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

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Contents

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ISO 9869:1994
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Annexes

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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.

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

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

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:

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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.

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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

1 Scope

1.1 Limits of application

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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	[m^2]
q	density of heat flow rate = Φ/A	[W/m^2]
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/m^3]
d	thickness of a layer	[m]
c	specific heat capacity	[J/(kg·K)]
C	thermal capacity of a layer: $C = \rho c d$	[J/(m^2·K)]
F_i, F_e	correction factors calculated with equation (8) to take into account the storage effects	[J/(m^2·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

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

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

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

where R_T is the total thermal resistance which is given by

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

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 $(m^2 \cdot K/W)$; U and Λ have units of watts per square metre kelvin $[W/(m^2 \cdot K)]$.

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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 dependence 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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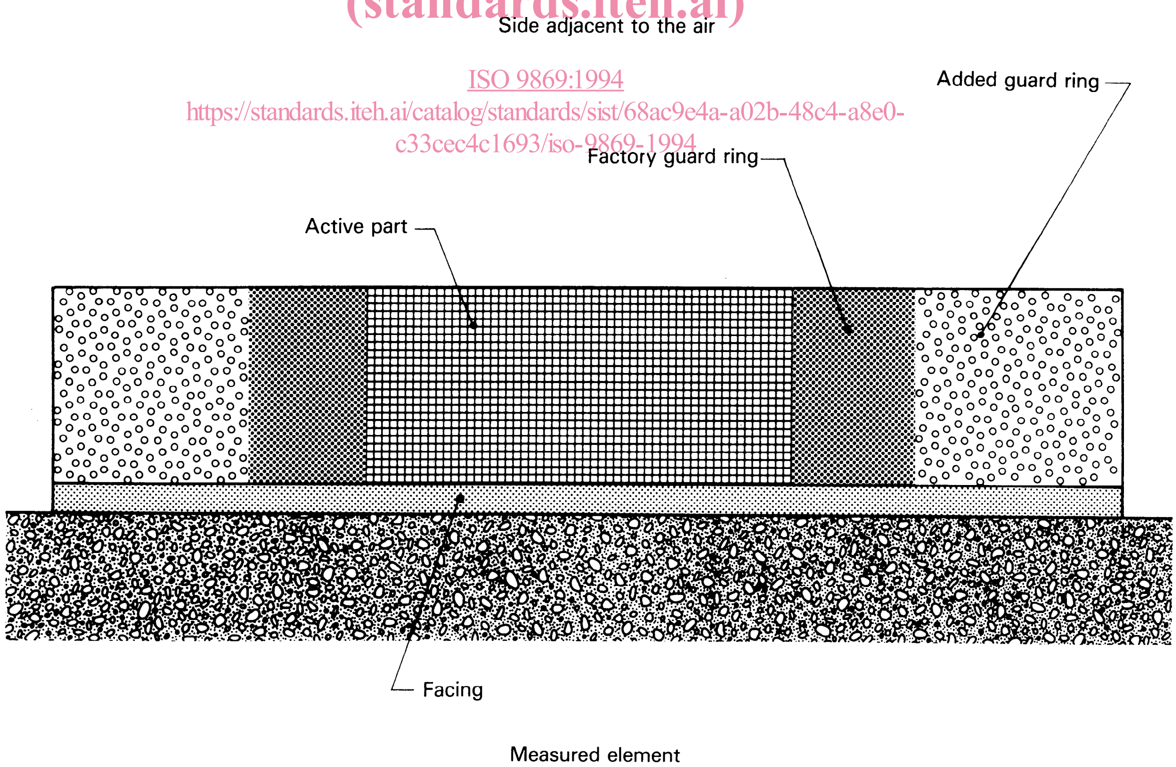

Figure 1 — Section through a typical heat flowmeter showing the various parts (the vertical scale is enlarged)

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.

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ISO 9869:1994
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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 factor 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.

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ISO 9869:1994
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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).

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.

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

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

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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.