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Thermal insulation — Building elements — *In-situ* measurement of thermal resistance and thermal transmittance

Isolation thermique — Éléments de construction — Mesurage in situ de la résistance thermique et du coefficient de transmission thermique

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9869 was prepared by Technical Committee ISO/TC 163, *Thermal insulation*, Subcommittee SC 1, *Test and measurement methods*.

Annexes A, B and C form an integral part of this International Standard. Annexes D and E are for information only.

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Introduction

The thermal transmittance of a building element (*U*-value) is defined in ISO 7345 as the "Heat flow rate in the steady state divided by area and by the temperature difference between the surroundings on each side of a system".

In principle, the *U*-value can be obtained by measuring the heat flow rate through an element with a heat flowmeter or a calorimeter, together with the temperatures on both sides of the element under steady state conditions.

However, since steady state conditions are never encountered on a site in practice, such a simple measurement is not possible. But there are several ways of overcoming this difficulty:

a) imposing steady-state conditions by the use of a hot and a cold box. This method is commonly used in the laboratory (ISO 8990) but is cumbersome in the field.

b) assuming that the mean values of the heat flow rate and temperatures over a sufficiently long period of time give a good estimate of the steady state. This method is valid if

   1) the thermal properties of the materials and the heat transfer coefficients are constant over the range of temperature fluctuations occurring during the test,

   2) the change of amount of heat stored in the element is negligible when compared to the amount of heat going through the element. This method is widely used but may lead to long periods of measurement and may give erroneous results in certain cases;

c) using a dynamic theory to take into account the fluctuations of the heat flow rate and temperatures in the analysis of the recorded data.

NOTE 1 The temperatures of the surroundings, used in the definition of the *U*-value, are not precisely defined in ISO 7345. Their exact definition depends on the subsequent use of the *U*-value and may be different in different countries (see annex A).

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Thermal insulation — Building elements — *In-situ* measurement of thermal resistance and thermal transmittance

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1 Scope

1.1 Limits of application

This International Standard describes the heat flowmeter method for the measurement of the thermal transmission properties of plane building components, primarily consisting of opaque layers perpendicular to the heat flow and having no significant lateral heat flow.

It is not intended as a high precision method replacing the laboratory instruments such as calorimeter, hot boxes.

The properties which can be measured are

a) the thermal resistance, R, and thermal conductance, Λ, from surface to surface;

b) the total thermal resistance, R_T, and transmittance from environment to environment, U, if the ambient temperatures of both environments are well defined.

The heat flowmeter measurement method is also suitable for components consisting of quasi-homogeneous layers perpendicular to the heat flow, provided that the dimensions of any inhomogeneities in close proximity to the heat flowmeter (HFM) are much smaller than its lateral dimensions and are not thermal bridges which can be detected by infrared thermography (see 6.1.1). For other components, an average thermal transmittance may be obtained using a calorimeter or by averaging the results of several heat flowmeter measurements.

1.2 Content of this International Standard

This International Standard describes the apparatus to be used, the calibration procedure for the apparatus, the installation and the measurement procedures, the analysis of the data, including the correction of systematic errors and the reporting format.

1.3 Personnel qualifications

The heat flowmeter measurement method requires personnel with special knowledge and experience in the fields of building technology, building physics and measurement techniques.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 6781:1983, *Thermal insulation — Qualitative detection of thermal irregularities in building envelopes — Infrared method.*

ISO 6946-1:1986, *Thermal insulation — Calculation methods — Part 1: Steady state thermal properties of building components and building elements.*

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

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.*

ISO 8990:—[1], *Thermal insulation — Determination of steady-state thermal transmission properties — Calibrated and guarded hot box.*

3 Terms, symbols and units

The terms, symbols and units used in this International Standard are in accordance with ISO 7345. Listed below are the most commonly used terms in this International Standard. For a fuller description of other terms, ISO 7345 should be consulted.

Φ	heat flow rate	[W]
A	area	[m²]
q	density of heat flow rate = Φ/A	[W/m²]
T_i	interior ambient temperature	[°C or K]
T_e	exterior ambient temperature	[°C or K]
T_{si}	interior surface temperature of the building element	[°C or K]
T_{se}	exterior surface temperature	[°C or K]

The ambient temperatures shall correspond with those used in the definition adopted for the U-value (see annex A).

The following special symbols are used in clauses 7 and 8 :

ρ	density of a material	[kg/m³]
d	thickness of a layer	[m]
c	specific heat capacity	[J/(kg·K)]
C	thermal capacity of a layer: $C = \rho c d$	[J/(m²·K)]
F_i, F_e	correction factors calculated with equation (8) to take into account the storage effects	[J/(m²·K)]
e	operational error (of an installed HFM) which is the relative error between the measured and the actual heat flow	[dimensionless]

1) To be published.

In the steady state, the thermal properties of the elements have the following definitions:

R is the thermal resistance of an element, surface to surface and is given by

$$R = \frac{T_{si} - T_{se}}{q} = \frac{1}{\Lambda} \quad \ldots (1)$$

where Λ is the thermal conductance of the building element, surface to surface.

U is the thermal transmittance of the element, environment to environment and is given by

$$U = \frac{q}{(T_i - T_e)} = \frac{1}{R_T} \quad \ldots (2)$$

where R_T is the total thermal resistance which is given by

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

where R_{si} and R_{se} are the internal and external surface thermal resistances, respectively.

R and R_T have units of square metres kelvin per watt (m²·K/W); U and Λ have units of watts per square metre kelvin [W/(m²·K)].

4 Apparatus

4.1 Heat flowmeter (HFM)

The HFM is a transducer giving an electrical signal which is a direct function of the heat flow transmitted through it.

Most HFMs are thin, thermally resistive plates with temperature sensors arranged in such a way that the electrical signal given by the sensors is directly related to the heat flow through the plate (see figure 1). The HFM can also have facing sheets to provide protection. Metal temperature levelling plates or foils are sometimes used to improve or simplify the measurements, but these must be arranged so as not to make the results dependent on the thermal properties of the element being measured (see annex D). The area of the measuring section of the HFM is often smaller than the total area of the HFM.

The essential properties of an HFM are that it should have a low thermal resistance in order to minimize the perturbation caused by the HFM, and a high enough sensitivity to give a sufficiently large signal for the lowest heat flow rates measured. This signal must be a monotonic function of the heat flow rate. The de-

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pendence of this signal on the thermal conductivity of the material on which the HFM is installed, the temperature of the HFM or on other physical quantities such as stresses, electromagnetic radiation etc., have to be taken into account (see clause 5).

More detailed information on the structure of HFMs can be found in ISO 8301.

4.2 Temperature sensors

Temperature sensors are transducers giving an electrical signal which is a monotonic function of its temperature. A minimum of two temperature sensors are used, one on each side of the element under test.

Good temperature sensors have an accuracy such that temperature errors are small when compared with the measured temperature difference across the element. The effects of the heat flow going through the sensor and on other physical quantities, such as stresses, electromagnetic radiation etc. on the signal have to be taken into account (see clause 5).

Suitable surface temperature sensors (for R- or Λ-value measurements) are thin thermocouples and flat resistance thermometers. It is possible, for the conductance measurements, for one or several sensors to be incorporated within one side of the HFM, the side which will be in contact with the surface of the element being measured.

Ambient temperature sensors (for U-value measurements) shall be chosen according to the temperature to be measured. For example, if the U-value is defined by the ratio of density of heat flow rate to the air temperature difference, air temperature sensors are to be used. These sensors are shielded against solar and thermal radiation and are ventilated. Other sensors may measure the so-called sol-air temperature, the comfort temperature etc. (see annex A).

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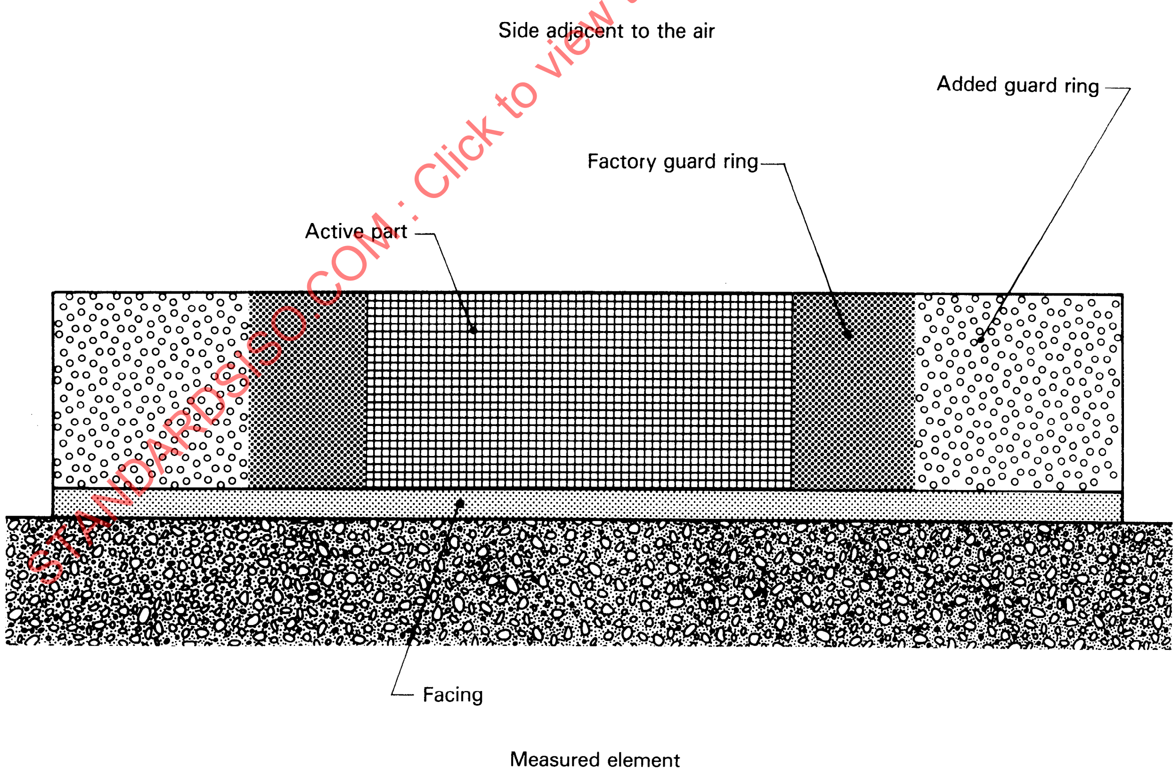

Figure 1 — Section through a typical heat flowmeter showing the various parts (the vertical scale is enlarged)

5 Calibration procedure

5.1 Calibration of the HFM

The HFM calibration factors (e.g. the density of heat flow rate for a signal equal to one unit) may change with the temperature, the thermal conductivity of the material on which the HFM is installed, and the heat flow itself. Therefore, the calibration factor of a new type of heat flowmeter shall be evaluated on various materials through an absolute test method such as the guarded hot plate apparatus (ISO 8302) or a heat flowmeter apparatus (ISO 8301) on various materials, at various temperatures, and heat flow rates. The HFM is placed, with its facings and a guard ring of similar average resistance and same thickness, in the guarded hot plate apparatus, the side adjacent to the element being measured on a material of known thermal conductivity and the other side, which will be in the air, against an insulating layer [thermal conductivity less than 0,04 W/(m·K)].

The calibration procedure shall be such that the calibration factor is known with an accuracy of ± 2 % in the conditions of use. The heat flow rates as well as the temperatures and the thermal conductivities of the materials shall cover the range of values usually encountered in practice.

Since the HFM is not homogeneous over most of its area, extreme care is required to calibrate it. Calibrating the HFM between a material of known thermal conductivity and an insulating material defines precisely the boundary conditions, which are, however, not the boundary conditions encountered when using the HFM in the measurements. If the HFM were calibrated in a hot box apparatus, the boundary conditions were similar to those encountered in practice, but not well defined. In this case, the corrections described in 8.2 are different.

5.1.1 Calibration of a new type of HFM

A set of calibration curves or an equation shall be prepared (calibration factor versus mean temperature, thermal conductivity of the underlying material, and eventually the density of heat flow rate) for any new type of heat flowmeter or any modified HFM (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 HFM versus q. If the relationship is not linear, more densities of heat flow rate shall be tested 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 third point shall be measured at the average of the two temperatures to test the linearity of the relationship of the calibration factor to the temperature. If the relationship is not linear, more temperatures shall be used in order to obtain the dependence of the calibration factor on the temperature.

The complete calibration shall be done with the HFM placed on at least two materials (low and high thermal conductivity). If any dependence of the calibration factor to this parameter is found, more materials shall be used in order to get the complete relationship between the thermal conductivity of the material and the calibration factor.

NOTE 2 A partial calibration may be done if the HFM is used only for a specific application. In this case, it may be calibrated only on the material on which the HFM will be installed and/or for the temperatures used.

The HFM shall be tested for the following characteristics:

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

b) effect of stresses on the calibration factor. This effect shall be negligible in the range of perpendicular and parallel stresses involved in the measurements;

c) effect of electromagnetic radiation (50 Hz to 60 Hz, radio waves). This effect shall be negligible in the range of electromagnetic fields encountered in practice.

5.1.2 Calibration of a known type of HFM

For an HFM whose effects mentioned above are well known, the calibration factor shall be measured for one heat flow, at a temperature close to its temperature in use and on a typical building material.

Every two years, or more frequently if required, the calibration factor shall be verified by a measurement at one temperature on one material. A drift of the calibration factor can be caused by material ageing or delamination. If the variation of the calibration factor is more than 2 %, a complete calibration procedure shall be followed.

In all cases a correction shall be applied to the measurements where a change in the calibration fac-

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tor of greater than ± 2 % occurs over the range of operation.

5.2 Temperature sensors

The calibration procedure shall be such that the temperature difference between a pair of sensors is determined with an accuracy better than ± 2 % and that the temperature can be measured with an accuracy better than 0,5 K. If the temperature difference is obtained by subtracting two temperatures, the sensors shall be calibrated to an accuracy of ± 0,1 K.

The surface and air temperature sensors are calibrated for several temperatures in the relevant range (generally − 10 °C to 50 °C) in a well-stirred medium (e.g. water or air), in a well-insulated container, in comparison with a reference thermometer having an accuracy better than 0,1 K. Sensors manufactured to this accuracy may be used without calibration.

Special procedures shall be used for the sensors measuring the environment temperatures, according to the temperature to be measured.

The effects of stresses and of electromagnetic radiation (solar and thermal radiation, 50 Hz to 60 Hz, radio waves) at reasonable levels have to be examined and eliminated if the changes are greater than the accuracy mentioned above.

5.3 Measuring equipment

Where direct readout equipment is provided, adequate provision shall be made for calibration of this equipment. Calibrated voltage sources and resistances can be used in place of the HFM and temperature sensors.

6 Measurements

6.1 Installation of the apparatus

6.1.1 Location of the measured area

The sensors (HFMs and thermometers) shall be mounted according to the purpose of the test. The appropriate location(s) may be investigated by thermography (in accordance with ISO 6781). Sensors shall be mounted in such a way so as to ensure a result which is representative of the whole element.

NOTE 3 It can be appropriate to install several HFMs so as to obtain a representative average.

HFMs shall not be installed in the vicinity of thermal bridges, cracks or similar sources of error. Sensors shall not be under the direct influence of either a heating or a cooling device or under the draught of a fan.

The outer surface of the element should be protected from rain, snow and direct solar radiation. Artificial screening may be used for that purpose.

6.1.2 Installation of the HFM

The dimensions of the HFM are chosen according to the structure of the element under test. For homogeneous elements, any reasonable dimensions can be used, but some corrections may be necessary (see clause 8). If an HFM is used to measure an element in which there is lateral heat flow, a check shall be done (e.g. by calculations) to verify that the output of the HFM is proportional to the average heat flow through the element.

The HFM (with its surface temperature sensor if any) shall be mounted directly on the face of the element adjacent to the more stable temperature. The HFM shall be in direct thermal contact with the surface of the element over the whole area of the sensor. A thin layer of thermal contact paste can be used for this purpose.

A guard ring, made of a material which has similar thermal properties as the HFM and of the same thickness, may be mounted around the HFM.

6.1.3 Temperature sensors

If the thermal resistance (or the conductance) is to be measured, surface temperature sensors shall be used. If not incorporated in the HFM, the internal surface temperature sensor shall be mounted on the internal surface either under or in the vicinity of the HFM. The external surface temperature sensor shall be mounted on the external surface opposite the HFM.

Both surface temperature sensors shall be mounted so as to achieve good thermal contact between the surface and both the sensor and 0,1 m of lead wires.

NOTE 4 For accurate results, it is recommended that the HFM and surface temperature sensors have the same colour and emissivity as their respective substrates. This is particularly important for sensors exposed to sunlight.

To measure the U-value or the total resistance, ambient temperature sensors shall be used. These sensors shall measure the temperature used in the definition of the U-value. They are chosen and installed accordingly at both sides of the element being measured (see annex A).

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The duration of the test can be greatly reduced if the temperatures on both sides of the element, but particularly on the side where the HFM is installed, are stable before and during the test.

6.2 Data acquisition

The electrical data from the HFM and the temperature sensors shall be recorded continuously or at fixed intervals over a period of complete days. The maximum time period between two records and the minimum test duration depends on

- the nature of the element (heavy, light, inside or outside insulation);
- indoor and outdoor temperatures (average and fluctuations, before and during measurement);
- the method used for analysis.

The minimum test duration is 72 h (3 d) if the temperature is stable around the HFM. Otherwise, this duration may be more than 7 d. However, the actual duration of test shall be determined by applying criteria to values obtained during the course of the test. These values shall be obtained without interrupting the data acquisition process.

It is useful to record the data so that it can be used for computer analysis. It is recommended that recordings are made at fixed time intervals which are the average values of several measurements sampled at shorter intervals.

The recording interval depends on the method used for analysis (see clause 7). It is typically 0,5 h to 1 h for the average method and may be less for the dynamic method.

The sampling interval shall be shorter than half the smallest time constant of the sensors.

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7 Analysis of the data

Two methods may be used for analysis of the data in accordance with this International Standard: the so-called average method, which is simple, or the dynamic method, which is more sophisticated but which gives a quality criteria of the measurement and may shorten the test duration for medium to heavy elements submitted to variable indoor and outdoor temperatures.

The average method is described below and the dynamic method is described in annex B.

7.1 Average method

This method assumes that the conductance or transmittance can be obtained by dividing the mean density of heat flow rate by the mean temperature difference, the average being taken over a long enough period of time. If the index j enumerates the individual measurements, then an estimate of the resistance is obtained by

$$R = \frac{\sum_{j=1}^{n} (T_{sij} - T_{sej})}{\sum_{j=1}^{n} q_j} \qquad \ldots (4)$$

an estimate of the conductance, Λ, is obtained by

$$\Lambda = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n} (T_{sij} - T_{sej})} \qquad \ldots (5)$$

and an estimate of the transmittance, U, is obtained by

$$U = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n} (T_{ij} - T_{ej})} \qquad \ldots (6)$$

When the estimate is computed after each measurement, a convergence to an asymptotical value is observed. This asymptotical value is close to the real value if the following conditions are met:

a) the heat content of the element is the same at the end and the beginning of the measurement (same temperatures and same moisture distribution);

b) the HFM is not exposed to direct solar radiation. It should be noted that a false result can be obtained when there is solar radiation on the exterior surface. For R- or Λ-value measurements, the emissivity of the surface temperature sensor will generally be different to that of the undisturbed surface, giving a false reading. The external ambient temperature in the U-value measurement generally takes no account of the solar flux to the exterior surface of the element;

c) the thermal conductance of the element is constant during the test.

If these conditions are not fulfilled, misleading results can be obtained.

For light elements, which have a specific heat capacity per unit area of less than 20 kJ/$(m^2 \cdot K)$, it is recommended that the analysis is carried out only on data acquired at night (from 1 h after sunset until sunrise), to avoid the effects of solar radiation. The test may be stopped when the results after three subsequent nights do not differ by more than ± 5 %. Otherwise, it shall be continued.

For heavier elements, which have a specific heat per unit area of more than 20 kJ/$(m^2 \cdot K)$, the analysis shall be carried out over a period which is an integer multiple of 24 h. The test shall be ended only when the following conditions are fulfilled:

- the duration of the test exceeds 72 h;
- the R-value obtained at the end of the test does not deviate by more than ± 5 % from the value obtained 24 h before;
- the R-value obtained by analysing the data from the first time period during INT($2 \times D_T/3$) d does not deviate by more than ± 5 % from the values obtained from the data of the last time period of the same duration. D_T is the duration of the test in days; INT is the integer part;
- if the change in heat stored in the wall is more than 5 % of the heat passing through the wall over the test period, one of the methods described in 7.2 or in annex B shall be used.

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7.2 Storage effects

The following procedure, relevant for structures of high R-value and high thermal mass, shall be applied in cases where the criteria of 7.1 (i.e. the criteria which determines when sufficient data have been recorded) are not fulfilled. The use of this correction procedure often permits a shorter measurement time than would otherwise be required to meet these criteria. The basis of the procedure is discussed further in annex E.

The procedure involves

- the calculation of internal and external thermal mass factors (F_i and F_e respectively) for the structure concerned;
- an adjustment, involving these factors, to the measured flux at each data point.

7.2.1 Calculation of the thermal mass factors

The factors shall be obtained for a structure consisting of N plane parallel layers, numbered from 1 to N with layer 1 at the interior surface, for heat flux measured at the interior surface, as follows.

For each layer k, estimate its thermal resistance R_k in square metres kelvin per watt $(m^2 \cdot K/W)$ (thickness divided by thermal conductivity or thermal resistance of airspace) and its thermal capacity C_k in joules per square metre kelvin [J/$(m^2 \cdot K)$] {product of specific heat capacity in joules per kilogram kelvin [J/(kg·K)], density in kilograms per cubic metre (kg/m^3) and thickness of component (m)}. Let R be the estimated total thermal resistance of the wall, i.e. the sum of all R_ks.

Then for each layer k calculate the inner (R_{ik}) and outer (R_{ek}):

$$R_{ik} = \sum_{j=1}^{k-1} R_j \qquad R_{ek} = \sum_{j=k+1}^{N} R_j \qquad \ldots (7)$$

and the factors:

$$F_{ek} = C_k \left[\frac{R_k}{R} \left\{ \frac{1}{6} + \frac{R_{ik} + R_{ek}}{3R} \right\} + \frac{R_{ik} R_{ek}}{R^2} \right]$$

$$F_{ik} = C_k \left[\frac{R_{ek}}{R} + \frac{R_k^2}{3R^2} - \frac{R_{ik} R_{ek}}{R^2} \right] \qquad \ldots (8)$$

NOTES

5 For the interior layer ($j = k = 1$), $R_{ik} = 0$; for the exterior layer ($j = k = N$), $R_{ek} = 0$.

6 When thermal transmittance is being measured, surface resistance should be included so that the measured temperatures are ambient temperatures rather than surface temperatures;

add R_{si} to each value of R_{ik}

add R_{se} to each value of R_{ek}

add $R_{si} + R_{se}$ to R

The thermal mass factors for the structure are then given by

$$F_i = \sum_{k=1}^{N} F_{ik} \quad \text{and} \quad F_e = \sum_{k=1}^{N} F_{ek} \qquad \ldots (9)$$

7.2.2 Correction to measured heat flux

No correction is applied to the data during the first 24 h. Thereafter, Σq_j in equations (4), (5) or (6) is replaced by

$$\sum q_j - \frac{(F_i\, \delta T_i + F_e\, \delta T_e)}{\Delta t} \qquad \ldots (10)$$

where

Δt is the interval between readings, in seconds;

δT_i is the difference between internal averaged temperature over the 24 h prior to the reading j and internal averaged temperature averaged over the first 24 h of the analysis period;

δT_e is the difference between external averaged temperature averaged over the 24 h prior to the reading j and external averaged temperature averaged over the first 24 h of the analysis period.

The corrected R-, Λ- or U-value shall be plotted against time.

NOTE 7 It is desirable to plot this on the same graph as the uncorrected value.

7.2.3 Interpretation of the results

The R-, Λ- or U-value of the structure shall be taken as the value of the corrected curve at the end of the measurement, with an uncertainty band equal to the range of the corrected curve over the final 24 h, provided that each of the following conditions hold:

a) the analysis period is not less than 96 h;

b) the analysis period is an integer multiple of 24 h;

c) the R-value so obtained is equal to the value of R used to derive the correction factors, to within 5 %;

d) the values of the corrected curve

1) at the end of the test,

2) 24 h before the end of the test,

3) 48 h before the end of the test,

are all the same within 5 %;

e) the same results to within 5 % are obtained if the first 12 h of data are discarded.

If condition c) above is not met, the thermal resistance chosen for each layer of the structure shall be reviewed and if alternative values can be justified (so as to make R consistent with the measured value), the data shall be re-analysed and new correction factors calculated using the revised thermal resistances. Any such revision shall be reported.

If conditions d) or e) above are not met, the first few hours of data should be discarded and the remaining data examined and judged against all five of the above conditions. This will be possible only if more than 4 d of data are available.

If the above conditions are not met, the result of the test is subject to a greater uncertainty band (see clause 9).

NOTE 8 When the composition of the structure is unknown but an estimate of its thermal mass can still be made, it can be of assistance in interpreting results to use the correction factors for a single layer structure. These are

$$F_i = \frac{C}{3} \quad \text{and} \quad F_e = \frac{C}{6}$$

where C is the product of specific heat capacity [approximately 1 000 J/(kg·K) for most materials], density and thickness of the element. The use of these factors will not give a valid result if the element contains an insulation layer.

7.3 Comparison of calculated and measured values

The calculated value, based on the structure of the element and obtained using ISO 6946-1, may be compared with the measurements. For that purpose, the structure of the element may be examined using the method described in annex C.

Significant differences (> 20 %) between the calculated value and the R- or U-value measurement may be caused by a combination of any of the following factors:

— the values assumed for the thermal conductivities are not the true values. This may arise from incorrect identification of the materials, particularly the insulating ones, from differences between the actual properties of the material and the assumed values, or from moisture effects;

— the values assumed for the surface resistances are not the true values. This source of error is usually important only for poorly insulated elements;

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— the exact thicknesses of the layers, especially those made of insulating materials, were not properly measured;

— the R- or U-value measurements were not properly carried out or were done under poor thermal conditions;

— the examination of the element and the R- or U-value measurements were not applied to the same location in a nonhomogeneous element;

— the heat flow lines during the measurement were not straight and perpendicular to the element;

— there were convective air flows in the element, which influenced the R- or U-value measurements but were not taken into account in the computation of the theoretical value;

— there are phase changes such as freezing, thawing, condensing or evaporating of water or moisture;

— the ambient temperatures used for the calculation of the U-value are not those measured (see annex A).

All these sources of error shall be taken into account when interpreting the comparison of the results given by calculation and measurement.

8 Corrections for the operational error

8.1 Corrections for the thermal resistance of the HFM

The HFM adds a thermally resistant layer to the measured element. If this layer were infinitely large and thin, the correction would be negligible. If it is large but of finite thickness, the correction is easily determined if the thermal resistance of the HFM, R_{hfm}, is known. There are three cases to be considered for this one-dimensional correction:

a) the interior surface temperature is measured under the HFM. No correction to the resistance or conductance is needed in this case;

b) the interior surface temperature is measured on the surface of the element next to the HFM. To a first approximation (see annex D), the resistance is then given by

$$R = \frac{\delta T}{q} - R_{hfm} \qquad \ldots (11)$$

where

q is the measured density of heat flow rate;

δT is the measured temperature difference between the surfaces;

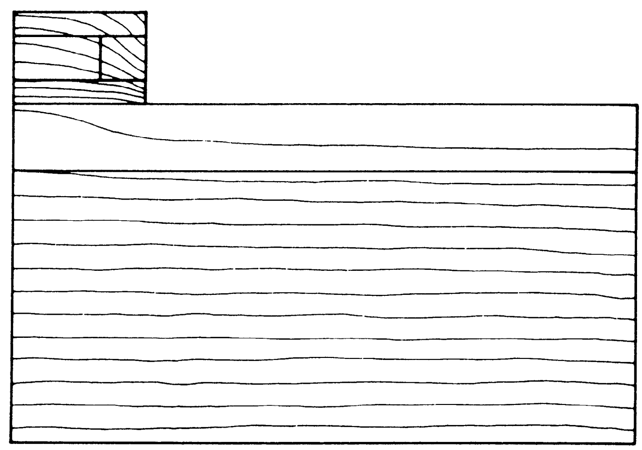
c) the U-value is measured. If the HFM is very large, the correct result is given by

$$U = \frac{q}{\delta T - R_{hfm} q} \qquad \ldots (12)$$

where δT is the temperature difference between both environments.

8.2 Correction for the finite dimension of the HFM

In most cases, the HFM has a finite surface and the isotherms are therefore modified in the region where the HFM is installed (see figure 2). This changes the heat flow through the HFM and a correction must be made to the measured results. The error caused by this change is called the operational error.



NOTE — The vertical scale is enlarged to show the phenomenon more clearly [see equation (D.8)]

Figure 2 — Isothermals ($\delta\theta$ = 0,05 K) **in a disc-shaped, faced and guarded HFM on a wall (cylindrical sections)**

If q is the measured density of heat flow rate and q' is the density of heat flow rate through the element without an HFM, the operational error, e, can be defined as

$$e = \frac{q - q'}{q'} \qquad \ldots (13)$$

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If this operational error is known, the corrected R'- and U'-values are

$$R' = (1 + e)R \qquad U' = \frac{U}{1 + e} \qquad \ldots (14)$$

This correction depends on the following parameters:

— surface resistance over the HFM;

— thermal conductivity and thickness of the layer of material located under the HFM (not taking into account thin films such as paints or paper);

— dimensions, structure and thermal properties of the HFM, guard ring, facings and fixing materials such as glue, thermal contact paste, adhesive tape etc.

The correction factors are obtained by solving the heat equation by means of a finite-element or finite-difference method, taking into account the properties of the heat flowmeter, an appropriate surface resistance and the thermal conductivity of the first layer. In the case of a square HFM, a two-dimensional model with cylindrical symmetry can be used instead of a three-dimensional one, thereby simplifying the calculations without loss of accuracy. In this case, the area of the calculated disc-shaped HFM shall have the area of the actual square HFM.

The correction calculated in this way takes into account the effect of the resistance of the HFM, this correction (see 8.1) shall not be added as well.

In general, large operational errors can be avoided by understanding the disturbance effect and by paying attention to the following:

— the operational error is mainly caused by the global distortion of the thermal field under the HFM. The local disturbance effect at the edge of the HFM has a significant importance only for HFMs whose width to thickness ratio is less than 10. As a consequence, the disturbance of a square and a disc-shaped HFM are the same, provided the areas are the same;

— the operational error is then an increasing function of the thermal conductivity of the material of the first layer under the HFM and of the surface transfer coefficient. Small errors are expected for measurements on thermal insulation materials in an inside environment, while large errors are expected for measurements on metals in an outside environment;

— the operational error is a decreasing function of the thermal resistance of the HFM;

— HFMs with large width to thickness ratios are advisable, since the operational error equals the one dimensional error in such cases. The correction is then calculated using equations (11) or (12). This correction is also valid for measurements on metals;

— a thin covering of the thermocouple junctions of the HFM is needed in order to avoid a dependency of the calibration factor on the thermal conductivity of the wall material. If an HFM is faced in that way, it shall be calibrated with the facing.

If the surface transfer coefficient is less than 10 W/(m^2·K), for HFMs of a diameter/thickness ratio greater than 20, installed on normal building materials [thermal conductivity less than 3 W/(m·K)] then the correction factor is less than 0,1 W/(m^2·K). This does not mean that the correction factor is necessarily more than 0,1 W/(m^2·K) outside of these limits.

Further information is given in annex D.

9 Accuracy

The accuracy of the measurement depends on

— the accuracy of the calibration of the HFM and the temperature sensors. The error is about 5 % if these instruments are well calibrated;

— the accuracy of the data logging system;

— random variations caused by slight differences in the thermal contact between the sensors and the surface. This variation is about 5 % of the mean value if the sensors are carefully installed. This contribution to the total error can be reduced by using several HFMs;

— the operational error of the HFM due to modifications of the isotherms caused by the presence of the HFM (see clause 8). If the operational error has been estimated by a suitable method such as finite-element analysis, and a correction is applied to the data, the residual uncertainty is about 2 % to 3 %;

— errors caused by the variations over time of the temperatures and heat flow. Such errors can be very large but, if the criteria described in 7.1 and 7.2 or annex C are fulfilled, they can be reduced to less than ± 10 % of the measured value. This contribution can be reduced by recording the data during an extended period of time, by reducing the variations of the indoor temperature to a minimum,

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and by using the dynamic interpretation method (see annex C);

— for U-value measurements, temperature variations within the space and differences between air and radiant temperatures.

If the above conditions are met, the total uncertainty can be expected to be between the quadrature sum and arithmetic sum, i.e. between

$$\left(\sqrt{5^2 + 5^2 + 3^2 + 10^2 + 5^2}\right) \% = 14 \%$$

and

$$(5 + 5 + 3 + 10 + 5) \% = 28 \%.$$

If the above conditions are not met, the test remains valid in terms of this International Standard provided that a greater uncertainty, calculated according to the circumstances of the test, is quoted.

The probability of obtaining a large error is increased when

— the temperatures (particularly the indoor temperature) show large fluctuations (before or during the test) compared to the temperature difference between both sides of the element;

— the element is heavy and the duration of the test is too short;

— the element is submitted to solar radiation or other strong thermal influences;

— no estimate is made of the operational error of the HFM (which can be up to 30 % in some circumstances).

The accuracy of the measurement of the U-value depends on the definition of the environment temperatures adopted for the U-value and their measurement.

10 Test report

The report shall contain

a) Data on the element measured:

— location of the building where the element is measured;

— location of the element in the building, particularly its orientation;

— purpose of the test (suspected bad workmanship, moisture, ageing of the materials, etc.);

— type of element (wall, ceiling, floor, etc.);

— probable structure of the element;

— thickness of the element.

b) Data on the measurements:

— name of the measuring institution;

— type and characteristics (make, serial number, calibration factors, history) of the temperature sensors and HFM;

— method used to fix the sensors;

— precise location of the sensors (HFM and temperature sensors);

— temperature measured (i.e. surface, air, radiant or other temperature);

— date and time of the beginning and end of the measurement;

— interval between records and number of measurements averaged in each record;

— graphs of the recorded data (heat flow rate and temperatures versus time) showing also the data discarded before analysis.

c) Data on the method of analysis:

— method used: average (clause 7) or dynamic (see annex C);

— graph of the integrated heat flow divided by the integrated temperature difference or the reciprocal, whichever is applicable;

— if corrections for storage effect are carried out:

1) assumed thermal capacity and thermal resistance of each layer;

2) average temperatures for the first and last day of integration;

3) corrected graphs (corrected R-, Λ- or U-value versus time);

— if the dynamic analysis is carried out:

1) number of equations;

2) optimal time constants found;

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3) standard deviation on the flow;

4) confidence interval;

— if any of the criteria mentioned in 7.1, 7.2 or in annex C (depending on the method used) are not fulfilled, this shall be reported and the uncertainty of the results increased accordingly.

d) Results:

— resistance and conductance or total resistance and transmittance;

— corrections used for the presence of the HFM;

— estimation of the accuracy, error analysis;

— any supplementary measurements undertaken, depending on the purpose of the test (moisture content, thermographic analysis, examination of the structure, etc.).

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Annex A
(normative)

Heat transfer at surfaces and *U*-value measurement

A.1 General

Heat is transferred to and from a building element both by radiation interchange between the surface of the element and other surfaces, and by convective heat transfer at the surface of the element.

The rate of radiant heat transfer depends on the temperatures and emissivities of the surface in question and on other relevant surfaces, and on the view factors between the surfaces. At the internal surface of the element the other relevant surfaces are the remaining surfaces bounding the room, and any furniture within it; at the external surface of the element they include the ground, the sky, other buildings, trees and hedges.

The rate of convective heat transfer depends on various factors such as the adjacent air temperature, surface roughness and air velocity.

The heat flow to or from the specimen is thus influenced by both the radiant and the air temperatures on either side of it.

A.2 Heat balance equation

Where the radiant temperature seen by the surface can be defined, a heat balance equation may be written

$$q = Eh_r(T'_r - T_s) + h_c(T_a - T_s) \qquad \ldots \text{(A.1)}$$

where

- q is the density of heat flow rate into surface [W/m^2];
- T'_r is the mean radiant temperature seen by surface [°C or K];
- T_a is the air temperature adjacent to surface [°C or K];
- T_s is the surface temperature [°C or K];
- E is the space emittance [dimensionless];
- h_r is the radiation transfer coefficient [W/(m^2·K)];
- h_c is the convection transfer coefficient [W/(m^2·K)].

This equation is valid for heat flow into or out of a surface provided that the sign of q is taken as positive if the heat flow is into the surface (i.e. positive on the warm side of the element, negative on the cold side).

h_r is approximately $4\sigma T_m^3$, when σ is the Stefan-Boltzmann constant: $\sigma = 5{,}67 \times 10^{-8}$[W/(m^2·K^4)] and $T_m = 1/2(T'_r + T_s)$ expressed in kelvins. The space emittance incorporates the view factors and emissivities of all surfaces involved.

If the ambient temperature T_{amb} is defined such that

$$q = (T_{amb} - T_s)/R_s \qquad \ldots \text{(A.2)}$$

where R_s is the surface resistance, this is equivalent to equation (A.1) with

$$T_{amb} = \frac{Eh_r}{Eh_r + h_c} T'_r + \frac{h_c}{Eh_r + h_c} T_a \qquad \ldots \text{(A.3)}$$

and

$$R_s = \frac{1}{Eh_r + h_c} \qquad \ldots \text{(A.4)}$$

A.3 Ambient temperature and *U*-values

Equation (A.3) therefore defines the ambient temperature that correctly indicates the heat flow to the surface. Nevertheless there are the following difficulties:

a) T_{amb} is not observable directly;

b) T_{amb} is not constant throughout an enclosure;

c) various different temperatures are used on a national basis in the definition of the *U*-value.

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A.3.1 Observation of T_{amb}

T_{amb} as defined by equation (A.3) is a notional temperature and cannot be measured directly. It could be calculated using equation (A.3) if all the quantities were known; but in practice the only one which can be determined with any certainty is h_r.

A good approximation to T_a can be obtained by direct measurement with a suitable shielded thermometer, but the value of the convection coefficient h_c is less certain. The usual value assumed is 3,0 $W/(m^2 \cdot K)$ for convection at vertical surfaces, but a different value can certainly be expected near heaters or in the vicinity of windows where the surface is not plane. There is also the question of where T_a should be measured.

E is a complicated function of emissivities and view factors, although in many practical cases a value of 0,9 $W/(m^2 \cdot K)$ could be assumed. T'_r is not measurable conveniently. It should be noted that it is not the mean radiant temperature at one point, but the mean radiant temperature seen by the surface in question, so that it is composed of temperatures of all surfaces **excluding** that of the element being measured.

A.3.2 Variations of T_{amb}

Even if T_{amb} can be defined at a point, e.g. adjacent to the test position on the element being measured, it is clear that it will not be constant over the whole element. A heated room will usually have a vertical temperature gradient, so that T_a varies with height; and different points on the test element will have different view factors to the various radiating surfaces, so that T'_r will not normally be constant over all the test element either. As indicated above, h_c and $E \cdot h_r$ will often vary with position.

A.3.3 Definition of U-value

Various different temperatures are used for the definition of the U-value:

a) air temperature;

b) resultant or comfort temperature, which is the average of the mean radiant temperature and air temperature. It should be noted that this mean radiant temperature is not T'_r as defined above as it includes **all** surfaces;

c) environmental temperature. This is the closest to T_{amb} but is subject to the measurement difficulties discussed above, and is usually defined in terms of the mean radiant temperature at the centre of the enclosure, rather than in terms of T'_r.

As a result, a U-value measured *in situ* may not be the appropriate U-value for use in heat loss calculations if different temperatures are involved in the two cases.

A.4 Conditions for U-value measurement

If, during the measurement, $T_a \approx T'_r$, then T_{amb} is insensitive to the values of Eh_r and h_c, and air temperature is a reasonable proxy. However, a problem remains that the surface resistance is $(Eh_r + h_c)^{-1}$. This quantity is liable to vary over the area of the test element. This means that

a) the U-value, as measured, will vary over the area of the test element, even though the element is uniform, that is, has a constant R-value;

b) the measured U-value is dependent on the conditions of measurement and is not a function only of the element itself.

A.5 Exterior surfaces

In the absence of solar radiation, a similar theory can be applied at exterior surfaces. Usually, because of wind velocity, h_c is much greater than Eh_r, so that air temperature can be used under overcast conditions.

Under clear-sky conditions, the effective radiant temperature can be much lower than the air temperature. This is particularly relevant for roofs.

Solar radiation onto a surface is not detected by an air temperature sensor, and this can cause very large errors in U-value measurements.

Both problems (of low radiant temperature and solar radiation) can be avoided by shading the exterior surface.

Surface temperature measurement is also hazardous when there is significant solar radiation onto a surface, as the temperature sensor needs to have a similar emissivity to that of the surface, both for solar radiation and for long-wave thermal radiation.

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Annex B
(normative)

Dynamic analysis method

B.1 General

The dynamic analysis method is a sophisticated method which may be used to obtain the steady-state properties of a building element from HFM measurements when large variations occur in temperatures and heat flow rates. It takes into account the thermal variations by the use of the heat equation.

The building element is represented in the model by its thermal conductance Λ and several time constants τ. The unknown parameters (Λ, τ_1, τ_2, τ_3...) are obtained by an identification technique using the measured densities of heat flow rates and temperatures.

With this approach, a set of linear equations must be solved which can be done by a microcomputer in a few minutes.

B.2 Algorithm of the dynamic method

The basic algorithms are as follows:

The measurements give N sets of data of the density of heat flow rate (q_i), indoor and outdoor surface temperatures (T_{Ii}, T_{Ei}) taken at the times t_i (i ranges from 1 to N). The time interval between two measurements is Δt, defined as:

$$\Delta t = t_{i+1} - t_i \qquad \dots (B.1)$$

The heat flow rate at time t_i is a function of the temperatures at that time and at all of the preceding times

$$q_i = \Lambda(T_{Ii} - T_{Ei}) + K_1\dot{T}_{Ii} - K_2\dot{T}_{Ei} + \sum_n P_n \sum_{j=i-p}^{i-1} T_{Ij}\ (1-\beta_n)\beta_n(i-j) + \sum_n Q_n \sum_{j=i-p}^{i-1} T_{Ej}\ (1-\beta_n)\beta_n(i-j) \qquad \dots (B.2)$$

where the derivative of the indoor surface temperature is

$$\dot{T}_{Ii} = \frac{(T_{Ii} - T_{I,i-1})}{\Delta t} \qquad \dots (B.3)$$

The same formula is valid for the derivative of the external temperature $\dot{T}_{Ei}$.

K_1, K_2 as well as P_n and Q_n are dynamic characteristics of the wall without any particular significance. They depend on the time constant τ_n.

The variables β_n are exponential functions of the time constant τ_n

$$\beta_n = \exp\left(-\frac{\Delta t}{\tau_n}\right) \qquad \dots (B.4)$$

The sum over n in equation (B.2) is over all the time constants, theoretically an infinite number.

These time constants, τ_n, however, decrease rapidly with n, as β_n increases. Hence only a few time constants (in practice, between 1 and 3 is sufficient) are needed to correctly describe the relationship between q, T_E and T_I.

Assuming that m time constants (τ_1, τ_2, ... τ_m) are chosen, equation (B.2) will contain $2m+3$ unknown parameters which are

$$\Lambda, K_1, K_2, P_1, Q_1, P_2, Q_2, \dots, P_m, Q_m \qquad \dots (B.5)$$

Writing equation (B.2) $2m+3$ times for $2m+3$ sets of data at various times, a system of linear equations can be solved to determine these parameters, particularly Λ. A number of supplementary sets, p, is needed however, for the integration corresponding to the sum over j in equation (B.2) (figure B.1). Finally, in order to eliminate stochastic variations, more measured sets are needed, leading to an overdetermined system of linear equations which can be solved by a classic least square fit.

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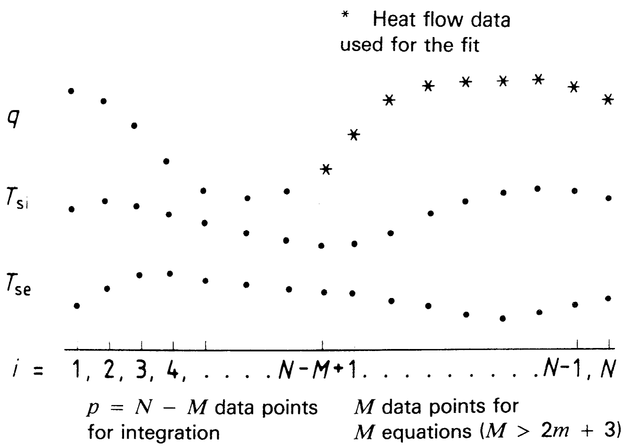

Figure B.1 — Utilization of the data for the dynamic interpretation method

This set of more than $2m+3$ equations can be written in a matrix form

$$\vec{q} = (X)\,\vec{Z} \qquad \ldots \text{(B.6)}$$

where

$\vec{q}$ is a vector, the M components of which are the last M heat flow density data, q_i. The value of M is then greater than $2m+3$ and i goes from $N-M+1$ to N;

$\vec{Z}$ is a vector, the $2m+3$ components of which are the unknown parameters listed in equation (B.5);

(X) is a rectangular matrix with M lines ($i = N-M+1$ to N) and $2m+3$ columns (1 to $2m+3$). The matrix elements are

$$X_{i1} = T_{\text{I}i} - T_{\text{E}i}$$

$$X_{i2} = \dot{T}_{\text{I}} = (T_{\text{I}i} - T_{\text{I},\,i-1})/\Delta t$$

$$X_{i3} = \dot{T}_{\text{E}} = (T_{\text{E}i} - T_{\text{E},\,i-1})/\Delta t$$

$$X_{i4} = \sum_{j=i-p}^{i-1} \dot{T}_{\text{I}j} \quad (1-\beta_1)\beta_1(i-j)$$

$$X_{i5} = \sum_{j=i-p}^{i-1} \dot{T}_{\text{E}j} \quad (1-\beta_1)\beta_1(i-j)$$

$$X_{i6} = \sum_{j=i-p}^{i-1} \dot{T}_{\text{I}j} \quad (1-\beta_2)\beta_2(i-j)$$

$$X_{i7} = \sum_{j=i-p}^{i-1} \dot{T}_{\text{E}j} \quad (1-\beta_2)\beta_2(i-j)$$

.

.

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$$X_{i,\,2m+2} = \sum_{j=i-p}^{i-1} \dot{T}_{\text{I}j} \quad (1-\beta_m)\beta_m(i-j)$$

$$X_{i,\,2m+3} = $$

$$= \sum_{j=i-p}^{i-1} \dot{T}_{\text{E}j} \quad (1-\beta_m)\beta_m(i-j) \qquad \ldots \text{(B.7)}$$

In the sums over j, p is large enough to make the residual sum ($j = i-p$ to minus infinity) negligible. Then, the number of data sets, N, has to be larger than $M+p$. Practically, $p = N-M$, where N is large enough.

The set of equations [see equation (B.12)] gives an estimate, $\vec{Z}_*$, of the vector $\vec{Z}$

$$\vec{Z}_* = [(X)'(X)]^{-1}(X)'q \qquad \ldots \text{(B.8)}$$

where $(X)'$ is the transposed matrix of (X).

In fact, the time constants τ_n are unknown. They are found by looking for the best estimate of $\vec{Z}$ by varying the time constants.

This is done in the following manner:

a) choose the number of time constants, m, to be used. Usually, this number is not more than 3;

b) choose a constant ratio r between these time constants (usually between 3 and 10) in such a way that

$$\tau_1 = r\tau_2 = r^2\tau_3 \qquad \ldots \text{(B.9)}$$

c) choose the number of equations M for the set of equations (B.7). This number must be larger than $2m+3$ but smaller than the number of data sets. Usually, 15 to 40 equations are enough. That means that at least 30 to 100 data points are needed;

d) choose the minimum and maximum values of the time constants. Since the computer has a limited accuracy, there is no sense in handling time constants smaller than $\Delta t/10$. On the other hand, $p = N-M$ points are needed for integration. This integration will not be terminated if the time con-

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stant is larger than $p\ \Delta t$. It is best to choose the largest time constant lying between

$$\Delta t/10 < \tau_1 < p\ \Delta t/2 \qquad \text{... (B.10)}$$

e) in this interval, compute the estimates, $\vec{Z}*$, of the vector $\vec{Z}$ using equations (B.8) for several time constant values. For each value of $\vec{Z}*$, the estimate $\vec{q}*$ of the heat flow vector will be computed by

$$\vec{q}* = (X)\ \vec{Z}* \qquad \text{... (B.11)}$$

f) the total square deviation between this estimate and the measured values will be computed by

$$S^2 = (\vec{q} - \vec{q}*)^2 = \sum (q_i - q_i*)^2 \qquad \text{... (B.12)}$$

g) the best time constant set is the one giving the smallest square deviation. They can be found by repeating steps e) and f) above;

h) the best estimate, $\vec{Z}*$, of the vector $\vec{Z}$ is found in this way. Its first component, Z_1, is the best estimate of the conductance (or the transmittance if air temperature is used).

If the largest time constant found for the best estimate is equal to (or greater than) the maximum value, ($p\ \Delta t/2$), the number of equations or the measurement time are not large enough to give a reliable result with this data set and this ratio between time constants. Changing the number of equations or the ratio of increasing (sometimes also by decreasing) the number of data sets may overcome this difficulty.

Quality criteria are needed to indicate confidence in the results when a single measurement is used to estimate the U-value. They have to be such that, if they are fulfilled for a given, unique measurement, there is good confidence (e.g. 90 % probability) that the result will be close enough to the actual value (e.g. within ± 10 %).

In the case of the classical analysis method, the only criterion is that the measurement time is long enough. Of course, if the recorded data show a quasi-steady state, the measurements have a high probability of giving a good result. However, if the temperatures of heat flow varied substantially just before the beginning of measurements, the final result would be erroneous as the measurement time was not long enough to "forget" the preliminary events.

Such a criterion exists in the case of the dynamic interpretation method. The confidence interval for the estimate of the conductance described above is

$$I = \sqrt{\frac{S^2 Y(1,1)}{M - 2m - 4} F(P, M - 2m - 5)} \qquad \text{... (B.13)}$$

where

S^2 is the total deviation obtained by equation (B.12);

$Y(1,1)$ is the first element of the matrix inverted in equation (B.14):

$$(Y) = [(X)'(X)]^{-1} \qquad \text{... (B.14)}$$

M is the number of equations in system (6) and m the number of time constants;

F is the significance limit of the Student t-distribution, where P is the probability and $M - 2m - 5$ is the degree of freedom.

If this confidence interval for $P = 0,9$ is smaller than, for example, 5 % of the conductance, the computed conductance is generally very close to the actual value, which is in this case the value obtained under good conditions (night-time steady state for light elements, long measurements for heavy ones). For a given measurement time, the smaller the confidence interval, the narrower the distribution of the results of several measurements.

This criterion, however, is not sufficient since the distribution is still large for short periods of measurement and the mean value may be erroneous (generally too low).

The second criteria to fulfil is that the duration of the test is to be larger than the value given in 6.2.

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Annex C
(normative)

Examination of the structure of the element

C.1 General

It may be useful, for example, to explain unexpected results of an R-value measurement or to apply the correction for storage effects, to examine the structure, the workmanship and the moisture content of the element measured. To examine this structure, two methods may be used.

C.2 Sampling method

A sample of a whole section of the element is taken by boring with a hollow drill or by sawing. Other methods such as dust sampling may be suitable for moisture content analysis. Framed structures may also be opened. Thicknesses of the various layers should be measured as accurately as possible and the materials of the various layers identified as far as possible. The densities of these materials may be measured.

If it is considered that there are significant moisture effects, care has to be taken not to change the moisture content of the element by the sampling, either by heating with the drill or saw or by moistening with lubricating water used on diamond drills. The sampled parts should be packed in airtight plastic bags without delay for subsequent moisture content analysis.

C.3 Endoscope method

Another possibility is to drill a hole through the whole element of sufficient diameter to allow inspection of the sides of this hole with an endoscope. Before examination, it is advisable to clean the hole with a small brush and with compressed air or gas.

The thicknesses of the various layers are measured with the endoscope and the materials are identified by their visual appearance. This method is less accurate, particularly for the identification of the materials but causes less damage than the sampling method.

C.4 Interpretation

The thermal resistance of each layer, R_i, is computed using

$$R_i = d_i/\lambda_i \qquad \text{... (C.1)}$$

where d_i is the thickness of the layer (m) and λ_i is a thermal conductivity for the material of the layer, given by the national standards, in watts per metre kelvin [W/(m·K)].

The total thermal resistance is the sum of the resistances of all the layers; the thermal conductance is the reciprocal of the thermal resistance and the U-value is computed using surface resistances taken from national standards or from ISO 6946-1:1986, clause A.1. The result obtained may be compared to the results of the R- or U-value measurements, taking into account all the possible sources of error mentioned (see 7.3).

C.5 Reporting format

The report shall contain

a) data on the examined element (building, location in the building, type of element);

b) method used for the examination;

c) results of the examination (structure of the elements, thicknesses and materials of the various layers);

d) any other measurement taken, e.g. thermography, moisture content or moisture detection, density and thermal conductivity, etc.;

e) interpretation and error analysis.

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Annex D
(informative)

Perturbations caused by the heat flowmeter

D.1 General

The HFM itself has a thermal resistance, and changes by its presence, the heat transfer through the element being measured. The heat flow lines are no longer parallel and the heat flow through the HFM is not the same as the heat flow through the undisturbed element. Reciprocally, the element may have an influence on the flow pattern in the HFM.

This effect can be taken into account by computations, using the equation for heat by conduction.

D.2 One-dimensional perturbation

If the heat flow lines are all straight and perpendicular to the HFM during measurement, the only perturbation is caused by the supplementary resistance of the HFM, which lowers the heat flow rate under given temperature conditions.

D.2.1 *U*-value measurements

In this case, the measured temperature difference from environment to environment is given by

$$\delta T = R_T q' = (R_T + R')q \qquad \ldots \text{(D.1)}$$

where (see figure D.1)

R_T is the total thermal resistance of the element alone;

R' is the resistance of the HFM;

q' is the density of heat flow rate through the element without HFM (not measured);

q is the measured density of heat flow rate in the presence of the HFM.

From equation (D.1) the total thermal resistance or the thermal conductance can be obtained easily:

$$R_T = \frac{\delta T}{q} - R' \quad \text{and} \quad U = \frac{q}{\delta T - R'q} \qquad \ldots \text{(D.2)}$$

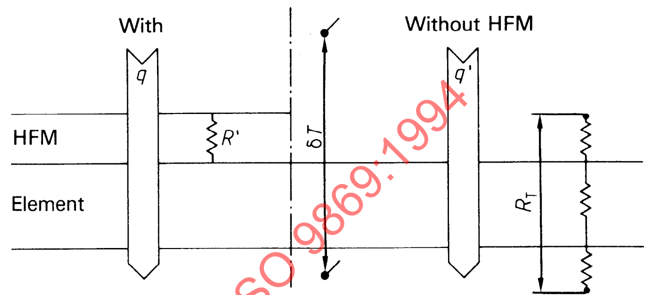

Figure D.1 — Description of the parameters used in equations (D.1) and (D.2)

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D.2.2 *R*-value measurements

Here the surface temperatures are measured (see figure D.2). Two cases are to be examined:

a) if one surface temperature measurement is taken under the HFM, the *R*-value is given by both the following equations:

$$R = \frac{\delta T}{q'} = \frac{\delta T'}{q} \qquad \ldots \text{(D.3)}$$

and the measured value is the actual one and no correction is needed;

b) if one surface temperature measurement is taken beside the HFM, q and δT are obtained, which are not directly related to R. To find the relationship, one can write the ratio of the heat flows, assuming that the environmental temperature and the surface resistance, R'', are the same with and without the HFM:

$$\frac{q'}{q} = \frac{R + R' + R''}{R + R''} \qquad \ldots \text{(D.4)}$$

Combining this relationship with equation (D.3), we eliminate q' to obtain

$$R^2 + R\left(R'' + R' - \frac{\delta T}{q}\right) - R''\frac{\delta T}{q} = 0 \qquad \ldots \text{(D.5)}$$

from which R can be obtained easily. A simpler relationship can be derived if we assume that the actual