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

Part 1:
Heat flow meter method

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

Partie 1: Méthode du fluxmètre

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 1, *Test and measurement methods*.

This first edition cancels and replaces ISO 9869:1994, which has been technically revised.

Annexes A, B and C form an integral part of this part of ISO 9869. Annexes D, E and F 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 flow meter 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 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).

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

Part 1:
Heat flow meter method

1 Scope

This part of ISO 9869 describes the heat flow meter 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.

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 environmental temperatures of both environments are well defined.

The heat flow meter measurement method is also suitable for components consisting of quasi homogeneous layers perpendicular to the heat flow, provided that the dimensions of any inhomogeneity in close proximity to the heat flow meter (HFM) is much smaller than its lateral dimensions and are not thermal bridges which can be detected by infrared thermography (see 6.1.1).

This part of ISO 9869 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.

NOTE 1 It is not intended as a high precision method replacing the laboratory instruments such as hot boxes that are specified in ISO 8990:1994.

NOTE 2 For other components, an average thermal transmittance may be obtained using a calorimeter or by averaging the results of several heat flow meter measurements.

NOTE 3 In building with large heat capacities, the average thermal transmittance of a component can be obtained by measurement over an extended period, or the apparent transmittance of the part can be estimated by a dynamic analysis of its thermal absorption response (see Annex B).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 6946:2007, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*

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 8990:1994, *Thermal insulation — Determination of steady-state thermal transmission properties — Calibrated and guarded hot box*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 7345:1987 apply.

3.2 Symbols and units

Symbol	Quantity	Unit
R	thermal resistance	m²·K/W
R_T	total thermal resistance	m²·K/W
R_{si}	internal surface thermal resistance	m²·K/W
R_{se}	external surface thermal resistance	m²·K/W
Λ	thermal conductance	W/(m²·K)
U	thermal transmittance	W/(m²·K)
Φ	heat flow rate	W
A	area	m²
q	density of heat flow rate $=\Phi/A$	W/m²
T_i	interior environmental (ambient) temperature	°C or K

Symbol	Quantity	Unit
T_e	exterior environmental (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
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: $C=\rho cd$	$J/(m^2·K)$
F_i, F_e	correction factors calculated with Formula (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	-

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

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

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

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

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

where R_T is the total thermal resistance which is given by

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

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

4 Apparatus

4.1 Heat flow meter (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 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. Recent HFMs are very thin, with low thermal resistance, and highly sensitive. If the thermal resistance of the HFM is low enough, the effects of perturbation of the surface heat flow by positioning the HFM is negligible. The heat flow rate is influenced by building elements and the difference between indoor and outdoor temperature. Therefore, HFM with an appropriate sensitivity shall be selected in consideration of these influences (see Annex E).

NOTE More detailed information on the structure and calibration of HFMs can be found in ISO 8301:1991.

4.2 Temperature sensors

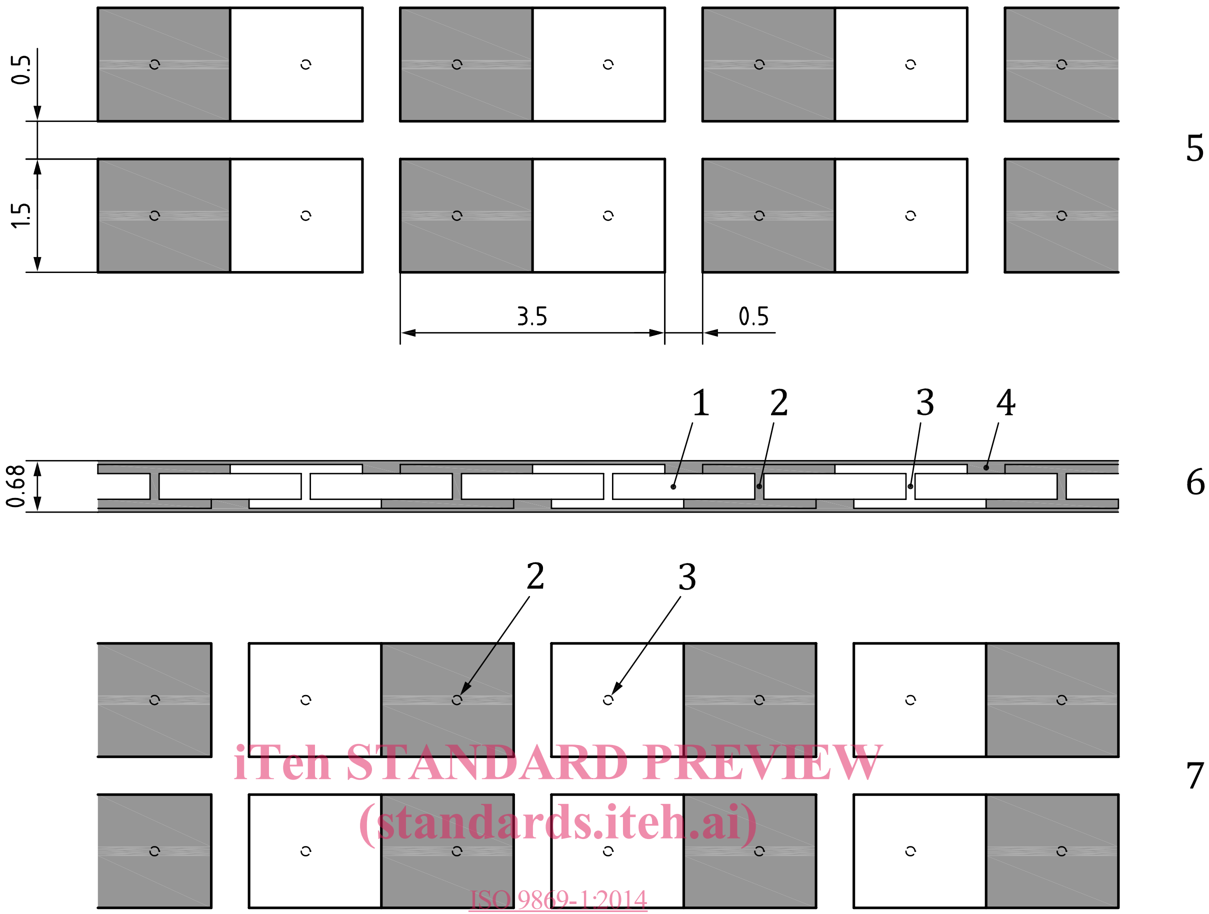
Temperature sensors are transducers giving an electrical signal which is a monotonic function of its temperature.

The effects of the heat flow going through the sensor and on other physical quantities, such as stresses, electromagnetic radiation 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.

Environmental (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).

Dimensions in millimetres



Key

1 base material
2 metal A
3 metal B
4 coating
5 upper surface
6 cross-section
7 under surface

Figure 1 — A typical heat flow meter 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 flow meter shall be evaluated on various materials through an absolute test method such as the guarded hot plate apparatus (ISO 8302:1991) or a heat flow meter 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 HFM calibration with the hot box method (ISO 8990:1994) shall be suited since the calibration condition of the method is closer to the condition of the practical measurement.

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.

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 flow meter 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.

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 (ambient) 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 6781:1983). Sensors shall be mounted in such a way so as to ensure a result which is representative of the whole element.

NOTE 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).

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.