SLOVENSKI STANDARD

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Toplotne značilnosti gradbenih materialov in delov stavb - Načela za ugotavljanje toplotnih lastnosti vlažnih materialov in sestavnih delov

Thermal performance of building materials and components - Principles for the determination of thermal properties of moist material and components

Baustoffe - Grundlagen zur Bestimmung der Wärmeleitfähigkeit feuchter Baustoffe

Performances thermiques des matériaux et composants pour le bâtiment - Principes pour la détermination des propriétes thermiques des matériaux et composants humides

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Thermal performance of building materials and components – Principles for the determination of thermal properties of moist materials and components

Performances thermiques des matériaux et composants pour le bâtiment – Principes pour la détermination des propriétés thermiques des matériaux et composants humides

This Technical Report was approved by CEN on 24 July 2003. It has been drawn up by the Technical Committee CEN/TC 89.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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Contents

Foreword

This document (CEN/TR 14613:2003) has been prepared by Technical Committee CEN /TC 89 "Thermal performance of buildings and building components", the secretariat of which is held by SIS.

Annexes A, B, C, D and E are informative.

Introduction

1 Background

1.1 General

CEN/TC 89/WG 8 has developed standards for determination of thermal properties of various masonry materials used in building envelopes, e.g. brick and lightweight concrete. In the work, considerable effort has been put into the development of methods of testing moist materials and estimating the errors in such measurements. This report describes some of the background material that has been developed as part of the standardisation work and which has provided a basis for formulation of the standards.

In this report it is assumed that the thermal properties are being determined using hot plate, heat flow meter or hot box apparatus and steady state conditions in accordance with

— EN 12664, *Thermal performance of building materials and products – Determination of thermal resistance by means of guarded hot plate and heat flow meter methods – Dry and moist products of medium and low thermal resistance*;

— EN ISO 8990, *Thermal insulation – Determination of steady-state thermal transmission properties – Calibrated and guarded hot box (ISO 8990:1994)*;

— EN 1934, *Thermal performance of buildings – Determination of thermal resistance by hot box method using heat flow meter – Masonry.*

1.2 Needs related to standardisation

In the future European system for the design of thermal performance of buildings, the *declared* thermal value and the *design* thermal values are of special importance.

declared thermal value
expected value of a thermal property of a building material or product

– assessed from measured data at reference conditions of temperature and humidity;
– given for a stated fraction and confidence level;
– corresponding to a reasonable expected service lifetime under normal conditions

There is consequently a need to have a method to determine the hygrothermal transmissivity, λ^*, at a moisture content corresponding to the reference condition of humidity. An alternative could be to determine λ^* at several other moisture contents (including dry) and establish a relationship for conversion to reference moisture content.

design thermal value
value of thermal property of a building material or product under specific external and internal conditions which can be considered as typical of the performance of that material or product when incorporated in a building component

Determination of the design value requires knowledge of the relationship between λ^* and moisture content and about expected moisture contents and movements under service conditions.

Measurements on moist materials are complicated and time-consuming. Therefore these measurements are not normally routine measurements but performed at special occasions to establish the necessary relationships for each material, product or building component.

1.3 Scope of this technical report

The theoretical background for the effects of moisture on heat transfer, which is given here, is valid for all types of materials, but the applications and detailed guidelines have been developed with a specific type of material in mind: masonry with medium or high thermal conductivity, the physical characteristics of which can be roughly expressed as follows:

hygrothermal transmissivity	$\lambda^* > 0{,}10$ W/(m·K)
vapour permeability	$\delta_v < 5 \times 10^{-6}$ m^2/s or $\delta_p < 0{,}4 \times 10^{-10}$ kg/(m·s·Pa)
moisture diffential capacity ("hygroscopicity")	$\xi > 10$ kg/m^3 (between 50 % RH and 80 % RH)

This document is restricted to moisture contents in the hygroscopic range, where moisture content is in equilibrium with 95 % relative humidity or lower. For most building materials, moisture content in equilibrium with air having up to 95 % relative humidity is usually below the threshold value where the flow of liquid takes place. This value is often called critical saturation, when expressed as the fraction of voids with liquid, or critical moisture content when expressed as a specific moisture content. For higher moisture contents, reference is made to ISO 10051.

Preferred moisture contents are:

a) in equilibrium with **50 %** relative humidity (due to the requirements in the material specifications);

b) in equilibrium with **80 %** relative humidity (because this level is sometimes considered as "the practical moisture content").

2 References

EN 1934, *Thermal performance of buildings – Determination of thermal resistance by hot box method using heat flow meter – Masonry.*

EN 12429, *Thermal insulation products for building applications – Conditioning to moisture equilibrium under specified temperature and humidity conditions.*

EN 12664, *Thermal performance of building materials and products – Determination of thermal resistance by means of guarded hot plate and heat flow meter methods – Dry and moist products of medium and low thermal resistance.*

EN ISO 8990, *Thermal insulation – Determination of steady-state thermal transmission properties – Calibrated and guarded hot box (ISO 8990:1994).*

EN ISO 10456, *Building materials and products – Procedures for determining declared and design thermal values (ISO 10456:1999).*

ISO 10051, *Thermal insulation – Moisture effects on heat transfer – Determination of thermal transmissivity of a moist material.*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this CEN Technical report the terms and definitions in EN 12664 apply.

3.2 Symbols and units

Symbol	Quantity	Unit
D_w	moisture diffusivity	m^2/s
R	thermal resistance	$m^2 \cdot K/W$
$R*$	thermal resistance of a moist component	$m^2 \cdot K/W$
T	thermodynamic temperature	K
g	density of moisture flow rate	$kg/(m^2 \cdot s)$
g_v	density of vapour flow rate	$kg/(m^2 \cdot s)$
h_e	specific latent enthalpy of evaporation or condensation	W·s/kg
l	half specimen thickness	m
p	partial vapour pressure	Pa
t	time	s
u	moisture content mass by mass	kg/kg
v	humidity by volume	kg/m^3
v_{sat}	humidity by volume at saturation	kg/m^3
w	moisture content mass by volume	kg/m^3
δ_p	vapour permeability with regard to partial vapour pressure	kg/(m·s·Pa)
δ_v	vapour permeability with regard to humidity by volume	m^2/s
ξ	moisture differential capacity, $dw/d\varphi$	kg/m^3
λ	thermal conductivity (at dry state)	W(m·K)
$\lambda*$	hygrothermal transmissivity	W/(m·K)
φ	relative humidity	-

4 Moisture effects on heat transfer

When discussing moisture effects on heat transfer it is convenient to divide the density of heat flow rate into three components:

a) Heat flow caused by a temperature gradient in a condition of moisture equilibrium i.e. no moisture transfer:

$$q_a = -\lambda * \frac{dT}{dx} \quad (1)$$

$\lambda*$, the hygrothermal transmissivity (thermal conductivity of a moist material), is an intrinsic material property depending on moisture content.

b) Convective heat transfer by moisture flow. The water and water vapour carry their respective enthalpies. This component is normally negligible.

c) Heat transfer due to phase changes. This effect depends entirely on the occurrence and magnitude of moisture transfer in the material. To determine this component it is necessary to know the moisture movements.

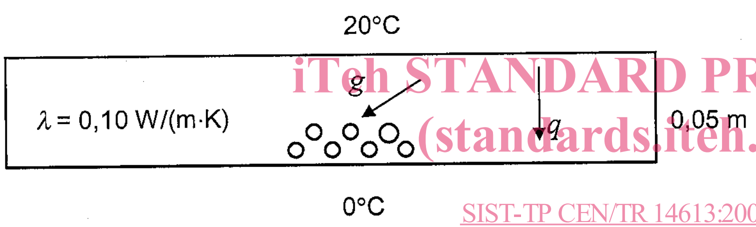
The determination of λ^* is described in ISO 10051. For the purpose of developing a strategy for masonry materials, relevant parts have been extracted from ISO 10051 and in some cases simplified or further elaborated.

5 Measurement procedures, dry material

Measurements on moist materials are complicated and time-consuming. Therefore, routine measurements shall, as far as possible, be carried out on dry materials. General rules are set down in EN 12664.

The test specimen shall be dried to constant mass in a ventilated oven at 105 °C to 110 °C that takes the air from an environment at (23 ± 2) °C and (50 ± 5) % relative humidity. Constant mass is considered to have been established when the change of mass during 24 h is less than 0,1 % of the total mass. For thick specimens (> 0,1 m) a more strict criterion may be needed. The background for the constant mass criterion is given in annex A.

After the drying, the test specimen shall be enclosed in a vapour-tight envelope. The reason for this is primarily to prevent moisture from entering the specimen, condensing in the cold parts of the specimen and thus affecting the density of heat flow rate and temperature distribution. Consider a test under the following conditions:



The density of sensible heat flow rate is

$$q = 0{,}10 \times \frac{(20-0)}{0{,}05} = 40 \ \text{W/m}^2 \qquad (2)$$

Assuming that an acceptable density of latent heat flow rate is 1 % of the density of sensible heat flow rate (which is 0,4 W/m^2), then we have the following equation:

$$g\,h_e = 0{,}4 \qquad (3)$$

where

g is the rate of moisture accumulation, in kg/(m^2 x s);

h_e is the specific enthalpy of condensation (at 10°C) ≈ 2480 × 10^3 J/kg;

from which g is calculated

$$g = \frac{0{,}4}{2480 \times 10^3} = 1{,}6 \times 10^{-7} \ \text{kg/(m}^2 \text{ x s)} \qquad (4)$$

By dividing by the thickness of the test specimen we get the change in moisture content per time (hour)

$$\frac{dw}{dt} = \frac{1{,}6 \times 10^{-7} \times 3600}{0{,}05} \approx 0{,}01 \ \text{kg/(m}^3 \text{ x h)} \qquad (5)$$

Most of the moisture accumulation will take place in the guard zone and therefore a requirement

$$\frac{dw}{dt} < 0{,}01 \ \text{kg/(m}^3 \text{ x h)} \qquad (6)$$

is considered reasonable and on the safe side.

The envelope shall consequently be impermeable enough to prevent a change in moisture content larger than 0,01 kg/(m^3 x h).

The mass of the specimen shall be measured before and after the test, to determine the relative mass changes.

A vapour-tight envelope may be omitted if the moisture accumulation in the test specimen during the test is known to be lower than 0,01 kg/(m^3 x h) and no visible condensation occurs on the cold plate.

NOTE The vapour-tight envelope can change the contact resistance and special precaution should be taken to measure correct surface temperatures.

6 Measurement procedures, moist material

6.1 Introduction

Determination of λ^* always requires a temperature gradient. Normally this causes a redistribution of the moisture in the material, which leads to two types of problems:

a) Redistribution of the moisture. This means that the test is carried out on a specimen with a moisture distribution, which is no longer uniform. The lower the temperature gradient, the lower the rate of distribution.

   The recommendation is consequently not to use an unnecessarily high temperature gradient or long duration of the test.

b) Redistribution of the moisture simultaneously induces phase changes (latent heat effects). These effects have to be well known or negligible during the test. Otherwise it is not possible to determine λ^*.

   Observe that using small temperature gradients does **not** guarantee that phase-change effects will be negligible.

There are three options to deal with these problems:

1) to have a situation with moisture movements so small, that effects of phase changes can be neglected;

2) to measure at moisture equilibrium;

3) to determine the effects of phase changes and correct for them.

Option 3 is the most complicated one and is not covered in this technical report. If necessary, reference is made to ISO 10051. Options 1 and 2 are described in 6.3 where the relevant measurement errors are estimated.

6.2 Conditioning

When the measurements are carried out on moist materials, the test specimens shall be conditioned to the desired moisture content before the test. A suitable procedure is described in EN 12429. After such a conditioning the moisture distribution is more or less uniform.

After conditioning the test specimen shall be enclosed in a vapour-tight envelope. The envelope shall be impermeable enough to prevent a change in moisture content larger than 0,01 kg/(m^3 x h).

The mass of the moist specimen shall be measured before and after the test, to determine the relative mass changes.

6.3 Errors due to moisture redistribution

6.3.1 General

In this clause the two options

- to have a situation with moisture movements so small that effects of phase changes can be neglected;
- to measure at moisture equilibrium,

are considered.

6.3.2 Moisture movement small enough to neglect effects of phase changes

This is the most straightforward option, because in this situation the materials can be tested without being concerned with the effects of moisture movements.

The additional density of heat flow rate due to phase changes may be estimated by

$$q_l = g_v \, h_e \tag{7}$$

where

q_l is the additional density of latent heat flow rate due to phase changes, in W/m²;

g_v is the density of vapour flow rate, in kg/(m²·s);

h_e is the specific latent enthalpy of evaporation or condensation, in J/kg.

NOTE It should be noted that the use of "enthalpy of evaporation/condensation" is a simplification. Strictly speaking the "enthalpy of sorption" should be used but the difference is probably negligible in this context.

If g_v is expressed by Fick's law

$$g_v = \delta_v \frac{dv}{dx} \tag{8}$$

where

δ_v is the vapor permeability with regard to humidity by volume, in m²/s;

v is the (air) humidity by volume, in kg/m³;

x is the coordinate in thickness direction, in m;

and considering that

$$v = \varphi \, v_{sat} \tag{9}$$

where

φ is the relative humidity;

v_{sat} is the humidity by volume at saturation, in kg/m³;

q_l can be approximately expressed as

$$q_l = g_v h_e = \delta_v \frac{dv}{dx} h_e = \delta_v h_e \frac{d}{dx}(\varphi \, v_{sat}) = \delta_v h_e \left(\varphi \frac{dv_{sat}}{dx} + v_{sat} \frac{d\varphi}{dx} \right) \tag{10}$$

The test specimen is assumed to be conditioned to a uniform moisture content, which means that initially:

$$\frac{dw}{dx} = 0 \tag{11}$$

and if we disregard the temperature dependence of the hygroscopic sorption curve (φ is assumed to be a function of w only, which is quite reasonable for practical purposes) we also get

$$\frac{\mathrm{d}\varphi}{\mathrm{d}x} = 0 \tag{12}$$

Then moisture movements result in increasing relative humidity on the cold side, leading to different signs for the two terms within the brackets in Equation (10); hence the initial value of q_l is the maximum value. This is also illustrated in Figures 2 to 7, which show a decreasing effect of phase changes with time.

The maximum value of q_l can therefore be written as

$$q_l = \delta_v h_e \left(\varphi \frac{\mathrm{d}v_{sat}}{\mathrm{d}x} \right) \quad \text{or} \quad q_l = \delta_v h_e \varphi \frac{\mathrm{d}v_{sat}}{\mathrm{d}T} \frac{\mathrm{d}T}{\mathrm{d}x} \tag{13}$$

The relationship between the density of latent heat flow rate, q_l, due to phase change and the density of sensible heat flow rate, q, expressed by $\lambda^* \,\mathrm{d}T/\mathrm{d}x$ is consequently:

$$\frac{q_l}{q} = \frac{\delta_v h_e \varphi \frac{\mathrm{d}v_{sat}}{\mathrm{d}T}}{\lambda^*} \tag{14}$$

With $\mathrm{d}v_{sat} / \mathrm{d}T = 10^{-3}$ kg/(m^3·K) and h_e = 2450 × 10³ J/kg (actual values at 20 °C), then

$$\frac{q_l}{q} = 2450 \frac{\delta_v \varphi}{\lambda^*} \tag{15}$$

and the maximum relative error due to phase change, expressed in %, is

$$100 \frac{q_l}{q} = 25 \times 10^6 \frac{\delta_v \varphi}{\lambda^*} \tag{16}$$

The error is calculated on the assumption that the moisture content is uniform and that the temperature at the point where the density of heat flow rate is measured is 20 °C. Non-uniform moisture distribution and/or lower temperature will decrease the error.

Table 1 gives very approximate properties for some products. The table shows that autoclaved aerated concrete (AAC) is the most sensitive material of those in the table.

Table 1 — Moisture permeability (δ_v) and hygrothermal transmissivity with quotient δ_v / λ^*

Product	δ_v	λ^*	δ_v / λ^*
Ordinary concrete, 2300 kg/m^3	$0{,}3 \times 10^{-6}$	1,75	$0{,}17 \times 10^{-6}$
Brick, 1500 kg/m^3	4×10^{-6}	0,5	8×10^{-6}
Autoclaved aerated concrete, 500 kg/m^3	3×10^{-6}	0,15	20×10^{-6}
Lime-cement mortar, 2000 kg/m^3	$1{,}5 \times 10^{-6}$	1,0	$1{,}5 \times 10^{-6}$

Even if the phase changes are negligible, moisture redistribution during the test will cause the thermal resistance to increase slightly during the test. This effect has been studied in a computer model. The one-dimensional model solves the coupled heat and moisture fields by a finite difference procedure. The moisture transfer is modelled as a flow in vapour phase only with the humidity by volume as the driving force. The error in λ^*, $\Delta\lambda^*$, due to non-uniform moisture distribution is calculated as