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Measurement of apparent thermal conductivity of wet porous building materials by a periodic method

Détermination de la conductivité thermique apparente des matériaux de construction poreux et mouillés par une méthode périodique

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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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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*.

Introduction

Most building materials, with the exception of glass and metals, are porous and, thus, absorb moisture due to condensation, rain and water uptake from the ground. The absorbed moisture may damage the materials through, e.g. rotting or frost damage and, thus, may cause their performance to deteriorate. In particular, an increase in the moisture content of insulation material causes a reduction of its thermal resistance, which must be avoided as much as possible to preserve its performance. However, infiltration of rain water into a brick wall or joints of tiles and uptake of ground water into the foundation (footing) are very difficult to avoid. Therefore, it is important to understand the changes in the thermal properties (thermal conductivity and heat capacity) of porous materials due to changes in their moisture content.

ISO 10051 specifies a steady-state method for measuring the thermal conductivity of a moist building material. In the steady-state method, a nonuniform distribution of moisture content in the test piece is inevitable, since the imposed temperature gradient causes moisture transfer. The nonuniform moisture distribution makes it difficult to define which moisture content the measured thermal conductivity corresponds to. ISO 10051 categorizes the moisture distribution in the test piece into several types and estimates the thermal conductivity corresponding to each type.

Since theoretical and experimental research has recently been performed concerning heat and moisture transfer in porous materials (see References [5], [7], [8], [9] and [10]), along with measurements and the construction of a database of hygrothermal properties (see Reference [6]), hygrothermal behaviour can now be predicted with reasonable accuracy.

This International Standard describes a transient method for measuring the thermal conductivity of a wet porous building material and a method of evaluating the measurement uncertainty, on the basis of both theoretical developments for heat and mass transfer and the constructed database of hygrothermal properties. The evaluation of the measurement uncertainty makes possible a simple and, thus, practical method for measuring thermal conductivity.

NOTE Thermal conductivity is one of the necessary hygrothermal properties. Since heat transfer and mass transfer in porous material interact with each other, an exact value of the thermal conductivity must be given in order to examine the validity of the theoretical models. Thus, precisely speaking, the above-mentioned theoretical models have not been validated, and the construction of the model and the measurements of the hygrothermal properties must be carried out in parallel. Nonetheless, it seems reasonable to expect that measurement of the thermal conductivity with an allowable accuracy is possible using a suitable measuring method. This is the basis for the present document.

INTERNATIONAL STANDARD ISO 16957:2016(E)

Measurement of apparent thermal conductivity of wet porous building materials by a periodic method

1 Scope

This International Standard describes a method of measuring the thermal conductivity (diffusivity) of a wet porous building material and a method of evaluating the measurement uncertainty.

While ISO 10051 is the current International Standard, based on a steady-state method, this International Standard proposes a method that makes use of a non-steady-state method which uses a small temperature change with a short period as an input. Along with the measurement, an evaluation of the measurement uncertainty is described, which makes possible a simple and practical measuring method.

This International Standard intends to measure the apparent (effective) thermal conductivity, including latent heat transfer caused by vapour movement. The situation in which moisture and/or air movement occur due to convection or gravity is excluded. The application of this International Standard to high moisture content is excluded so that the gravity effect can be neglected. This International Standard can be applied to a porous material heavier than about 100 kg/m^3, in which radiative heat transfer can be neglected.

This International Standard specifies the following:

a) a non-steady-state method of measuring thermal conductivity;

b) an approximation formula for the measurement uncertainty caused by moisture movement and nonuniform moisture distribution (and, thus, a determination of the measuring conditions that satisfy the upper limit of measurement uncertainty);

c) an estimate of the heat transfer caused by moisture (vapour) movement.

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.

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9346, ISO 10051 and the following apply.

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

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
apparent thermal conductivity of a wet material

λ^*

intrinsic material property dependent upon moisture content and temperature, but not on testing conditions

Note 1 to entry: Since this value includes the influence of heat transfer due to phase change (condensation and evaporation), it is called apparent thermal conductivity.

4 Symbols and units

Symbol	**Quantity**	**Units**
a	thermal diffusivity of the material	m^2/s
A, B, C, D	defined in Formula (B.14)	—
c	porosity	m^3/m^3
c'	specific heat of the material	J/(kg·K)
c_s	specific heat of the dry material	J/(kg·K)
D_T	moisture (vapour and liquid water) conductivity related to temperature gradient	kg/(m·s·K)
D_θ	Moisture (vapour and liquid water) conductivity related to water content gradient	m^2/s
D_{Tl}	liquid water conductivity related to temperature gradient	kg/(m·s·K)
$D_{\theta l}$	liquid water conductivity related to water content gradient	m^2/s
D_{Tv}	vapour conductivity related to temperature gradient	kg/(m·s·K)
$D_{\theta v}$	vapour conductivity related to water content gradient	m^2/s
E, E_1, E_2	defined in Formula (B.12)	—
I_0	amplitude of the input surface temperature	K
k_v	vapour diffusivity	kg/[m·s·(kg/kg′)]
R	latent heat of vaporization	J/kg
S	specific surface area inside the material, i.e. ratio of pore surface area to the material volume	m^2/m^3
t	time	s
T	temperature	K
T_0	initial temperature	K
$T_1, T_2, \theta_1, \theta_2$	the first and second terms of the perturbation solution of the temperature and water content, respectively	K, kg/m^3
x	coordinate	m
X	humidity ratio of moist air in the pores of the specimen	kg/kg′
X_i	equilibrium humidity ratio with liquid or capillary water at the interface in the material	kg/kg′
$U_3, U_7, Q_1 - Q_6, R_1 - R_6, V_{18}$	coefficients appearing solutions θ_2 and T_2	—
α_1, α_2	defined in Formula (B.13)	—
α'	effective vapour transfer coefficient at the interface	kg/(m·s·kg)/kg′
γ	specific weight of dry air	kg/m^3
γ'	density of the material	kg/m^3
γ_s	density of the dry material	kg/m^3
$\eta_1, \zeta_1, \beta_1, \xi_1, \kappa_1, \gamma_1$	water content coefficients of $D_{\theta l}$, $D_{\theta v}$, D_{Tl}, D_{Tv}, c' γ', λ	—
$\eta_2, \zeta_2, \beta_2, \xi_2, \gamma_2$	temperature coefficients of $D_{\theta l}$, $D_{\theta v}$, D_{Tl}, D_{Tv}, λ	—
λ	thermal conductivity without moisture movement	W/(m·K)

Symbol	Quantity	Units
λ^*	thermal conductivity defined as $\lambda^* = \lambda + RD_{\mathrm{TV}}$	W/(m·K)
θ	water content of material	kg/m^3
θ_0	initial water content of material	kg/m^3
Θ_0	water content by weight	%
ω	angular velocity of the input surface temperature	rad/s

5 Determination of thermal conductivity of a wet porous material by non-steady-state method (periodic method)

When measuring the thermal conductivity of a porous material in which moisture transfer may occur, the nonuniformity of the water content distribution must be kept as low as possible under the temperature gradient. In order to minimize the nonuniformity, a periodic method is adopted as a transient method of measuring thermal conductivity (see example in Annex C). Since positive and negative temperature gradients are generated in turn in this method, the (time-averaged) water content distribution can be expected to remain uniform.

By measuring the temperatures at two points in the sample (usually one of them is at the sample surface), the thermal diffusivity (not conductivity) can be determined based on the amplitude ratio or phase difference of these two temperatures. If moisture movement does occur, a similar method can be used to determine the thermal diffusivity if the input cyclic temperature fluctuation is kept small enough that the change in transport properties is also small enough that the system can be regarded as linear (see Annex B).

6 Measurement by periodic method

6.1 Test procedure

A schematic diagram of the apparatus for the periodic method is given in Figure 1. The whole system is installed in a climate chamber whose temperature is kept at the mean temperature of the sample under measurement. The sample is preconditioned at a certain water content, and then the whole surface is made impermeable to moisture movement. A periodic temperature variation is imposed on the sample, and the temperatures at (at least) two points in the sample are measured by thermocouples.

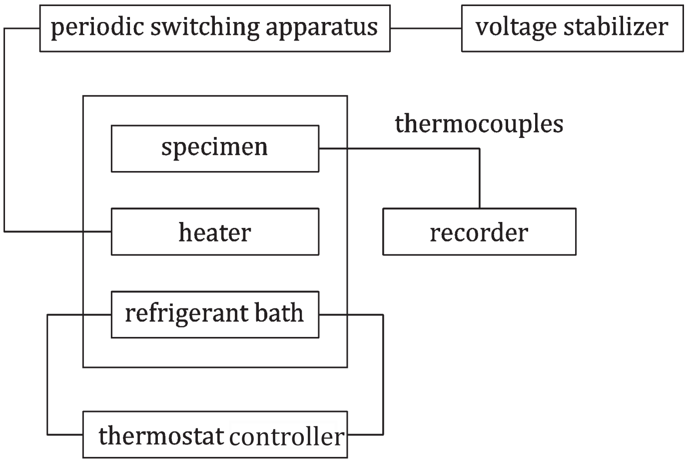


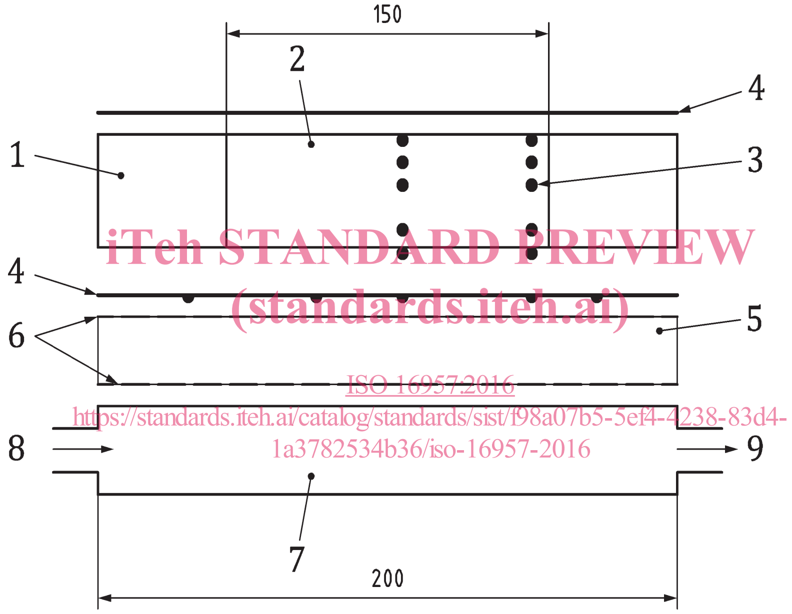
Figure 1 — Schematic diagram for measuring thermal diffusivity

6.2 Measuring apparatus

6.2.1 Overall design

A detailed schematic of the measuring apparatus is shown in Figure 2. Refrigerant kept at a low constant temperature is circulated in a metal refrigerant bath [200 mm (length) × 200 mm (wide) × 50 mm (height)] in order to avoid a temperature increase due to heating by the heater. A heater, a damping layer and a sample are placed on the refrigerant bath in order, and another damping layer is placed on the sample to reduce the influence of the temperature fluctuations of the climate chamber surrounding the measuring apparatus. Either a sinusoidal or stepwise electric current is generated in the heater. The stepwise wave becomes almost sinusoidal as it flows through the damping layers before arriving at the sample surface. Thermocouples are inserted into the sample and connected to the recorders. The output from the thermocouples is recorded by both an analogue recorder and a digital recorder. The digital recorder is used for a long-term record for temperatures at multiple points, while the analogue recorder is used for recording the temperature wave in a short-term measurement.

Dimensions in millimetres



Key

1	thermal insulation material
2	specimen
3	thermocouple
4	rubber film
5	heater
6	copper plates
7	refrigerant bath
8	refrigerant in
9	refrigerant out

Figure 2 — Vertical cross section of apparatus

6.2.2 Generator of the sinusoidal or stepwise electric wave

A sinusoidal electric wave is generated by an arbitrary wave generator and is sent to the heater. When such an apparatus is not available, a cyclic stepwise electric wave is generated and input to the heater by switching a constant electric current on and off using a relay. A cyclic on-off switching of the relay can be realized with a combination of two timers.

6.2.3 Heater

The lower surface of the sample is uniformly heated (with a cyclic change) by a film heater. The refrigerant bath under the sample works to reduce any increase in the average sample temperature due to the heating and to realize the necessary average temperature.

6.2.4 Specimen

The sample size should follow the requirement in ISO 10456 for thermal conductivity measurement, that is, it should be 150 mm × 150 mm. However, the sample should be thick enough that the amplitude of the temperature variation arriving at the upper surface of the sample becomes almost 0. The sample surfaces (boundary) should be made impermeable to moisture flow by a suitable water barrier and should also be made adiabatic by a thermal insulation material.

6.3 Specimen preparation and preconditioning

6.3.1 Initial uniform moisture content and adiabatic and impermeable boundaries

Before the measurement, a predetermined amount of water is added to the sample in order to obtain the required average moisture content. The sample is placed in a climate chamber with a constant temperature and kept for a time long enough to produce a uniform distribution of moisture content in the sample.

6.3.2 Embedding and the position of the thermocouples

Several thermocouples are inserted into the sample from its side surfaces. At least two thermocouples on the lower and upper surfaces and one at one depth in the vertical direction are necessary. In addition, the temperature distribution on the lower and upper surfaces should be measured in order to check the uniformity of the temperature distribution in the horizontal direction.

The exact positions of the thermocouples are decided, for example, by making use of the linear temperature distribution under steady-state conditions when the sample is dry with a temperature difference between the upper and lower surfaces.

6.4 Derivation of thermal diffusivity from measured temperatures (see Annex B)

6.4.1 Solution for heat flow without moisture

When a sample is dry and, thus, the thermal properties are constant, the temperature at time t and position x under a sinusoidal surface temperature input (at $x = 0$) is given in Formula (1):

$$T\left(t,x\right)=I_0\exp\left(-\sqrt{\frac{\omega}{2a}}x\right)\times\sin\left(\omega t-\sqrt{\frac{\omega}{2a}}x\right)+T_\mathrm{m} \tag{1}$$

where

T_m is the (constant) average temperature;

a is the thermal diffusivity of the sample material;

I_0 is the amplitude of the surface temperature variation;

ω is the angular velocity of the input temperature.