the edge heat loss error Φ_5 is low. The use of insulation on the edge of the specimen helps in reducing edge heat loss errors, hence it may be used to increase the maximum allowed specimen thickness for the apparatus.



NOTE Heat flows at a rate Φ_1 through the metering area $A = (2l)^2$; in the metering area the density of heat flow rate, q, is expected to be uniform; Φ_2 is an imbalance heat flow rate parallel to the specimen; Φ_5 is the transverse heat flow rate at the edge of the specimen; g is the guard width.

Figure 1 — Principle of a heat flow meter hot box apparatus

5 Limitations and sources of errors

5.1 General

The operation of the apparatus, to a certain desired accuracy, is limited by a number of factors related to equipment design, calibration and operation and specimen properties, e.g. thickness, thermal resistance and homogeneity.

5.2 Limitations and errors due to apparatus

5.2.1 *Limitations due to lateral heat flow rate*

To keep the lateral heat flow rate Φ_2, equal to zero, even when testing homogeneous specimens, the hot and cold surfaces of the specimen should be kept at uniform temperatures; this in turn requires that environmental temperatures and local surface heat transfer coefficients be uniform both on the hot and on the cold side of the specimen. These requirements are always met with a certain approximation even with an adequate air flow on both surfaces of the specimen and correct choice of apparatus size and design. Consequently there is usually a temperature difference between the average temperatures of the metering and guard portion of the hot side surface of the specimen. Additionally, this temperature difference, due to the mentioned non-uniformities, is known with a level of uncertainty, so that, in practice, it is almost impossible to reduce to zero the lateral heat flow rate Φ_2. Furthermore, specimens tested in a heat flow meter hot box are not homogeneous (otherwise they could be tested with better accuracy in a guarded hot plate apparatus). To keep imbalance errors within acceptable limits when testing a wall made of elements (bricks, blocks), the heat flow meter should cover an integral number of wall elements.

The error due to the heat flow rate Φ_2 in the specimen due to imbalance between the metering and guard sections, is proportional to the perimeter of the metering section. The relative influence of this diminishes as the metering area is increased. This fact shall be compared with the increment of edge heat losses while reducing the guard width, see **5.2.2**.

Table 1 — Minimum and maximum allowed specimen thickness

Dimensions in millimetres

Overall size	Metering section width	Guard width	Max. specimen thickness (no edge insulation)	Max. specimen thickness (with edge insulation)
800	500	150	115	260
1 000	500	250	175	315
1 250	500	375	245	380
1 500	500	500	315	450
2 000	500	750	450	580

5.2.2 *Size of metering section and edge heat loss error*

The size of the metering section determines the maximum thickness of the specimen that can be tested in a given apparatus while keeping the error due to edge heat losses within acceptable limits (1 % for this standard test method). Assuming the worst case condition of no insulation at the edge of the specimen, kept at the same temperature as the hot surface, the maximum specimen thicknesses shall not exceed the values of the fourth column in Table 1.

NOTE The ratios specimen-side/specimen-thickness and guard-width/specimen-thickness are governed by the same principles as for the guarded hot plate, see ISO 8302:1991, **2.2.1** and **2.3.2** on which Table 1 is based for a hot box with a 500 mm × 500 mm heat flow meter.

Typical arrangements of heat flow meter hot box apparatus include edge insulation, see Figure 2. If at least 100 mm of edge insulation is added with a thermal conductivity of at least five times lower than that of the specimen, and if the edge of the insulation not in contact with the specimen is kept at the temperature of the hot surface of the specimen, the maximum specimen thickness shall not exceed the values of the fifth column in Table 1. The error due to edge heat losses remains 1 % if all the dimensions in one line of Table 1, together with the thickness of edge insulation (when used), are multiplied by the same factor, e.g. a hot box with no edge insulation, an overall size of 3 000 mm, and a heat flow meter of 1 000 mm × 1 000 mm can test specimens up to 630 mm, see the fourth line in Table 1.

To allow a meaningful interpretation of measurement results, the size of the metering section shall be large enough to cover a representative portion of a specimen incorporating random irregularities or shall cover an integral number of regularly occurring inhomogeneities. As a consequence the metering section and hence the appropriate heat flow meter have to be chosen according to the type of test walls (size of blocks, influence of mortar layers, symmetry etc.).

5.2.3 *Surface coefficients of heat transfer, contact thermal resistances between the specimen and the heat flow meter*

Any non-uniformity in surface coefficients of heat transfer, or in the contact resistances between the specimen and heat flow meter is a source of non-uniform temperatures on the surface of the specimen. The thermal resistance of the specimen shall be large compared with non-uniformities of surface and contact resistances, and in no case less than 0,5 $m^2 \cdot K/W$.

5.3 Limitations and errors due to specimen

5.3.1 ***Specimen thickness***

Depending upon specimen properties and boundary conditions at its edges an upper limit for the specimen thickness is governed by edge heat losses Φ_5. Another limit related to the specimen thickness is the maximum specimen thermal resistance that can be tested with acceptable accuracy. This thermal resistance, together with the minimum temperature difference through the specimen, defines the minimum density of heat flow rate to be measured by the heat flow meter. This last parameter is limited by the characteristics of the heat flow meter and by the instrumentation used.

5.3.2 ***Specimen inhomogeneity***

Most test specimens of masonry will be inhomogeneous. Inhomogeneities in the test specimen will affect the pattern of the density of heat flow rate in such a manner that it is neither one-dimensional nor uniform. The effects of these are increased non-uniformities in temperatures and local transfer coefficients making the following more difficult or even impossible:

— the definition of a mean surface temperature;

— the detection of imbalance between metering and guard sections;

— the definition of the metering section;

— the error analysis of test results for a given specimen.

For the purpose of this standard, inhomogeneities in the test specimen shall not create by themselves [i.e. when non-uniformities in surface coefficients and environmental temperatures, see paragraph ii) in **6.2.1**c), are negligible] temperature non-uniformities on the surface in contact with the heat flow meter, that will create an imbalance heat flow rate Φ_2'' larger than 2 % of the heat flow rate Φ_1 through the specimen, see **6.2.1**c). Such specimens have been defined "moderately inhomogeneous" in **3.1**.

It is not possible to provide immediate solutions to all types of problems; for multilayered products special considerations are needed. The operator is advised to be fully aware of the effects of anomalies.

NOTE See also the bibliography in annex B.

Calculations of the importance and effect of inhomogeneities are of great help in predicting the thermal performance of the test specimen. If significant differences exist between its predicted and measured performance which cannot be explained, as a minimum where such divergences exists, a careful inspection of the specimen should be performed to identify any difference between the specified sizes, dimensions, materials etc. and those actually found in the tested specimen. Any differences or irregularities from the original specification shall be reported.

5.3.3 ***Moisture content in the specimen***

Moisture transfer during the test may have a significant effect on the test results. To deal with the moisture, ideally one of the following conditions shall be fulfilled.

1) The test specimen shall be dry and kept dry during the test.

2) The test shall be carried out under moisture equilibrium, which means that no redistribution of moisture within the specimen and no moisture exchange at the specimen surfaces takes place. The test specimen has consequently to be conditioned to moisture equilibrium with those temperature and moisture conditions foreseen at the hot box measurement.

3) The test shall be carried out on a specimen with an arbitrary moisture content, but so that effects of moisture transfer and phase changes are negligible.

The effects of moisture transfer and phase changes are limited by the adoption of an adequate conditioning procedure (see **8.2**), a maximum permissible moisture content below equilibrium with a relative humidity of 95 % and a maximum measurement duration of 120 h.

5.4 Accuracy

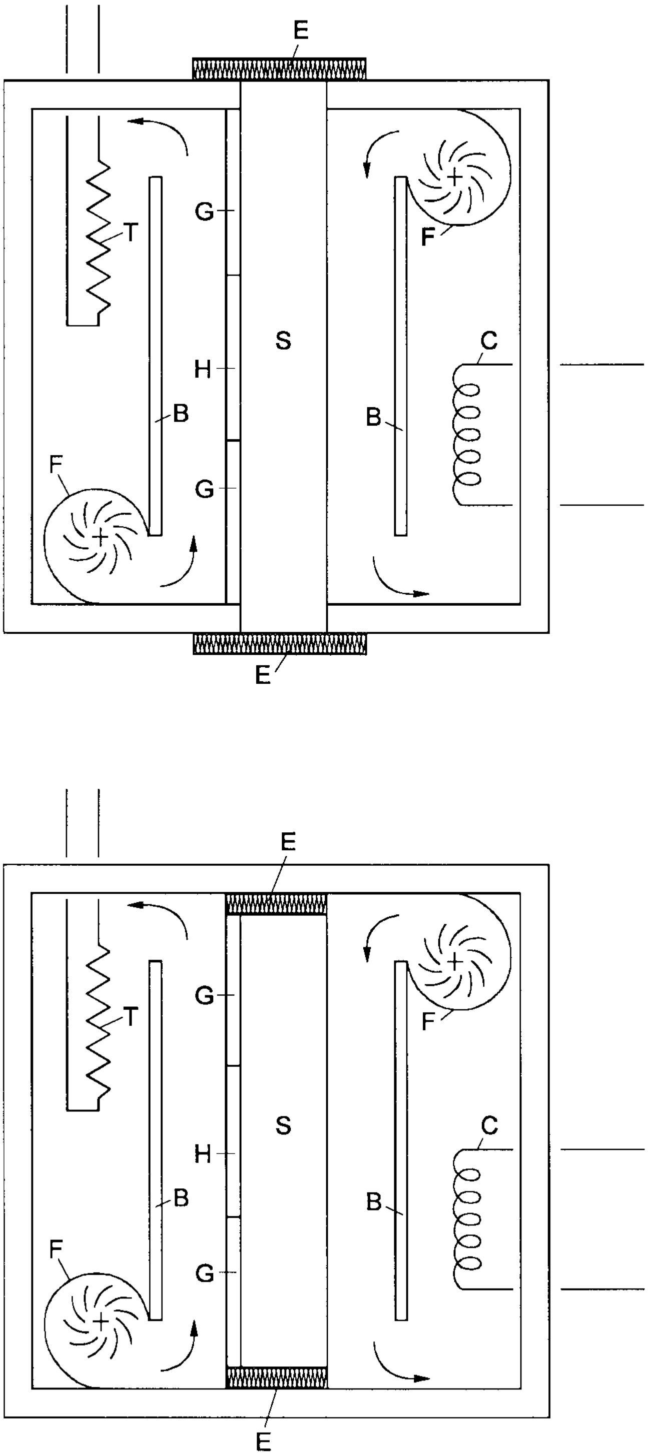
When homogeneous and dry specimens are tested according to this standard the estimated accuracy has been shown by experience to lie within ±5 %. Homogeneous specimens are necessary for the validation of the apparatus and the only available error analysis is for homogeneous specimens. The accuracy of an individual apparatus shall be estimated after careful consideration of this standard. The larger the inhomogeneity in the specimen the more complex becomes the prediction of the testing accuracy. For homogeneous and moderately inhomogeneous masonry walls an elementary estimation of the testing accuracy is given in clause **9**.

6 Apparatus design

6.1 General

As stated in clause **5**, it is impractical to impose specific design details for an apparatus. However, clauses **6** and **7** give requirements and the aspects to be considered.

Figure 2 shows typical arrangements of the test specimen and major elements of the apparatus. The heat transfer through the specimen is affected by the interaction between the hot box wall (shape, emissivity and thermal resistance), the air flow distribution and the specimen itself (in particular its thickness, thermal resistance and temperature difference). In general the apparatus design and construction shall be made considering the expected types of specimens to be tested and the expected testing conditions.



B	baffle	G	guard sheet
C	cooling coil	H	heat flow meter
E	edge insulation	S	specimen
F	fan	T	is the electric heater

Figure 2 — Typical arrangements of the heat flow meter hot box apparatus

6.2 Design requirements

6.2.1 *Apparatus size related to imbalance and edge heat losses*

The apparatus shall be sized according to the intended use, considering the minimum and maximum thermal resistance of the specimens to be tested, the maximum thickness of the specimen to be tested and the size of the modules (bricks, blocks, etc.) for modular specimens. Considering these parameters, the following requirements shall be fulfilled.

a) The metering section shall correspond to a representative area of the specimen. For specimens incorporating random irregularities (e.g. gravel in concrete walls) the side of the metering section shall be at least 20 times the maximum expected irregularity. For modular components the metering section should preferably span exactly an integral number of modules.

b) The error due to edge heat flow rate Φ_5 shall not exceed 1 % of Φ_1.

NOTE 1 As a starting design guideline, the side of the metering section and the guard width should be at least 1,6 times the maximum specimen thickness, see the fourth line of Table 1. The maximum specimen thickness for a given apparatus can be increased by the use of edge insulation (see Table 1) and/or a tight control of the edge environment. For more guidance see ISO 8302:1991, **2.2** and annex B of prEN 1946-2:1995, *Building products and components — Specific criteria for the assessment of laboratories performing heat transfer property measurements — Part 2: Measurements by the guarded hot plate method.*

c) The imbalance heat flow rate Φ_2 in a heat flow meter hot box shall be less than 4 % of the heat flow rate Φ_1 passing through the specimen in the metering section. Φ_2 is mainly due to temperature non-uniformities of the surface of the specimen in contact with the heat flow meter due to non-uniformities both in the surface coefficients of heat transfer and in environmental temperatures related to the region close to the periphery of the metering section.

NOTE 2 It is essential to ensure uniform velocities and temperatures of the air flow in contact with the surface of the specimen or heat flow meter mounted on it. At the same time it is necessary to ensure uniform temperatures of the walls of the apparatus "seen" from the specimen or heat flow meter in order to have uniform heat transfer by radiation. These concepts are also applicable to the cold side of the apparatus.

The above non-uniformities have two effects:

i) the average temperature of the surface of the specimen in the metering section and the average temperature of the surface of the specimen in the guard section are not equal;

ii) there is an uncertainty in measuring the average surface temperature in each of the sections.

Of the 4 % imbalance error, 2 %, called Φ_2', is credited to the average temperature imbalance between the metering and guard section, see paragraph i) above, and the remaining 2 %, called Φ_2'', is credited to the temperature non-uniformity within both the guard and the metering section, see paragraph ii) above.

The portion Φ_2' of Φ_2, credited to the average temperature imbalance ΔT_g between the metering and guard section, see paragraph i) above, may be estimated by equation (1):

$$\Phi_2' = (\lambda_f + \lambda_s)\, p \Delta T_g / 2 \quad (1)$$

NOTE 3 Equation (1) is based on the concept of imbalance error described in ISO 8302:1991, **2.2.1**.

The imbalance temperature difference ΔT_g on the surface of the specimen in contact with the heat flow meter is evaluated as the difference between the average of the temperatures measured by the temperature sensors in the metering section and the average of the temperatures measured by the temperature sensors in the guard section between the edge of the metering section and one half of the guard width. For a multilayered specimen of total thickness d, i layers are counted, starting from the specimen layer in contact with the heat flow meter, up to the layer whose thickness, summed to those of the other layers, exceeds 100 mm. Then, in equation (1) it is $\lambda_s = \Sigma(\lambda_i d_i)/\ \Sigma d_i$, where d_i and λ_i are the thickness and thermal conductivity of layer i. Equation (1) shows that imbalance may be critical for a layered specimen having a high conductivity layer, e.g. a facing, and a core of low conductivity that keeps Φ_1 small in the metering section. According to equation (1), the imbalance error Φ_2'/Φ_1 is proportional, for homogeneous and moderately inhomogeneous specimens, to the ratio between the specimen thickness and side of the metering section and to the maximum temperature non-uniformity divided by the temperature difference through the specimen.

Equation (1) can also be used to evaluate the portion Φ_2'' of Φ_2 credited to temperature non-uniformities in the guard and metering section, see paragraph ii) above. ΔT_g shall then be assumed as 1/4 of the maximum temperature difference measured in either the metering section or the portion of the guard section described in the preceding paragraph.

NOTE 4 The presence of inhomogeneities in the specimen further increases the temperature non-uniformity on the surface of the specimen. The foregoing criterion for the non-uniformity of surface temperatures of the specimen has also been used in **5.3.2** to assess the maximum allowed inhomogeneity of the specimen: an imbalance heat flow rate Φ_2'' corresponding to the impossibility of getting an exact balance with inhomogeneous specimens is evaluated and the corresponding imbalance error Φ_2''/Φ_1 is computed.

The actual value of surface coefficients of heat transfer affects heat transfer within inhomogeneous specimens and hence surface temperature non-uniformities, but the limitations described above are such that it is not mandatory to exactly replicate surface coefficients of heat transfer in the real use of the specimen.

d) The size of the cold-side chamber shall be the same as that of the hot-side chamber, see Figure 1.

e) The walls of the hot-side and the cold-side chambers should be so constructed as to avoid a large load on the heating and refrigerating equipment and to prevent moisture condensation on the cold side.

6.2.2 ***Heat flow meter***

The heat flow meter is a transducer giving an electrical signal which is a direct function of the density of heat flow rate transmitted through it. Heat flow meters are thermally resistive plates with temperature sensors arranged in such a way that the electrical signal given by the sensors is directly related to the density of heat flow rate through the plate (see Figure 3). The heat flow meter can also have facing sheets to provide protection. The area of the measuring section (active part) of the heat flow meter is often smaller than the total area of the heat flow meter.

NOTE For more details about the perturbations caused by the heat flow meter see the bibliography in annex B and see annex D of ISO 9869:1994, *Thermal insulation — Building elements — In-situ measurement of thermal resistance and thermal transmittance.*

The following requirements have to be considered. The heat flow meter should have a thermal resistance such that the total thermal resistance from the specimen surface to the environment should correspond to the end use surface thermal resistance within 30 %. The sensitivity of the heat flow meter shall be sufficient (i.e. the resulting signal shall be large enough) to provide an error less than 0,5 % in reading the electromotive force for the lowest density of heat flow rate measured. The heat flow meter signal shall be a monotonic function of the density of heat flow rate. The dependence of this signal on the thermal conductivity of the material on which the heat flow meter is installed, on the temperature of the heat flow meter or on other physical quantities such as stresses, electromagnetic fields etc., shall be taken into account (see heat flow meter calibration procedure in annex A).

6.2.3 ***Heat supply, refrigeration and air circulation, apparatus surface emissivities***

Heat supply, refrigeration and air circulation shall be designed to give uniform air temperature distribution parallel to the specimen surface and acceptable air temperature gradients along the air flow direction.

The emissivity of surfaces of the apparatus (on both the hot and cold sides) which have radiative exchange with the specimen surfaces can be either high or low. High emissivity, 0,8 or greater, will in most cases be typical of actual use of building and industrial components.

Variations in air temperature across the air flow parallel to the specimen surface and air temperature gradients along the air flow shall be such that, considering the local values of surface heat transfer coefficients and radiation heat exchanged with the box walls, the criteria for the temperature uniformity on the specimen or heat flow meter surface fixed in **6.2.1** are met.

In the hot side chamber, electric resistance heaters are normally the most suitable heat sources. Also for fine tuning of the cold side temperature, electric resistance heaters in the outlet from the evaporator are often useful. They shall be shielded by insulated reflective shields so as to minimize non-uniform heat transfer by radiation on the specimen or heat flow meter surfaces, see also the preceding paragraph.

In the heat flow meter hot box apparatus, forced convection shall be used on both the hot and cold sides. Best results are expected when on both sides nearly the same surface coefficients of heat transfer are obtained and the air flow is in opposite directions. A baffle shall be positioned parallel to the surface of the specimen. The baffle may be moveable, perpendicular to its surface, to aid adjustment of the air velocity parallel to the surface of the specimen. As an example, a distance of 0,04 m from the specimen surface may be suitable for an air velocity of 2 m/s.

The baffle on the hot side acts also as radiation shield between the heater and the specimen, hence low emissivity on the side towards the heater could be preferred. With regard to the side of the baffle towards the specimen, the above considerations on apparatus emissivity also apply to this baffle surface.

6.3 Temperature measurements

6.3.1 ***General***

The sensors for the measurement of the air temperature and the surface temperature of the specimen shall be evenly spaced over the specimen surface and located opposite each other on the hot and cold sides.

Surface temperatures of the equipment "seen" by the specimen shall be investigated to calculate the mean radiant temperature and its non-uniformities, see c) of **6.2.1**.

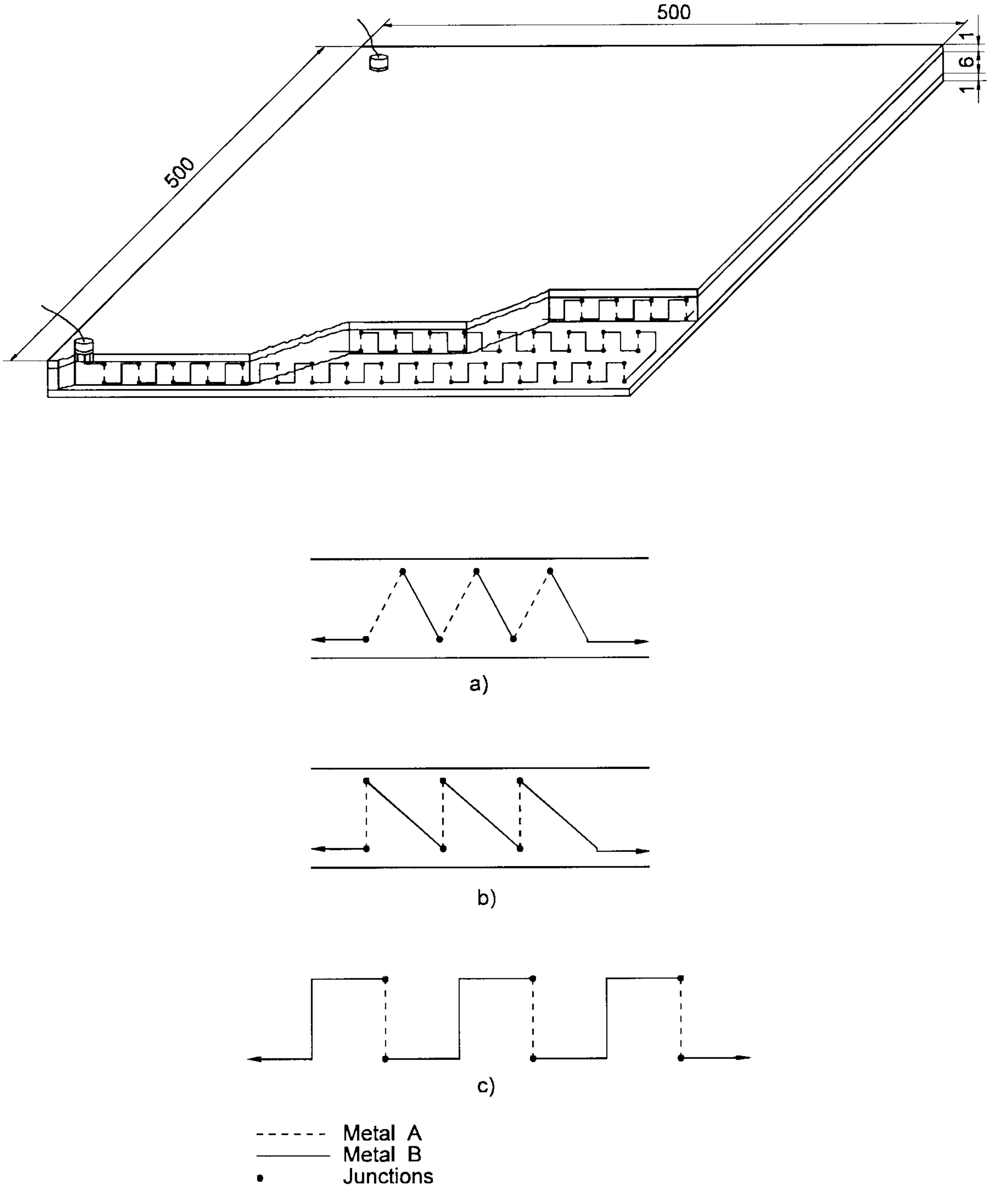
Air and surface temperature differences over the specimen can be determined by differential measurements to improve accuracy.

6.3.2 ***Specimen surface temperature measurement***

The temperature sensors mounted on the specimen surface shall be distributed in a way which allows a satisfactory determination of the average temperature of the metering and guard section to be made and the temperature uniformity requirements of **6.2.1** to be verified.

The criteria outlined in **6.2.1** to assess the non-uniformity of surface temperatures of the specimen shall also be applied to assess the maximum allowed inhomogeneity of the specimen.

The number of sensors required for the surface temperature measurement shall be not less than nine in the metering section and 12 in the guard section. These numbers shall be increased when inhomogeneities exist in the specimen. Care shall be taken to identify the positions at which the maximum expected temperature non-uniformities for modular specimens are likely to occur, e.g. mortar joints and centre of the bricks or blocks. The mean surface temperature of each region shall then be weighted proportionally to the area of that region to obtain the mean surface temperature of the metering and guard section in accordance with **6.2.1**.



Dimensions in millimetres

NOTE At the top an example of a heat flow meter made of rubber sheets; there are 252 pairs of junctions; the thermal resistance is 0,035 $m^2 \cdot K/W$; the total thickness is 8 mm. At the bottom some layouts of thermopiles. Thermopile a) is sensitive to temperature differences both perpendicular and longitudinal to the heat flow meter; thermopiles b) and c) are only sensitive to temperature differences perpendicular to the heat flow meter and hence should be preferred.

Figure 3 — The heat flow meter

These measurements shall be made with sensors chosen and applied to the surface in such a way that the sensors do not change the temperature at the measuring point. This requirement can be met by using thermocouples of wire diameter not more than 0,25 mm, with their junctions and at least 100 mm of adjoining wire in thermal contact with the surface, along the most isothermal path, and attached with cement or tape of emissivity close to that of the surface.

The surface temperature sensors between the heat flow meter and the specimen shall be mounted in such a way that there are no air pockets between the heat flow meter and the specimen surface, and that deformations of the heat flow meter are avoided. This can be accomplished by fixing the temperature sensors to small metal plates (e.g. 400 mm^2), which are cemented to the specimen, sensor side down, with the plate flush with the surface of the specimen. The wires of the sensor shall be cemented into grooves on the specimen surface to ensure accurate temperature measurements.

6.3.3 ***Air temperature measurement***

The air temperature sensors shall be distributed in a way which allows the air temperature uniformity requirements of **6.2.3** to be verified satisfactorily.

The number of sensors for air temperature measurement shall be at least two per square metre and not less than nine in total.

Air temperatures shall be measured with a system having a suitable time constant. Air temperature sensors shall be radiation-shielded, unless it is shown that the difference between shielded and unshielded ones is so small that the accuracy requirements are met.

Fully-developed turbulent air flow shall exist between the specimen and the baffle, and sensors shall be placed so as to detect bulk air temperatures (temperature of adiabatic mixing).

6.3.4 ***Temperature control***

At steady-state, the controllers shall keep any random temperature fluctuations of the air within ±2 % of the air-to-air temperature difference, and so that the induced fluctuations on the reading of the heat flow meter are less than 2 % of its steady state output. The maximum long-term drifts shall not exceed 1 % of the temperature difference through the specimen.

6.4 Instrumentation

The determination of temperature differences shall be made with an accuracy of ±1 % of the air-to-air temperature difference. This accuracy includes the calibration accuracy of the temperature sensor. The instrumentation shall not add an uncertainty greater than 0,05 K. The error due to the incorrect position of the temperature sensor shall be restricted to 2 % of the temperature difference through the specimen. The measurement of absolute temperatures shall be made with an accuracy of ±2 % of the air-to-air temperature difference. This accuracy includes the calibration accuracy of the temperature sensor.

The output from the heat flow meter thermopile shall be measured with such accuracy that the error in the measurement of the specimen heat flow rate, Φ_1, due to instrumentation accuracy is less than 0,5 %.

The mean heat flow meter temperature shall be determined with an accuracy such that the effect on the calibration factor, f, is less than 0,1 %.

Some relevant temperatures and the density of heat flow rate shall be recorded or plotted in order to establish that steady-state conditions have been reached.

In the case of a moist specimen, additional sensors for measuring the relative humidity of the air or the moisture content of the specimen may be used.

7 Performance evaluation and calibration

7.1 Initial performance check

After completion of the construction, an initial check of performance shall be made, to ensure that design requirements are fulfilled. This is done with homogeneous specimens of known thermal resistance covering the anticipated range of the thermal resistance.

This initial check should cover the uniformity and stability of the temperatures and the air flow for both hot and cold sides and the effect on accuracy of imbalance between metering and guard sections and of the environment adjacent to the edge of the specimen.

7.2 Complementary measurements

The thermal conductivity of materials used in the construction of the equipment can be measured by guarded hot plate or similar methods. Infrared scanning systems can be used to locate thermal bridges and air leakages as well as to find suitable locations for surface temperature measuring points. After construction of the air circulation system, a velocity scan should be performed across the air-flow boundary layer to verify that a uniform air curtain has been formed.

7.3 Calibration

7.3.1 ***Heat flow meter calibration procedure***

The calibration procedure for heat flow meters shall be carried out in accordance with annex A.

7.3.2 ***Verification specimen***

The performance of the equipment shall be verified using homogeneous specimens of known thermal resistance covering the intended thermal resistance range of use. Such specimens can be made from panels of high-density mineral wool or aged cellular plastics, which have been measured in the guarded hot plate apparatus. The joints between the panels shall not form thermal bridges. The specimens shall be faced on both sides with a facing impervious to air and moisture transfer.

8 Test procedure

8.1 Applicability of the method

The applicability of the method to a particular specimen should be assessed, see also the introduction.

Layered specimens with highly conducting facings and a core material of low thermal conductivity may induce a lateral heat flow larger than permitted by **6.2.1**, hence measurements of the individual layers and subsequent calculations on the whole structure may be necessary.

Simplified calculations are also a suitable means to assess measured values and related accuracy.

8.2 Conditioning of the specimen

Specimens shall be stored for a sufficient period of time to achieve an even moisture distribution within them. Three conditioning alternatives apply.

a) Dry specimen: as a general rule, drying shall be done at 105 °C until constant mass is reached. For specimens containing materials susceptible to property changes at this temperature, the drying should be at 70 °C (e.g. polystyrene plastic foams) or at 40 °C (e.g. materials containing gypsum). The specimen shall then be allowed to cool before starting the test. To keep the specimen dry it may be necessary to enclose the specimen in a vapour-tight envelope.

b) Conditioning under a temperature gradient: the test specimen shall be conditioned at the same boundary conditions (temperature and relative humidity) as those foreseen for the hot box test. The conditioning shall continue until moisture equilibrium is reached.

c) Conditioning to a specified moisture content: the test specimen shall be conditioned at (23 ± 2) °C and a certain relative humidity (not exceeding 95 %, in order to stay in the hygroscopic range), until constant mass is reached. After conditioning, it may be necessary to enclose the test specimen in a vapour-tight envelope.

For measurements on masonry walls in a moist condition, according to options b) and c) of this subclause, the range of moisture content of the specimens should correspond to the practical moisture content or at least not exceed this value by more than 3 % by volume.

To keep the influence of moisture redistribution during the test within acceptable limits, the duration of the measurements shall be kept as short as possible, i.e. testing should be finished as soon as the thermal steady-state condition is reached.

The mass of the specimen before and after the test shall be reported, or core samples shall be taken before and after the test.

The dry bulk densities of all building materials are to be determined. The size and bulk density of masonry have to be examined in accordance with the relevant product standard. For masonry mortar, the dry bulk density shall be measured; for light masonry material both the bulk density and mortar density shall be measured. The bulk density of concrete and similar materials shall be examined in accordance with the respective product standards. Aggregates and their mixing ratio and grain size distribution shall be measured. For loose fill insulation materials, the bulk density in the dry state and, if possible, grain size distribution are to be determined in accordance with respective product standards.

8.3 Specimen selection and mounting

The test specimen shall be selected or constructed in such a way that it is representative and according to common practice; areas likely to have different surface temperatures should be included in the metering section in a representative way. For specimens of this type, the local density of heat flow rate can be estimated by preliminary additional measurements before the installation of the heat flow meter. For this purpose small size heat flow meters can be used whose thermal resistances do not significantly alter the local density of heat flow rate (thickness: less than 1 mm) and whose areas correspond to the influence areas of the thermal bridges. Also thermographic inspections can help in evaluating inhomogeneities. Specimens not meeting the homogeneity criteria defined in **5.3.2**, see also **6.2.1** and **6.3.2**, shall be tested according to another method or calculations shall be undertaken.

If the specimen is modular, the metering section should be an integral multiple of the module. The edge of the metering section should either coincide with the module lines or be midway between module lines.

Specimens should be tested without plaster. Air flow through the specimen shall be avoided by sealing the surfaces.

To ensure perfect contact with the heat flow meter and guard section cover sheet, specimens with coarse-pored or uneven surfaces have to be smoothed with plaster or other suitable material, having the minimum thickness necessary to achieve flatness.

The specimen shall be mounted or sealed in such a way that neither air nor moisture will gain ingress into the specimen from the edges or pass from the hot side to the cold side or vice versa.

It is necessary to control the dew-point of the air on the hot side, to ensure that in the selected testing condition no condensation will take place on the hot side of the specimen.

It should be considered whether continuous cavities in the specimen require barriers at the periphery of the metering section, and whether high conductivity facings should be cut at the perimeter of the metering section.

Surface temperature sensors shall be mounted in such a way that there is no air pocket between the sensor and the specimen surface. The sensors have to be mounted such as to avoid heat flow rates to or from the metering section.

The emissivities of sensors and specimen surfaces should be equal.

Surface temperature sensors between the heat flow meter (and guard section sheet) and the specimen shall be mounted as indicated in **6.3.2**.

The heat flow meter and the guard sheet shall be glued to the hot side surface of the specimen or shall be installed with a two sided adhesive foil, avoiding the formation of any air pocket. The glue shall be a thin layer not adding a significant thermal resistance, shall not penetrate deeply into the specimen, shall avoid the presence of any air pocket between the specimen and the heat flow meter and shall allow the disassembling of the heat flow meter without causing severe stresses to it that could cause a change in the heat flow meter calibration characteristics.

In general, test specimens are in a vertical position. If results can be influenced by convection (for specimens with hollow cores), tests shall be conducted in the position that corresponds to the practical end use application.

8.4 Measurement

8.4.1 *Test conditions*

Test conditions shall be chosen to suit the product standard requirements or specific end use applications, having in mind the effect of testing conditions on accuracy. Both mean test temperature and temperature differences affect the test results.

NOTE Mean temperatures of 10 °C to 20 °C and a difference of at least 20 K are common in building applications.

The moisture content of the specimen during the measuring period is determined by recording its mass before and after measurement and in the dry state after the test has been completed. The specimen can also be broken down into its constituents, and the individual building materials can be dried at their allowed maximum temperatures.

8.4.2 *Measurement period*

The required time to reach stability for steady-state tests depends upon such factors as thermal resistance and thermal capacity of the specimen, surface coefficient of heat transfer, presence of mass transfer and/or moisture redistribution within the specimen, type and the performance of automatic controllers associated with the apparatus. Due to variation of these factors, it is impossible to give a single criterion for steady-state.

To ensure that steady-state conditions have been reached, measurements of some relevant temperatures and the density of heat flow rate shall be plotted versus time to detect any monotonic variation.

8.4.3 *Calculations*

This test method allows the measurement of the specimen surface-to-surface thermal resistance, R_t.

$$R_t = (T_{si} - T_{se})/q \quad (2)$$

From this measured quantity and the surface resistances according to EN ISO 6946 the heat transfer properties are calculated according to the following equations:

$$R_T = R_{si} + R_t + R_{se} \quad (3)$$

$$U = 1/R_T \quad (4)$$

If the surface-to-surface thermal resistance R_t of a masonry test specimen is determined according to this standard for at least three levels of moisture content, a value R_{t*} of the surface-to-surface thermal resistance for each defined practical moisture content (moisture condition under national service conditions) and a moisture factor describing the influence of moisture content on the thermal properties of the tested material, can be derived.

9 Accuracy and reproducibility

Errors to be considered are the following:

Error	Maximum allowed value	See subclause
Edge heat loss error	1 %	**5.2.2**
Error due to imbalance heat flow rate	2 %	**6.2.1**
Uncertainty in imbalance heat flow rate	2 %	**6.2.1**
Added uncertainty in imbalance heat flow (for inhomogeneous specimens)	2 %	**5.3.2**
Accuracy in the reading of the heat flow meter output	0,5 %	**6.2.2**
Calibration accuracy of the heat flow meter	2 %	**A.1**
Calibration accuracy of temperature sensors	1 %	**6.4**
Accuracy in the reading of temperature sensors	0,05 K	**6.4**
Accuracy in the position of temperature sensor	2 %	**6.4**
Uncertainty in surface temperature (for homogeneous specimens)		**6.2.1**
Added uncertainty in surface temperature (for inhomogeneous specimens)		**5.3.2**

Error assessment is only possible for a given apparatus when details of the specimen to be tested are also defined. The maximum possible error is the sum of the above errors, but most probably the actual error is less than the square root of the sum of the square of the above errors. An accurate error analysis should be based on the error propagation method.

NOTE Typical additional systematic errors for masonry, due to moisture effects (and similar types of specimen) and the different conditioning alternatives, see **8.2**, are:

1) Dry specimen

— vapour-tight envelope:	no error	
— no vapour-tight envelope:	error	1 %

2) Conditioning under a temperature gradient (specimen in equilibrium with boundary conditions)

— the presence or not of a vapour-tight envelope is irrelevant	no error due to non-uniform moisture distribution

3a) Conditioning to a moisture content in equilibrium with relative humidity up to 80 %

— vapour-tight envelope	error	2 %
— no vapour-tight envelope	error	3 %

3b) Conditioning to a moisture content in equilibrium with relative humidity up to 95 %

— vapour-tight envelope	error	4 %
— no vapour-tight envelope	error	6 %

10 Test report

The test report shall include the following information:

a) reference to this standard and a statement of compliance which lists any deviations from this standard;

b) identification of the test laboratory with address, the date of test and the organization commissioning the test, if appropriate;

c) information on the test equipment, dimension and range of emissivities of internal surfaces;

d) identification and detailed description of the test specimen (manufacturer, dimensions, mass, bulk density and, if applicable, compressive strength, grain size distribution and mixing ratio);

e) location of sensors on the test specimen;

f) conditioning procedure for specimen and its timing (e.g. drying temperature, time maintained at this temperature, cooling time), mass before and after test, moisture content and procedure to determine it;

g) specimen orientation and direction of heat transfer during the heat flow meter hot box measurement;

h) average air velocity and direction on the hot and cold sides;

j) measured data: air temperatures and mean temperature of the specimen, surface temperatures, weighted surface temperatures on the hot and cold side, density of heat flow rate, q, through the metering section of the specimen, relative humidity of the air;

k) the calculated thermal resistance and the conventional surface thermal resistances used to calculate the thermal transmittance;

l) the estimated accuracy;

m) test duration;

n) other information relevant to the test, e.g. any significant or unexplained divergence between test results and tentative estimates in accordance with **8.1**, results of the consequent inspection of the specimen and possible interpretation of divergences.

Annex A (normative)
Calibration of heat flow meters

A.1 Heat flow meter calibration procedure

The heat flow meter is placed in the guarded hot plate or heat flow meter apparatus, the side adjacent to the element being measured on the cold metal plate. A specimen of insulating material [e.g. λ = 0,040 W/(m·K)], having an adequate long-term stability, is placed between the other side of the heat flow meter and the hot side of the apparatus. The area of the heat flow meter where the sensing elements are distributed shall be nearly equal to that of the guarded hot plate or heat flow meter. The specimen thickness shall not exceed one half of the maximum allowed thickness for the guarded hot plate or heat flow meter apparatus used. Its thermal resistance shall be such that the required densities of heat flow rate can be obtained with acceptable temperature differences. If the heat flow meter to be calibrated does not completely cover the cold plate of the apparatus, the free surface of the apparatus shall be covered with a sheet having the same thickness and thermal resistance as the heat flow meter to be calibrated. Temperature sensors shall detect the surface temperature on both sides of the heat flow meter to be calibrated to allow the measurement of its average temperature. The density of heat flow rate shall be measured through the guarded hot plate or heat flow meter apparatus.

The calibration procedure shall be such that the calibration factor *f* is known with an accuracy of ±2 %. The densities of heat flow rate, as well as the temperatures and the thermal conductivities for the portion of specimens in contact with the heat flow meter to be calibrated, shall cover the range of values usually encountered in practice.

A.2 Calibration of a new type of heat flow meter

The heat flow meter calibration factors, *f* (i.e. the density of heat flow rate for a signal equal to one unit), may change with the temperature, the density of heat flow rate itself and, for some heat flow meters, the thermal conductivity of the material on which the heat flow meter is installed. Therefore, the calibration factor of a new type of heat flow meter shall be evaluated using a guarded hot plate (conforming to ISO 8302:1991 single sided type) or heat flow meter apparatus (conforming to ISO 8301:1991 single specimen single heat flow meter type), at various temperatures and densities of heat flow rate and with the heat flow meter in contact with different materials.

A set of calibration curves or an equation shall be prepared (calibration factor versus mean temperature and possibly density of heat flow rate and thermal conductivity for the portion of specimens in contact with the heat flow meter) for any new type of heat flow meter or any modified heat flow meter (e.g. new facing or new incorporated guard ring).

The calibration shall be done at three different densities of heat flow rate (e.g. 3 W/m^2, 10 W/m^2 and 20 W/m^2), in order to check the linearity of the response of the heat flow meter versus the density of heat flow rate. If the relation is not linear, the calibration shall be carried out at more densities of heat flow rate and the precise function shall be taken into account during the measurements.

The calibration shall be done at a minimum of two temperatures (minimum and maximum limits). If there is a significant difference between the two results, a calibration shall be repeated at an intermediate temperature to check the linearity of the calibration factor versus temperature. If the relation is not linear, calibrations at additional temperatures are required to establish an accurate relationship for the calibration factor.

To check the dependence of the calibration factor on the conductivity of the material on which the heat flow meter is mounted, a thin sheet not exceeding the heat flow meter thickness, is installed between the cold plate of the apparatus and the heat flow meter to be calibrated. The conductivity of the thin sheet shall be the lowest expected for the portion of specimens in contact with the heat flow meter to be tested in the heat flow meter hot box. If an influence on the calibration factor is observed, the calibration shall be repeated also with other thin sheets covering the expected range of conductivities for the portion of specimens in contact with the heat flow meter to be tested in the heat flow meter hot box.

NOTE A partial calibration may be done if the heat flow meter is used only for a specific application. In this case, it need only be calibrated on the material on which it will be installed and/or for the temperatures used.

The heat flow meter shall be tested for the following characteristics:

a) zero offset: if there is a non-zero output for zero heat flow (heat flow meter placed in a thermally homogeneous medium), this may be due to a bad electrical connection, which shall be checked);

b) effects of stresses on the calibration factor: this effect shall be negligible for the range of perpendicular and parallel stresses occurring in the measurements;

c) ageing effects of the heat flow meter material.

A.3 Calibration check and recalibration

For a heat flow meter whose characteristics have already been quantified according to **A.1.1**, the calibration factor shall be measured for one density of heat flow rate, at a temperature close to its temperature in use and on a typical building material.

The calibration factor shall be verified at regular intervals (no more than six months after the first calibration) by a measurement at one temperature on one material. A drift of the calibration factor may be caused by material ageing or delamination. If the variation of the calibration factor is more than 2 %, a complete calibration according to **A.2** shall be undertaken. If the calibration factor shows satisfactory stability, the calibration interval can be increased.

In all cases a correction shall be applied to the measurements where a change in the calibration factor of greater than ±2 % occurs over the range of operation.

Annex B (informative)

Bibliography

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