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

Part 2:  
**Infrared method for frame structure  
dwelling**

*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.

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](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by ISO/TC 163, *Thermal performance and energy use in the built environment*, SC 1, *Test and measurement methods*.

A list of all parts in the ISO 9869 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

The ISO 9869 series describes the in-situ 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 thermal transmittance of a building element ( $U$ -value) is defined in ISO 7345 as the “Heat flow rate in the steady state condition divided by area and by the temperature difference between the surroundings on each side of a system”. Since steady state conditions are never encountered on a site in practice, such a simple measurement is not possible and thereby some statistical methods are introduced. One of the simplest methods is using the mean values over a sufficiently long period of time. The required time for observation for reliable measurements depends on the thermal properties of the building components and the natures of the temperature difference between the surroundings on each side of them.

ISO 9869-1 describes the method which is used to estimate the thermal steady-state properties of a building element from heat flow meter (HFM) measurements through plane building components. [Annex B](#) describes the statistical methods of simple mean and the sophisticated method of dynamic analysis method for steady state properties. This document, describes the calculation method for the density of heat flow rate through both the evaluation of the internal surface thermal resistance and the measuring of the temperature difference between the indoor surface temperature of the building element and the indoor environmental temperature using an infrared camera (thermo-viewer). It also describes the statistical methods of simple mean with less observing duration considering night observation and building components with light heat capacity.

This document provides a preliminary and handy measuring method for the in-situ measurement of the thermal transmission properties of plane building components and thereby the further simplifications are applied compared with the method described in ISO 9869-1. The method described in this document is expected as a method of a handy diagnostic method of the thermal transmission properties of plane building components with light heat capacity such as those in frame structure dwelling.

The thermal performance of a part of the building element is evaluated by obtaining the heat absorption (heat penetration) at the part of the indoor surface by multiplying the indoor total heat transfer coefficient of the part surface by the difference between the part indoor surface temperature and the indoor environmental temperature. The thermal transmittance ( $U$ -value) of the building components for steady state condition can be obtained with the averages of the observed values over the certain period of time.

The indoor surface temperature distribution of the building component is measured using an IR camera. The indoor environmental temperature is measured by installing the environmental temperature sensor (ET sensor) on the surface of the building component, and the indoor total heat transfer coefficient of the surface of the building component is measured using a heat transfer coefficient sensor. Even the indoor measurement is intended to be carried on with less influence of solar radiation so the standard can be used on building elements on which indoor sides are not exposed to direct sunlight through adjacent windows.

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

## Part 2: Infrared method for frame structure dwelling

### 1 Scope

This document describes the infrared method for measuring the thermal resistance and thermal transmittance of opaque building elements on existing buildings when observing high emissivity diffuse surface using an infrared (IR) camera. This document demonstrates a screening test by quantitative evaluation to identify the thermal performance defect area of building elements.

This document aims to measure the thermal transmittance (*U*-value) of a frame structure dwelling with light thermal mass, typically with a daily thermal capacity calculated according to ISO 13786 below 30 kJ/(m<sup>2</sup>K).

### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7345, *Thermal performance of buildings and building components — Physical quantities and definitions*

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

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

ISO 9869-1, *Thermal insulation — Building elements — In-situ measurement of thermal resistance and thermal transmittance — Part 1: Heat flow meter method*

### 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

#### 3.1

##### **thermography**

image of a specific band of surface radiance detected with an *infrared camera* (3.2)

Note 1 to entry: On known and uniform high emissivity surfaces, with known and controlled irradiance from the background, and with the proper instrument calibration and operator compensation, the radiance image can be converted to a temperature distribution.

**3.2  
infrared camera**

instrument that collects the infrared radiant energy from a target surface and produces an image in monochrome (black and white) or colour, where the grey shades or colour hues are related to target surface apparent temperature distribution

**3.3  
total heat transfer coefficient**

sum of the convective heat transfer coefficient and the radiative heat transfer coefficient of the surface of a building element

Note 1 to entry: It is assumed to be measurable using the heat transfer coefficient sensor.

**3.4  
heat transfer coefficient sensor**

sensor to approximately measure the *total heat transfer coefficient* (3.3) of the surface of a building element which can measure the total heat transfer coefficient in the neighbourhood of a section of the building element

**3.5  
environmental temperature**

conceptual temperature taking account of the indoor and outdoor air temperatures and radiant heat of a building element used for calculating the thermal transmittance (thermal resistance) of the building element

Note 1 to entry: A temperature measured by an *environmental temperature sensor* (3.6) is treated as the environmental temperature.

**3.6  
environmental temperature sensor  
ET sensor**

sensor that takes an approximate measure of the indoor and outdoor environmental temperatures of a building element to be measured

**4 Symbols and units**

Symbol	Quantity	Units
$A$	heat transfer area of the region	m <sup>2</sup>
$A_j$	region area of the region with surface temperature $\theta_{sj}$	m <sup>2</sup>
$h$	total heat transfer coefficient	W/(m <sup>2</sup> K)
$\theta_n$	environmental temperature	°C
$\theta_s$	surface temperature	°C
$\theta_a$	inside air temperature	°C
$\theta_{ni}$	inside environmental temperature of the region to be measured	°C
$\theta_{ne}$	outside environmental temperature of the region to be measured	°C
$\theta_{sj}$	surface temperature of section $j$	°C
$\theta_{hs}$	surface temperature of heat transfer coefficient sensor	°C
$\theta_{rj}$	plane radiant temperature of section $j$	°C
$Q$	heat flow rate	W
$q$	heat flow of the heat transfer coefficient sensor	W/m <sup>2</sup>

Symbol	Quantity	Units
$r_j$	area ratio of the heat transfer area of section $j$	—
$R_T$	total thermal resistance	(m <sup>2</sup> K)/W
$U$	thermal transmittance	W/(m <sup>2</sup> K)

## 5 Principle

This method (illustrated in [Figure 1](#)) measures the amount of irradiance of regions in contact with the outside air from the surface temperature, total heat transfer coefficient and environmental temperature. The difference between the inside and outside temperature is then used to determine thermal transmittance/thermal resistance of the regions that are in a steady-state.

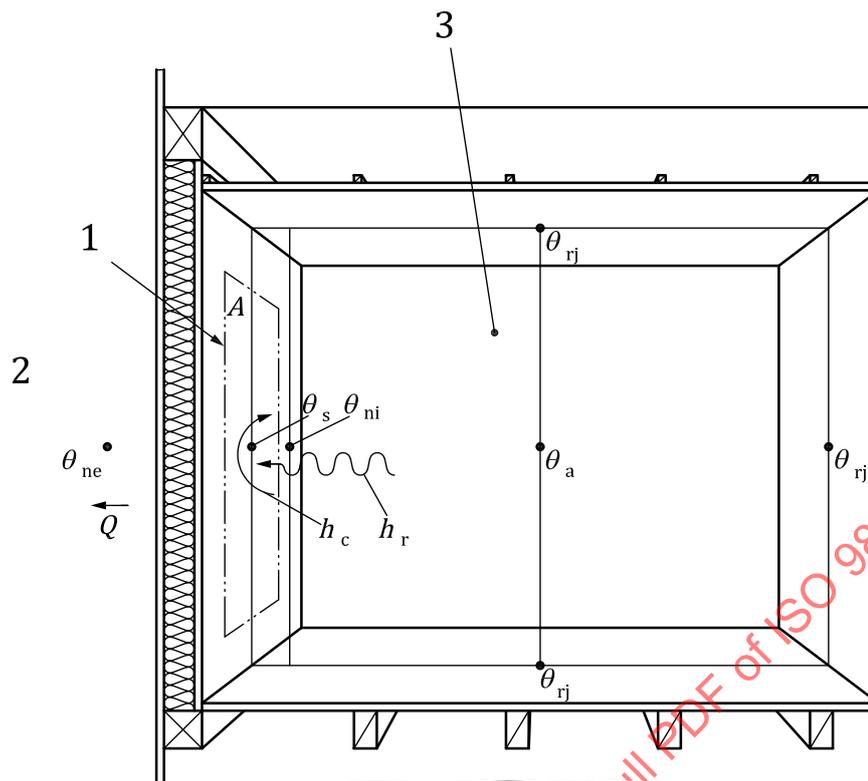
The amount of irradiance of regions in contact with the outside air when being heated is derived from [Formula \(1\)](#) in relation to the inside temperature ([Annex A](#)).

$$Q = h(\theta_n - \theta_s)A \quad (1)$$

The amount of irradiance of the region can be determined using [Formula \(1\)](#) and the measurement of the temperature of the inside surface temperature of the region made with an infrared camera, together with the readings of the total heat transfer coefficient and environmental temperature obtained from the heat transfer coefficient sensor and ET sensor mounted near the region. If the surface temperature of the region being measured varies, the average temperature is used by taking the temperature of each area of the region. This method defines the environmental temperature as a value approximately measured by an ET sensor. The method to obtain the environmental temperature is shown in [Annex B](#).

The amount of irradiance of the region is measured when it is in a constant state away from direct sunlight at night for at least three hours, and calculated using [Formula \(2\)](#) and the difference between the inside and outside environmental temperature.

$$U = \frac{Q}{(\theta_{ni} - \theta_{ne}) \cdot A} \quad (2)$$



**Key**

- 1 measurement area
- 2 outside
- 3 inside

**Figure 1 — Outline of measurement principle**

**6 Requirements for apparatus**

**6.1 General**

The necessary apparatus for in-situ measuring thermal resistance and thermal transmittance are as following:

**6.1.1 Infrared camera.**

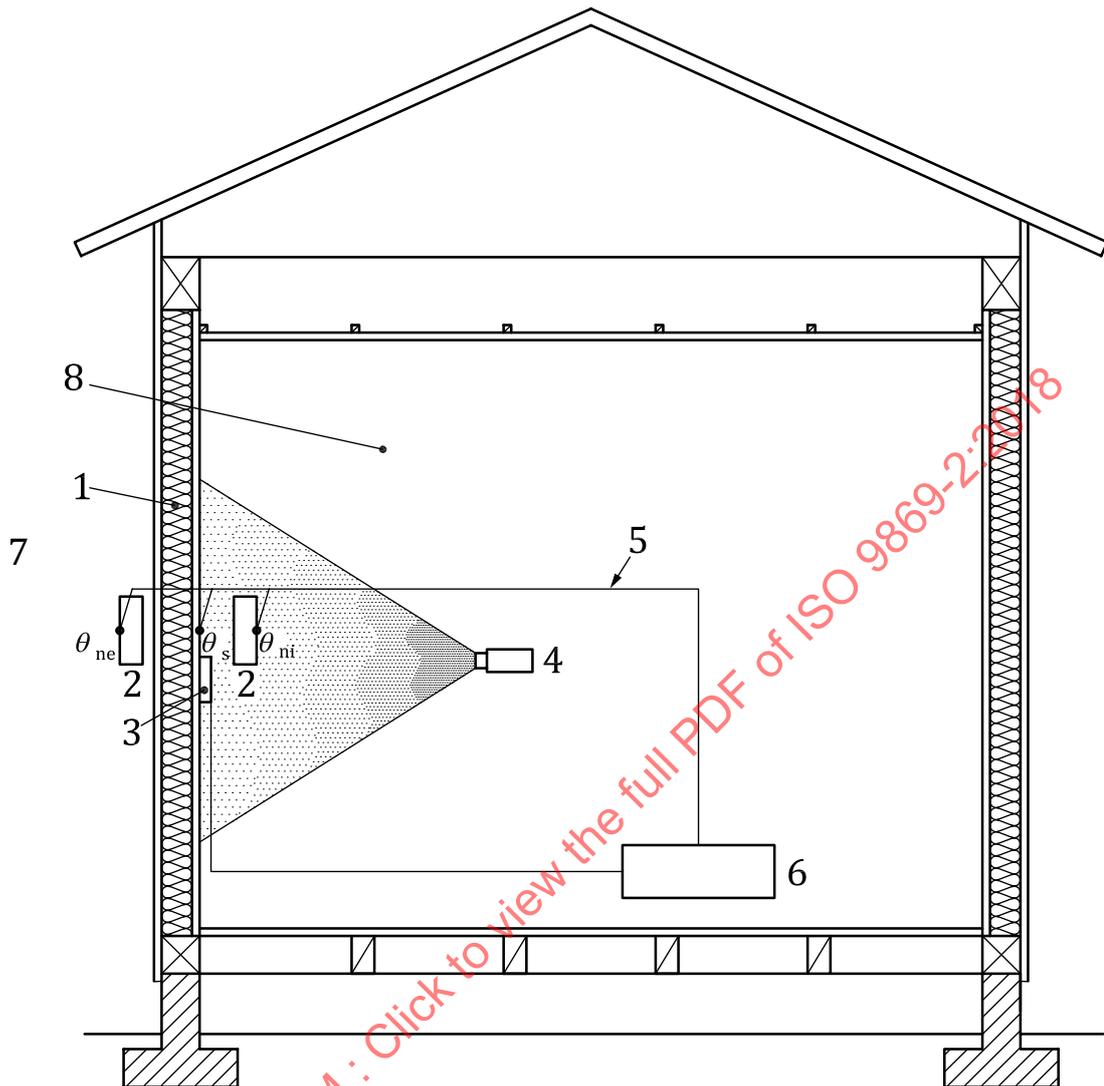
**6.1.2 Heat transfer coefficient sensor.**

**6.1.3 ET sensor.**

**6.1.4 Thermocouple thermometer.**

**6.1.5 Data logger.**

Configuration of the apparatus is shown in [Figure 2](#).



### Key

- 1 measurement area
- 2 ET sensor
- 3 heat transfer coefficient sensor
- 4 IR camera
- 5 thermocouple
- 6 data logger
- 7 outside
- 8 inside

Figure 2 — Measurement outline (cross-section)

## 6.2 Infrared camera

Infrared cameras detect infrared radiation on the surface of the object being measured, with the intensity distribution being displayed as a thermal image. The range of wavelength that can be measured is the same as normal thermal radiation at  $8\ \mu\text{m}$  to  $13\ \mu\text{m}$ . The camera shall be capable of detecting temperatures between the overall blackbody temperature range of at least  $-20\ ^\circ\text{C}$  to  $100\ ^\circ\text{C}$ .

Thermal sensitivity shall not be worse than  $80\ \text{mK}$  on a  $30^\circ$  blackbody object temperature. Measurements can be made at regular intervals for automatic logging of temperature. Infrared cameras

that come with software that processes and displays the measured temperature data as an image are preferable.

### 6.3 Heat transfer coefficient sensor

The heat transfer coefficient sensor is used to estimate the total heat transfer coefficient of the surface of the region of the object being measured. It has an insulating plastic foam backing and has a heating sheet connected to a heat flow meter. The surface of the heating sheet is copper sheet, with the heat flow meter attached to the front of the copper sheet. A sheet type electrical heater is used to heat the copper sheet in a uniform fashion. The surface of the copper sheet is finished with a matte black coating (with an emittance greater than 0,9), and a thermocouple (with a diameter of less than 0,2 mm or a thermocouple for surface measurements) is attached to the surface. The sensor shall have a size of 200 × 200 mm with a thickness of 25 mm as a standard.

Using the heat flow meter stretched on the heating sheet before building it into the heat transfer coefficient sensor, calibrate the relation of the heat flow density to the output, following the procedure specified in ISO 8301 or in ISO 8302. The structure and calibration of heat transfer coefficient sensor is shown in [Annex C](#).

### 6.4 ET sensor

The ET sensor is used to measure the environmental temperature of the regions of the object to be measured. The size of the meter is approximately 200 × 200 mm with a thickness of 50 mm, consisting of an insulating plastic foam and attached on the surface of copper sheet finished with a matte black coating (with an emittance greater than 0,9). A thermocouple (with a diameter of less than 0,2 mm or a thermocouple for surface measurements) is attached to the surface. The construction of the ET sensor is shown in [Annex B](#).

### 6.5 Thermocouple

The recommended temperature sensor is the type T thermocouple (copper/constantan) according to IEC 60584-1 made from wire with diameter not greater than 0,25 mm. The temperature range available consists of a standard temperature gauge and corrected for use with a data logger. If alternative sensors are used, they should be at least as accurate as the above-mentioned, not subject to drift or hysteresis.

### 6.6 Data logger

The data logger automatically records the measured data of the temperature and heat flow from this experiment with the required accuracy at regular intervals.

## 7 Measurement method

### 7.1 Building

The measurement object shall be a frame structure dwelling with a relatively small heat capacity [a heat capacity per unit area of about 30 kJ/(m<sup>2</sup>K) or less]. It is preferable if the details of the buildings are researched thoroughly in advance using floorplans. Visual observations are made in-situ before the measurements are made in order to select the appropriate regions for measurement.

### 7.2 Location of the measured area

The measurement position shall be selected according to the purpose of the test. The measured area shall not be under the direct influence of either a heating or a cooling device or under the draught of a fan. And the measurement area should be free of all visual interference from curtains, wall hangings, furnishings, plants, light fixtures and anything that impedes the field of view for the IR imager.

### 7.3 Measurement conditions

The conditions of the measurement state that there must be a difference greater than 10 °C between the inside and outside temperature when the heater is on. When the temperature differences is small, the accuracy required for measuring this quantity may be lowered. The heating is achieved with the heater that is used normally to keep the inside at a constant temperature. If there is no heating equipment, an electrical heater with a fan can be used to heat the inside of the building. When stirring the air in the room, take caution so that the airflow moving around the building element is not greatly different from that under normal room conditions. The inside of the region to be measured must be completely sealed by closing the building doors. If the room where the measurement takes place has openings such as a sash window, block the window with curtains, shades, etc. to eliminate any temperature variation. In the case of measurement conditions that are affected, such as infiltration, liquid water moisture, air leakage and other uncontrolled climatic conditions, this situation should be described in the report.

### 7.4 Measurement of heat transfer coefficient

The heat transfer coefficient sensor is mounted near the centre of the surface of the region to be measured. Next, the power to the heat transfer coefficient sensor electrical heater is turned on and the power adjusted so that the temperature of the surface of the sensor is between 2 and 4 °C higher than the inside air temperature of the region to be measured.

The use of the heat transfer coefficient sensor is assumed that the measured values would correspond to the plane averaged local total heat transfer coefficient over the testing building element. If there are some reasons that this assumption cannot be stood, for examples, the testing building element is vertically long enough and the local convective heat transfer coefficient will vary a lot from the bottom to the top, a number of heat transfer coefficient number sensors may be arranged including the centre. The variation of the measured values from the sensors might be recorded for the reference purpose of the measurement reliability. The surface temperature of the heat transfer sensor shall be preset to be the same as the difference (absolute value) between air temperature in the room where the measurement takes place and a typical surface temperature of the section to be measured. The temperature difference shall be higher than 2 °C.

Under the condition that the surface temperature of the heat transfer coefficient sensor is stable, measure the following:

- Surface temperature of the heat transfer coefficient sensor measured by an infrared camera:  $\theta_{hs}$
- Surface temperature of the ET sensor measured by an infrared camera (environmental temperature:  $\theta_{ni}$ )
- Heat flow meter output on the surface of the heat transfer coefficient sensor (heat flow density:  $q$ )

The total heat transfer coefficient is calculated with [Formula \(3\)](#).

$$h = \frac{q}{\theta_{hs} - \theta_{ni}} \quad (3)$$

In addition, when the thermal performance of the building elements is low (e.g. in case of the differences temperature between surface and air temperature are more than 2 K as an aim), the heat flow meter (HFM) can be attached directly to the inside surface, and surface temperature of HFM is measured by an infrared camera, and the total heat transfer coefficient can be calculated with [Formula \(3\)](#). Avoid attaching the heat flow meter to any areas where a heat bridge may be formed. The surface should be finished with a matte black coating (with an emittance greater than 0,9). When using a heat flow meter, refer to ISO 9869-1.

### 7.5 Measurement of environmental temperature

The environmental temperature is measured with the ET sensor on both the inside and outside of the building. The ET sensor on the inside of the building is mounted near the centre (but not attached

directly to the surface of the region) of the region to be measured. Measure the surface temperature of the indoor ET sensor, first using a thermocouple, and then using an infrared camera. When the resultant temperatures are different, adjust the emissivity to set the surface temperature measured by the infrared camera to that measured by the thermocouple. Use the environmental temperature measured by the infrared camera for calculating the total heat transfer coefficient and the heat flow rate, and use the temperature measured by the thermocouple for calculating the difference between the indoor and outdoor environmental temperatures.

The use of the ET sensor is assumed that the air temperature distribution close to the testing building element is not significant or almost uniform and there is no distinct imbalance of radiative temperature. If there is a large air temperature gradient or imbalance of the inner surface temperature distribution, a number of ET sensors may be arranged including the centre. The variation of the measured values from the ET sensors might have some relationship with the measured internal surface temperature of corresponding position and might give the same interpretation of the measured  $U$ -value of the testing building element.

Place the outdoor ET sensor, as well as the indoor sensor, around the centre of the section to be measured. Use a surface temperature of the ET sensor measured by the thermocouple as the environmental temperature.

## 7.6 Surface temperature distribution of building elements

The thermal image of the surface temperature (distributed temperature) of the region to be measured is measured with an infrared camera. Place the infrared camera in front of the section to be measured. Adjust the position of the infrared camera to be able to measure the surface temperature of the section as wide as possible. When the measurement covering the whole section is inevitably impossible, divide the section into subsections, measure all, observe the surface temperature distribution, and select a subsection representing the whole section. Since surface temperature cannot be measured properly, avoid selecting openings such as a sash window and the neighbourhood of local heat sources.

The surface temperature of a typical subsection shall be measured using thermocouples or other thermometers which enable measuring surface temperature with the same or more precise accuracy than thermocouples as well as an infrared camera. The measured values shall be used for emissivity correction for an infrared camera in order for the infrared camera to indicate the identical temperature at the place where thermocouple measurement is done.

## 7.7 Measurement time and measurement interval

The measurement time period is at night when there is no sunshine (from one hour after sunset to sunrise). When measuring a frame structure dwelling with a relatively small heat capacity [a heat capacity per unit area of about  $30 \text{ kJ}/(\text{m}^2\text{K})$  or less], select three to six hours between 0 am and 6 am as a measurement time period.

The standard measurement intervals shall be 30 min or less. The periodically measured data both with an infrared camera and thermocouples should be synchronically recorded.

## 7.8 Measurement terms

The following parameters should be measured by the infrared camera:

- a) Surface temperature of the section to be measured;
- b) Surface temperature of the heat transfer coefficient sensor;
- c) Surface temperature of the indoor ET sensor (indoor environmental temperature).

The following parameters should be measured by the thermocouple:

- a) Surface temperature of the heat transfer coefficient sensor;

- b) Surface temperature of the indoor ET sensor (indoor environmental temperature);
- c) Surface temperature of the outdoor ET sensor (outdoor environmental temperature);
- d) Typical surface temperature of the section to be measured;
- e) If necessary, indoor surface temperatures of sections other than the one to be measured;
- f) As a reference, indoor and outdoor air temperatures.

Measure the heat flow rate using a heat transfer coefficient sensor.

Use both an infrared camera and a thermocouple when measuring the surface temperature of the indoor ET sensor and that of the heat transfer coefficient sensor.

## 7.9 Measurement period

The recommended time period for measuring should be for three consecutive days. Finish the measurement after making sure that the results of the three-day measurement of all tests fall within a range of  $\pm 10\%$ . The measurement result is calculated by the procedure in [Clause 8](#). If they do not all fall within the range, continue the measurement until the results of consecutive three-day measurement of all fall within a range of  $\pm 10\%$ .

In the cases where consecutive measurement is impossible due to time limitation, a minimum of a one-day measurement is acceptable. In such cases, however, pay attention to weather, room temperature variations, and other conditions before starting the measurement, and try to realize a quasi-steady state condition as soon as possible within the measurement period. These efforts would be useful for studying factors affecting measurement accuracy (uncertainty).

NOTE As the quasi-steady-state condition, it is preferable that the  $U$ -value calculated every hour using [Formula \(6\)](#) fall within a range of  $\pm 10\%$ .

## 8 Calculations

### 8.1 Heat transfer area

Set a pre-measured subsection of the section to be measured as a heat transfer area and mark its four corners with a piece of adhesive tape so that the area fits into the thermography measured by the infrared camera.

### 8.2 Calculation of heat flow rate

Using the thermography showing the surface temperature (distribution) to apply area-weighting to the heat transfer area of the section, calculate the average surface temperature in the area. Obtain the heat flow rate passing through the section from the calculated average surface temperature, the measured total heat transfer coefficient, and the measured environmental temperature.

Perform image processing on the thermography of the section to be measured in 0,5 °C intervals or less, obtain the ratio,  $r_j$  of the area with the temperature concerned,  $\theta_{sj}$ , to the area to be measured,  $A$ , and use area-weighting to calculate the average temperature of the section from [Formula \(4\)](#):

$$\theta_s = \sum r_j \cdot \theta_{sj} \tag{4}$$

Using the obtained average temperature, calculate the heat flow rate,  $Q$ , passing through the section from [Formula \(5\)](#):

$$Q = h(\theta_{ni} - \theta_s)A \tag{5}$$

In addition, when it is considered that the indoor of a room is a natural convection state, the value of [Table 1](#) may be used for the value of the total heat transfer coefficient,  $h$ . If the values of [Table 1](#) were used, they shall be described in the report.

**Table 1 — Total heat transfer coefficient without forced convection**

Dimensions in W/(m<sup>2</sup>K)

Surface	Direction of heat flow		
	Upwards	Horizontal	Downwards
Internal	10	7,7	5,9

NOTE The radiative heat transfer coefficient,  $h_r$ , is not depended in the direction of heat flow, but is set to 5,1 W/(m<sup>2</sup>K) as fixed. This value is calculated for emissivity of the surface to 0,9, and evaluated the mean temperature of an internal surface as 20 °C. The value of  $h$  refer to ISO 6946.

### 8.3 Calculation of thermal transmittance

The total heat transfer coefficient is determined from [Formula \(6\)](#) after calculating the average values for irradiance and environmental temperature. The measurement results are rounded to 2 significant figures. Calculate the average of the heat flow rates and that of the environmental temperatures measured daily in a night-time measurement period. Using the results, obtain the thermal transmittance of the section from [Formula \(6\)](#). Round the measurement results to 2 significant figures. Then calculate the average of the thermal transmittance values consecutively measured for three days, and use it as the thermal transmittance of the section concerned. However, the actual duration of test shall be for circumstances. The total thermal resistance shall be calculated using [Formula \(7\)](#):

$$U = \frac{Q}{(\theta_{ni} - \theta_{ne}) \cdot A} \tag{6}$$

$$R_T = 1 / U \tag{7}$$

## 9 Measurement accuracy

The overall uncertainty of this test depends on many factors. It is desirable to conduct an analysis of uncertainty for the  $U$ -value obtained in accordance with this document and the analysis should be conducted with reference to [Annex D](#) and [Annex E](#).

## 10 Test reports

The results of the experiment should include the following items.

- a) Required details for measurement objectives:
  - Location of the building where the element is measured;
  - Position of the section to be measured in the building, and azimuth orientation in particular;

- Type of the building element (exterior wall, ceiling, floor, etc.);
  - Structure, material construction, and thickness of the building element;
- b) Required details for measurement conditions:
- Types, specifications, and installation of measuring instruments;
  - Measurement items, measurement points;
  - Measurement intervals, number of measurement;
  - Measurement start date and time, measurement finish date and time;
  - If In the case of measurement conditions that are affected by infiltration, liquid water, moisture, air leakage and climatic conditions, this situation should be described in the report;
- c) Measurement data:
- Graphs of measured temperatures, heat flow rates, etc.;
  - Thermography;
  - Inside and outside average environmental temperatures, average total heat transfer coefficient, average heat flow rate in the measurement time period;
- d) Measurement results:
- Thermal transmittance, thermal resistance;
- e) Measurement organization.

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## Annex A (informative)

### Measurement principle

#### A.1 Background

Under steady state heat flow conditions, the difference between the indoor surface temperature of a building element and the corresponding indoor environmental temperature reflects the thermal transmittance of the building element. A large difference between the indoor and outdoor environmental temperatures means the internal surface thermal resistance is high and the thermal resistance of the building element is lower. Conversely, a small temperature difference means the thermal resistance of the building element is much higher than the internal surface thermal resistance. Strictly defined, the indoor environmental temperature cannot be measured. However, the inner surface temperature of an adiabatic plane material placed close to but not in contact with a building element provides a good representation of the indoor environmental temperature, since its surface temperature reaches equilibrium with the convective heat transfer from the surrounding air and the radiation heat transfer from the indoor building element. In this document, the surface temperature of the adiabatic plane material is assumed to represent the indoor environmental temperature.

It is well known that the reciprocal of internal surface thermal resistance, the total heat transfer coefficient (including both convective and radiative heat transfer) of the internal surface, does not vary significantly and shows most of the same common values as other buildings. Therefore, the heat flow rate through a building element can be evaluated by the difference between the temperatures of the indoor building element surface and the indoor environment and the total heat transfer coefficient. Since the internal surface thermal resistance with convection depends on the nature of the thermal boundary layer on the internal surface and is usually assumed to be thin, and the density of the convective heat transfer rate is assumed to reach equilibrium quickly, and since the internal surface resistance caused by radiative heat transfer is very rapid and reaches equilibrium instantly, the product of the temperature difference between the internal surface temperature and the indoor environmental temperature and the total heat transfer coefficient can express the density of the heat transfer flow through a building element immediately and is substituted for measurement with a heat flow meter (HFM).

An infrared (IR) camera can easily observe the internal surface temperature of the entire area of one building element and is an effective technique for identifying thermal weak points and heat bridges. It can also give the plane-averaged surface temperature of building elements. Thus, the IR camera is useful for identifying thermal performance defects of building elements. A method which measures the thermal transmittance ( $U$ -value) of building elements quantitatively is also useful, even though the accuracy of the method may be limited.

#### A.2 Measurement principle

[Formula \(A.1\)](#) expresses the heat transfer at the indoor surface of a building element exposed to the outdoor air (hereafter called the wall to be measured), considering both convection and radiation.

$$q = h_c (\theta_a - \theta_s) + h_r (\theta_r - \theta_s) \quad (\text{A.1})$$

where

- $q$  is the heat transfer from inside (W/m<sup>2</sup>);
- $h_c$  is the convective heat transfer coefficient (W/(m<sup>2</sup>K));
- $h_r$  is the radiative heat transfer coefficient (W/(m<sup>2</sup>K));
- $\theta_a$  is the indoor air temperature (°C);
- $\theta_s$  is the surface temperature of wall (°C);
- $\theta_r$  is the inside average surface radiative temperature excluding wall surfaces (°C).

[Formula \(A.1\)](#) is modified as

$$\frac{q}{(h_c + h_r)} = \frac{h_c \cdot \theta_a + h_r \cdot \theta_r}{(h_c + h_r)} - \theta_s \quad (\text{A.2})$$

On the assumption of [Formula \(A.1\)](#):

$$\theta_n = (h_c \cdot \theta_a + h_r \cdot \theta_r) / (h_c + h_r), \quad h = h_c + h_r, \quad (\text{A.3})$$

[Formula \(A.2\)](#) is expressed as [Formula \(A.4\)](#).

$$q = h(\theta_n - \theta_s) \quad (\text{A.4})$$

where

- $h$  is the total heat transfer coefficient (W/(m<sup>2</sup>K));
- $\theta_n$  is the environmental temperature (°C).

The value of  $q$  can be obtained by measuring  $h$ ,  $\theta_n$  and  $\theta_s$ .  $\theta_s$  is measured with an IR camera, and  $h$  is measured with a heat transfer coefficient sensor placed near the wall. The environmental temperature  $\theta_n$ , a conceptual quantity, is defined here as the temperature measured by an environmental temperature (ET) sensor.

The temperature distribution on an actual wall surface is non-uniform and varies from area to area. The area-weighted average surface temperature can be obtained by calculating the areas of parts of the wall surface with equal temperatures.

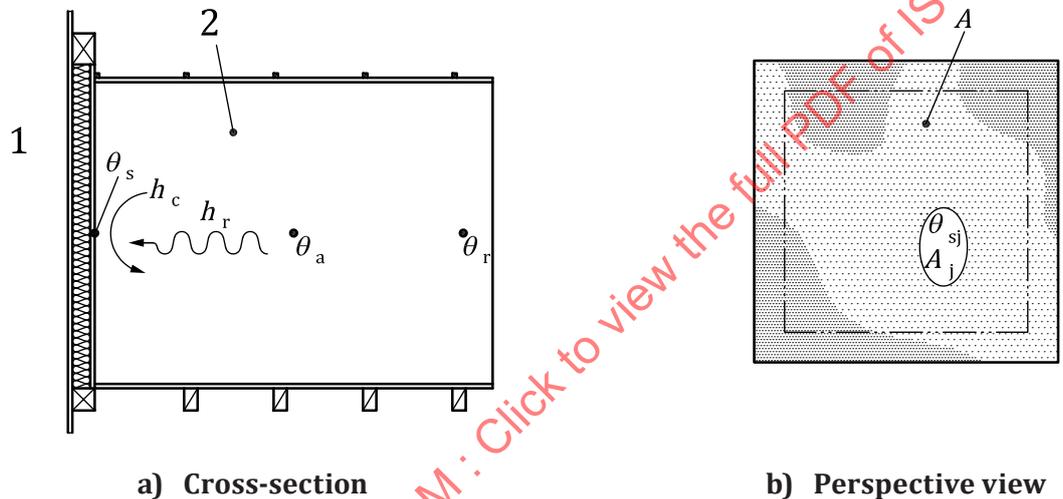
Using the measured outdoor environmental temperature and assuming that a quasi-stationary state exists, [Formula \(A.5\)](#) gives the thermal transmittance of the wall to be measured.

$$U = Q / [(\theta_{ni} - \theta_{ne}) \cdot A] \tag{A.5}$$

where

- $U$  is the thermal transmittance (W/(m<sup>2</sup>K));
- $Q$  is the heat transfer from entire wall (W);
- $\theta_{ni}$  is the indoor environmental temperature (°C);
- $\theta_{ne}$  is the outdoor environmental temperature (°C);
- $A$  is the heat transfer area (m<sup>2</sup>).

If the outdoor air temperature is measured, and the air is assumed to be in a constant state, the irradiance of the wall can be determined.



- Key**
- 1 outside
  - 2 inside

**Figure A.1 — Measurement principle**

### A.3 Applications and limitations

This document, in which an IR camera is used, provides a method for evaluating the thermal performance of a part of a building element by obtaining the heat absorption (heat penetration) of the part by multiplying the total heat transfer coefficient of the part surface by the difference between the part surface temperature and the indoor environmental temperature.

The surface temperature distribution of the building element is measured with an IR camera. The indoor environmental temperature is measured by installing an environmental temperature sensor ET sensor on the surface of the building element, and the total heat transfer coefficient of the surface of the building element is measured by using a heat transfer coefficient sensor.

An IR camera can easily observe the internal surface temperature of the entire area of one building element, and enables measurement of the apparent plane-averaged thermal transmittance of the building element by the difference between the indoor and outdoor environmental temperatures,

even when a heat bridge or thermal weak point exists in the part and heat transfer occurs due to 2-dimensional thermal flux or a vent layer (aerated zone).

The  $U$ -value of building elements in the steady state can be obtained by this method from the averages of the observed values over a certain period of time.

With this method, only the internal surface temperature is observed with the IR camera; the outer surface temperature is not observed. During daytime, the outer surface temperature is easily affected by local shade and solar radiation. The effects of shade and solar radiation last a relatively long time, and the outer surface temperatures of each building element vary greatly with time and space. The total heat transfer coefficient of the outer surface of building elements also depends strongly on the outdoor wind velocity and varies greatly with space and time. These factors make it difficult to measure or estimate the density of the heat flow through building elements by outdoor IR camera observation. Therefore, in the method in this standard, the internal surface temperature is observed with an IR camera only at night. This condition is applied because that the outdoor air temperature and room temperature are relatively stable at night, temperature is unaffected by sunlight, and heat transmission through building elements is in a relatively steady state condition due to the relatively light thermal mass properties of wood frame dwellings. Although the method in this standard is only applied to the light thermal capacity building elements of wood frame dwellings, the  $U$ -value of building elements for the steady state condition should be estimated statistically.

When the  $U$ -value is high, the value obtained by this method can be quantified accurately. However, when the  $U$ -value is low, the heat flow of the building element is low, making it difficult to ensure that the measurement is reliable.

In buildings with large heat capacities, the average thermal transmittance of a part can be obtained by measurement over an extended period, or the apparent thermal transmittance of the part can be estimated by a dynamic analysis of its thermal absorption response.

## Annex B (informative)

### Calculation of environmental temperature, structure of ET sensor

#### B.1 Determining the environmental temperature

The environmental temperature of a certain region inside the building can be calculated from the radiative and convective heat transfers as described in [Annex A](#), however the following describes how the ET sensor can be used to determine the environmental temperature from nearby regions.

[Formula \(B.1\)](#) expresses the radiative heat transfer rate  $Q_r$  of a section  $j$  [[Figure B.1](#) (a)]

$$Q_{rj} = A_j F_{jn} \sigma (T_r^4 - T_j^4) \tag{B.1}$$

where

$Q_{rj}$  is radiative heat transfer rate of the section  $j$  (W);

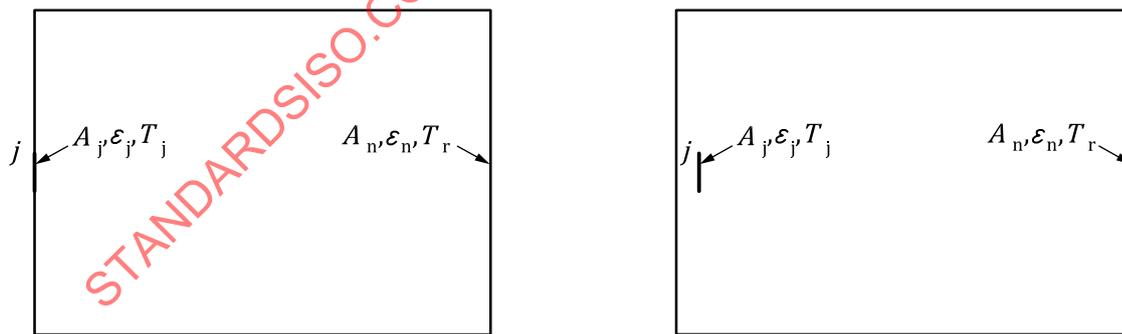
$A_j$  is area of the section  $j$  (m<sup>2</sup>);

$F_{jn}$  is view factor of the room looked from the section  $j$  (-);

$T_r$  is plane radiation temperature of the section  $j$  (K);

$T_j$  is surface temperature of the section  $j$  (K);

$\sigma$  is Stefan-Boltzmann constant (W/m<sup>2</sup>K<sup>4</sup>).



a) Section  $j$  on the wall to be measured

b) ET sensor ( $j$ ) placed in the neighbourhood of the wall to be measured

**Figure B.1 — Radiant heat transfer between the section  $j$  and the indoor environment**

Since the section  $j$  is completely enclosed by indoor space, [Formula \(B.1\)](#) can be expressed as [Formula \(B.2\)](#):

$$Q_{rj} = A_j \frac{1}{\frac{1}{\varepsilon_j} + \frac{A_j}{A_n} \left( \frac{1}{\varepsilon_n} - 1 \right)} \sigma (T_r^4 - T_j^4) \quad (\text{B.2})$$

where

$\varepsilon_j$  is emissivity of the section  $j$  (-);

$\varepsilon_n$  is emissivity of the room (-);

$A_n$  is area inside the room ( $\text{m}^2$ ).

[Formula \(B.3\)](#) expresses the radiative heat transfer rate per unit area of the section  $j$ :

$$q_{rj} = \frac{Q_{rj}}{A_j} = \frac{1}{\frac{1}{\varepsilon_j} + \frac{A_j}{A_n} \left( \frac{1}{\varepsilon_n} - 1 \right)} \sigma (T_r^4 - T_j^4) \quad (\text{B.3})$$

Where  $q_{rj}$  is radiative heat transfer rate per unit area of the section  $j$  ( $\text{W}/\text{m}^2$ ).

Since the section  $j$  is extremely small compared to the room space, setting  $A_j \ll A_n$  gives the simplified version of [Formula \(B.3\)](#) (wall materials have a value of  $\varepsilon_n$  of about 0,9) as shown in [Formula \(B.4\)](#):

$$q_{rj} \approx \varepsilon_j \sigma (T_r^4 - T_j^4) \quad (\text{B.4})$$

[Formula \(B.4\)](#) is transformed into [Formulae \(B.5\)](#) and [\(B.6\)](#):

$$q_{rj} = \varepsilon_j \sigma (T_r^4 - T_j^4) \approx 4\varepsilon_j \sigma \left( \frac{T_r + T_j}{2} \right)^3 (T_r - T_j) = h_{rj} (T_r - T_j) \quad (\text{B.5})$$

$$h_{rj} = 4\varepsilon_j \sigma \left( \frac{T_r + T_j}{2} \right)^3 \quad (\text{B.6})$$

where  $h_{rj}$  is radiative heat transfer coefficient of the section  $j$  ( $\text{W}/\text{m}^2\text{K}$ ).

[Formula \(B.7\)](#) expresses the convective heat transfer rate per unit area  $q_{cj}$  of the section  $j$ :

$$q_{cj} = h_{cj} (T_a - T_j) \quad (\text{B.7})$$

where

$h_{cj}$  is convective heat transfer coefficient of the section  $j$  ( $\text{W}/\text{m}^2\text{K}$ );

$T_a$  is air temperature in the room (K).

Taking account of the radiative heat transfer rate and the convective heat transfer rate, the heat transfer rate to the section  $j$  can be expressed as [Formula \(B.8\)](#):

$$q_j = q_{cj} + q_{rj} = h_{cj} (T_a - T_j) + h_{rj} (T_r - T_j) \quad (\text{B.8})$$

where  $q_j$  is heat transfer rate of the section  $j$  ( $\text{W}/\text{m}^2$ ).

Place an ET sensor in the neighbourhood of the section  $j$  [[Figure B.1](#) (b)] and assume that the heat balance of the surface of the ET sensor is zero (completely insulated) ( $q_j = 0$ ). Since the ET sensor is

placed in the neighbourhood of the section  $j$ , it has the same state of heat balance as that of the section  $j$ . Denoting the surface of the ET sensor by  $j$ , the heat balance of the surface of the ET sensor in the completely insulated state is expressed as [Formula \(B.9\)](#):

$$h_{cj}(T_a - T_j) + h_{rj}(T_r - T_j) = 0 \tag{B.9}$$

As such, the ET sensor surface temperature becomes [Formula \(B.10\)](#).

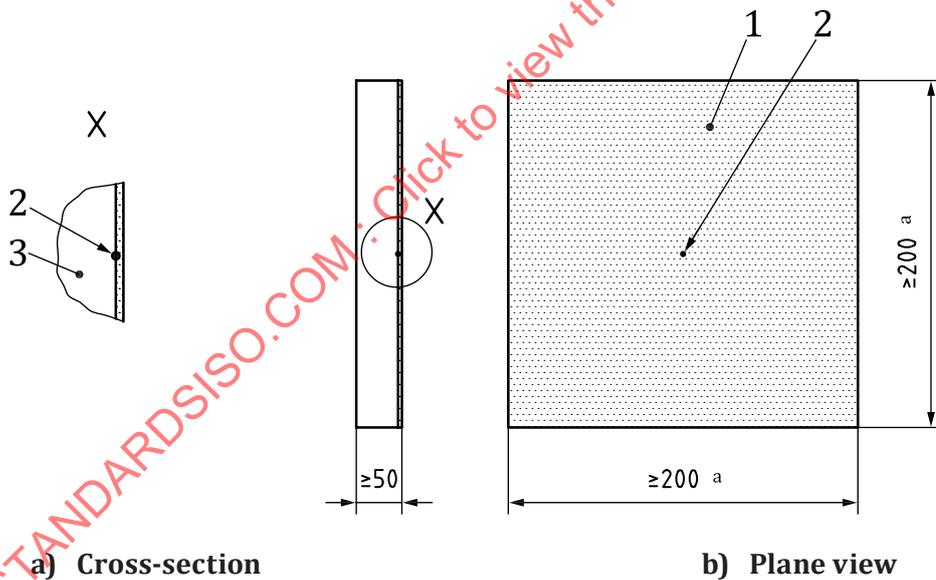
$$T_j = \frac{h_{cj}T_a + h_{rj}T_r}{h_{cj} + h_{rj}} \tag{B.10}$$

[Formula \(B.10\)](#) shows the weighted average of the radiative temperature and the air temperature, i.e. the environmental temperature ( $T_n$ ). It can be hence assumed that the surface temperature of an ET sensor placed in the neighbourhood of the section  $j$  of the wall to be measured shows the environmental temperature in the neighbourhood of the section  $j$ .

The ET sensor shows the environmental temperature in the neighbourhood of the section where it is placed, but not that of the whole wall to be measured. It can be assumed, however, that the section represents the whole wall to be measured if the sensor is placed around the centre of the wall. In the cases where the temperature varies greatly or strong radiation sources exist, this assumption does not hold.

## B.2 Construction of the ET sensor

The structure of ET sensor is shown in [Figure B.2](#).



### Key

- 1 copper sheet (matte black finish)
- 2 thermocouple
- 3 thermal insulation

Figure B.2 — Construction of the ET sensor

## Annex C (informative)

### Structure and calibration of heat transfer coefficient sensor

#### C.1 Explain/define this term

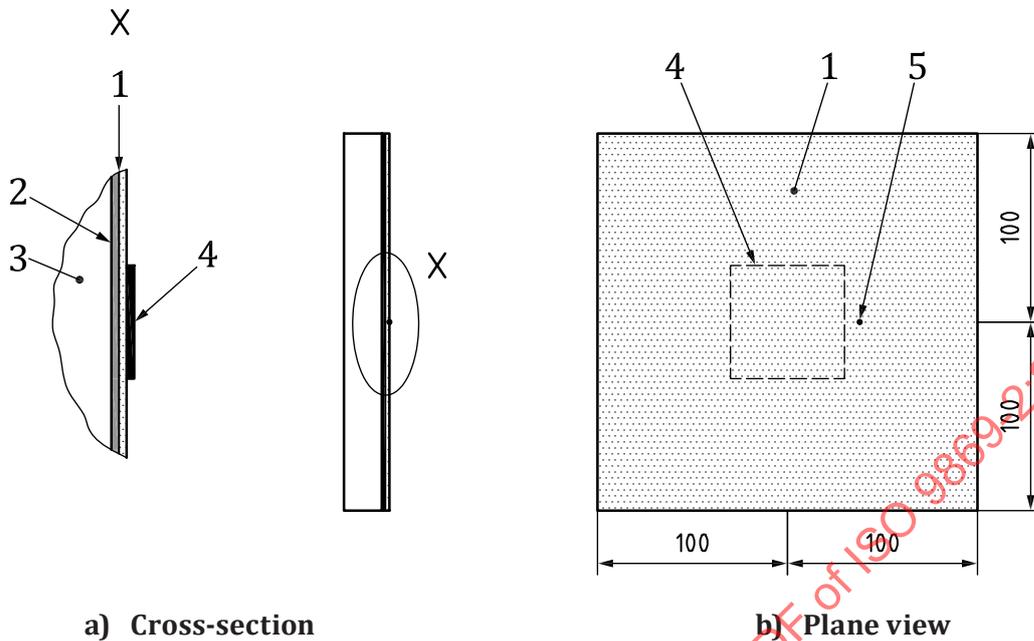
The construction of the heat transfer coefficient sensor is displayed in [Figure C.1](#).

To ensure that the heat from the heater is transferred uniformly across the surface of the sensor, copper sheet with a thickness of 0,5 mm or another flat sheet with a better heat transfer coefficient is used. The surface of the sensor is finished so that the emissivity of long wavelength regions is greater than 0,9.

A heat flow meter is attached to the rear of this copper sheet to measure the irradiance. When the heat transfer sensor, copper sheet and heater are attached to the insulating material (XPS), ensure that the copper sheet on the surface is not rough.

The heat flow meter used is of a standard 50 mm × 50 mm size, and a sensitivity greater than 50 mV/(W/cm<sup>2</sup>).

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a) Cross-section

b) Plane view

**Key**

- 1 copper sheet (matte black finish)
- 2 heater
- 3 thermal insulation
- 4 heat flow meter (50 mm × 50 mm)
- 5 thermocouple

**Figure C.1 — Structure of heat transfer coefficient sensor**

**C.2 Calibration of heat transfer coefficient sensor**

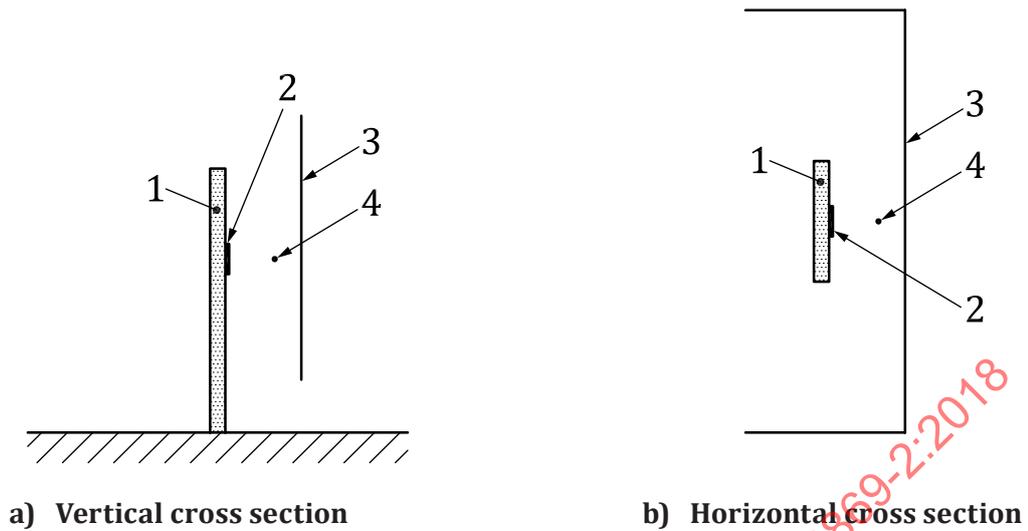
Calibration of a heat transfer coefficient sensor shall be made under natural convection.

[Figure C.2](#) outlines the measurement of the heat transfer coefficient. Place a heat transfer coefficient sensor vertically in a temperature-controlled room, and draw a black curtain around it.

The black curtain is used for suppressing convection caused by an air conditioner in the temperature-controlled room (for keeping the surface of the heat transfer coefficient sensor in a state of natural convection) and for preventing the effect of environmental radiation. Place the black curtain apart from the floor and the ceiling so that the upper and lower space is kept open in the temperature-controlled room.

Place a thermocouple for measuring the air temperature between the black curtain and the heat transfer coefficient sensor.

The environmental temperature of the heat transfer coefficient sensor can be obtained from the radiation temperature of the surface of the black curtain and the air temperature in the temperature-controlled room. Since the black curtain is placed in the temperature-controlled room, the surface temperature of the curtain and the air temperature in the room are almost the same. We can hence use the air temperature in place of the environmental temperature, assuming that the air temperature is nearly the same as the environmental temperature.

**Key**

- 1 thermal insulation
- 2 heat transfer coefficient sensor
- 3 black-out curtain
- 4 thermocouple

**Figure C.2 — Outline of heat transfer coefficient measurement**

Supplying power to the electrical heater of the heat transfer coefficient sensor, adjust the power to set the surface temperature of the sensor at a value about 3 °C to 10 °C higher than the air temperature.

Under the condition that the surface temperature of the heat transfer coefficient sensor is stable, measure the following:

- Surface temperature of the heat transfer coefficient sensor:  $\theta_{hs}$ ;
- Air temperature:  $\theta_a$ ;
- Heat flow meter output on the surface of the heat transfer coefficient sensor (heat flow density:  $q$ ).

Perform the measurement at 3 to 5 temperature points under the condition that the difference between the surface temperature of the heat transfer coefficient sensor and the air temperature falls within a range of about 3 °C to 10 °C. Repeat the process several times.

Calculate the heat transfer coefficient from [Formula \(C.1\)](#):

$$h = \frac{q}{\theta_{hs} - \theta_a} \quad (\text{C.1})$$

where

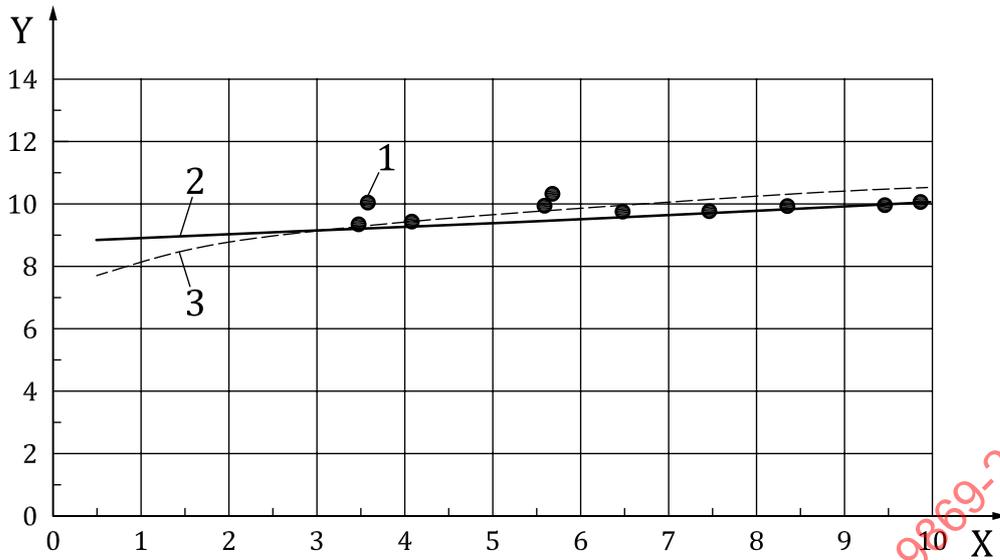
$h$  is total heat transfer coefficient (W/(m<sup>2</sup>K));

$q$  is heat flow density of the heat transfer coefficient sensor (W/m<sup>2</sup>);

$\theta_{hs}$  is surface temperature of the heat transfer coefficient sensor (°C);

$\theta_a$  is air temperature (°C).

[Figure C.3](#) shows a measurement example as well as the results calculated from the references.



Key

- X temperature difference, K
- Y heat transfer coefficient, W/(m<sup>2</sup>mK)
- 1 actual measurement values from Reference [4]
- 2 values 1 calculated from Reference [5]
- 3 values 2 calculated from Reference [6]

**Figure C.3 — Example of heat transfer coefficient measurement**

- Actual measurement values: cited from Reference [4]
- Values 1: calculated from Reference [5]

Convective heat transfer coefficient  $h_c$ : Nusselt formula under natural convection is used.

$$h_c = 3,0 + 0,08\Delta t(\text{kcal/m}^2\text{h}^\circ\text{C})(\Delta t \geq 15^\circ\text{C}) \tag{C.2}$$

Radiative heat transfer coefficient  $h_r$ :

$$h_r = \varepsilon_1 C_b \left[ \left( \left( T_m + \frac{1}{2} \Delta T \right) / 100 \right)^4 - \left( \left( T_m - \frac{1}{2} \Delta T \right) / 100 \right)^4 \right] \frac{1}{\Delta T} \tag{C.3}$$

- Values 2: calculated from Reference [6]

Convective heat transfer coefficient  $h_c$ :

$$h_c = N_u \frac{\lambda}{l} (\text{kcal/m}^2\text{h}^\circ\text{C}), N_u = C(G_r \cdot P_r)^{1/4} \tag{C.4}$$

where

$C$  is equal to 0,56;

$G_r$  is equal to  $g\beta\theta l^3/\nu^2$ ;

$P_r$  is equal to  $\nu/a$ .

Radiative heat transfer coefficient  $h_r$ :

$$h_r = \varepsilon_1 C_b \left[ \left( \left( T_m + \frac{1}{2} \Delta T \right) / 100 \right)^4 - \left( \left( T_m - \frac{1}{2} \Delta T \right) / 100 \right)^4 \right] \frac{1}{\Delta T} \quad (\text{C.5})$$

NOTE See References [4], [5] and [6].

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## Annex D (informative)

### Uncertainty analysis

#### D.1 Mathematical model

[Formula \(D.1\)](#) expresses the indoor heat transfer coefficient  $h$ :

$$h = \frac{q}{\Delta\theta_{hs}} \quad (\text{D.1})$$

where

$h$  is heat transfer coefficient (W/(m<sup>2</sup>K));

$Q$  is heat flow rate of the heat transfer coefficient sensor (W/m<sup>2</sup>);

$\Delta\theta_{hs}$  is difference between the surface temperature of the heat transfer coefficient sensor and the indoor environmental temperature (K) ( $=\theta_{hs} - \theta_{ni}$ );

$\theta_{hs}$  is surface temperature of the heat transfer coefficient sensor (°C);

$\theta_{ni}$  is indoor environmental temperature (°C).

Using measurement variables, it is expressed as [Formula \(D.2\)](#):

$$h = \frac{V/a}{\Delta\theta_{hs}} \quad (\text{D.2})$$

where

$V$  is heat flow meter output of the heat transfer coefficient sensor (mV);

$a$  is sensitivity coefficient of the heat flow meter of the heat transfer coefficient sensor (mV/(W/(m<sup>2</sup>K))).