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Higrotermalno obnašanje sestavnih delov stavb in elementov stavb - Ocenjevanje prenosa vlage z numerično simulacijo

Hygrothermal performance of building components and building elements - Assessment of moisture transfer by numerical simulation

Wärme- und feuchtetechnisches Verhalten von Bauteilen und Bauelementen - Bewertung der Feuchteübertragung durch numerische Simulation

Performance hygrothermique des composants et parois de bâtiments - Évaluation du transfert d'humidité par simulation numérique

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Hygrothermal performance of building components and building elements - Assessment of moisture transfer by numerical simulation

Performance hygrothermique des composants et parois de bâtiments - Evaluation du transfert d'humidité par simulation numérique

Wärme- und feuchtetechnisches Verhalten von Bauteilen und Bauelementen - Bewertung der Feuchteübertragung durch numerische Simulation

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
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European foreword

This document (prEN 15026:2022) has been prepared by Technical Committee CEN/TC 89 “Thermal performance of buildings and building components”, the secretariat of which is held by SIS.

This document is currently submitted to the CEN Enquiry.

This document supersedes EN 15026:2007.

Introduction

This document defines the practical application of hygrothermal simulation software used to predict transient heat and moisture transfer in multi-layer building envelope components subjected to dynamic climate conditions on either side.

In contrast to the steady-state assessment of interstitial condensation by the Glaser method (as described in EN ISO 13788), transient hygrothermal simulation provides more detailed and accurate information on the risk of moisture problems within building components and on the design of remedial treatment. While the Glaser method considers only steady-state conduction of heat and vapour diffusion, the transient hygrothermal simulation models which are composed of the formulae defined in this document also take account of heat and moisture storage, latent heat effects and liquid and convective transport under realistic boundary and initial conditions. The application of such models has become widely used in building practice in recent years, resulting in a significant improvement in the accuracy and reproducibility of hygrothermal simulation.

The following examples of transient heat and moisture phenomena in building components can be simulated by the models covered in this document:

— drying of initial construction moisture;

— moisture accumulation by interstitial condensation due to diffusion in winter;

— moisture penetration due to driving rain exposure;

— summer condensation due to migration of moisture from outside to inside;

— outside surface condensation due to cooling by long-wave radiation exchange;

— moisture-related heat losses by transmission and moisture evaporation.

The factors relevant to hygrothermal simulation of building components are summarized below. The document starts with the description of the physical model on which hygrothermal simulation tools are based. Then the necessary input parameters and their procurement are dealt with. The evaluation, interpretation and documentation of the output form the last part. Benchmark cases for the assessment of numerical simulation tools are discussed in Annex B.

Input parameters include:

— assembly, orientation and inclination of building components;

— hygrothermal material parameters and functions;

— boundary conditions, surface transfer for inside and outside climate;

— initial condition, calculation period, numerical control parameters.

Output parameters include:

— temperature and heat flux distributions and temporal variations;

— water content, relative humidity and moisture flux distributions and temporal variations.

Post-processing includes:

— energy use, economy and ecology;

— biological growth, rot and corrosion;

— moisture-related damage and degradation.

1 Scope

This document specifies the model components to be used in a numerical hygrothermal simulation model for calculating the transient transfer of heat and moisture through building structures.

This document specifes a method to be used for validating a numeric hygrothermal simulation model claiming conformity with this ocument.

2 Normative references

The following referenced documents are indispensable for the application 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.

EN ISO 7345, *Thermal performance of buildings and building components — Physical quantities and definitions (ISO 7345:2018)*

EN ISO 9346, *Hygrothermal performance of buildings and building materials — Physical quantities for mass transfer — Vocabulary (ISO 9346:2007)*

3 Terms, definition, symbols and units

For the purposes of this document, the terms and definitions given in EN ISO 9346 and EN ISO 7345 apply and specific terms not covered by these cocuments, see below.

Symbol	Quantity	Unit
a_r	rain water retention factor of a surface	– (0 ... 1)
c_1	specific heat capacity of liquid water	J/(kg·K)
c_v	specific heat capacity of water vapour	J/(kg·K)
c_{ice}	specific heat capacity of ice	J/(kg·K)
c_a	specific heat capacity of air	J/(kg·K)
c_s	specific heat capacity of dry material (solid)	J/(kg·K)
D_1	liquid conductivity	m²/s
E_{sol}	total flux density of incident solar radiation	W/m^2
g, g_w	density of moisture flow rate	kg/(m²·s)
g_l	density of liquid water flow rate	kg/(m²·s)
g_v	density of water vapour flow rate	kg/(m²·s)
$g_{l,max}$	density of water flow rate which can be absorbed at the surface of a material	kg/(m²·s)

Symbol	Quantity	Unit
g_p	density of moisture flow rate of available water from precipitation	kg/(m²·s)
h	surface heat transfer coefficient	W/(m²·K)
h_c	convective heat transfer coefficient	W/(m²·K)
h_r	radiative heat transfer coefficient	W/(m²·K)
h_e	specific latent enthalpy of evaporation or condensation	J/kg
h_l	specific enthalpy of liquid water	J/kg
h_v	specific enthalpy of water vapour	J/kg
K_l	liquid conductivity	s/m
n_{vent}	air change rate	1/s
p_a	ambient atmospheric pressure	Pa
p_c	capillary pressure	Pa
p_v	partial water vapour pressure	Pa
$p_{v,e}$	partial water vapour pressure in the environment/ambient air	Pa
$p_{v,s}$	partial water vapour pressure at a surface	Pa
$p_{v,sat}$	saturated water vapour pressure	Pa
q	density of heat flow rate	W/m²
q_{sens}	density of sensible heat flow rate	W/m²
r_l	liquid moisture flow resistance of interface	m/s
R_N	normal (i.e. vertical) rain rate	mm/s
r_s	rain exposure factor of a surface	–
r_v	water vapour diffusion resistance of interface	m/s
R_v	gas constant of water vapour	J/(kg·K)
$S_{d,s}$	equivalent vapour diffusion thickness of a surface layer	m
S_u	source term for internal energy	J/(m³·s)

Symbol	Quantity	Unit
S_w	source term for moisture	kg/(m³·s)
T	thermodynamic temperature	K
T_a	ambient air temperature	K
T_s	temperature of a surface	K
t	time	s
u	internal energy density of the material	J/m³
v	wind speed	m/s
w	moisture content	kg/m³
w_l	liquid water content	kg/m³
w_{sat}	saturation moisture content	kg/m³
w_{ice}	ice content	kg/m³
x	distance	m
α_{sol}	solar absorptance	– (0 ... 1)
δ_0	vapour permeability of still air	kg/(m·s·Pa)
δ_v	vapour permeability of a material	kg/(m·s·Pa)
ε	long-wave emissivity of the outside surface	– (0 ... 1)
ϑ	Celsius temperature	°C
λ	thermal conductivity	W/(m·K)
φ	relative humidity	– (0 ... 1)
μ	water vapour diffusion resistance factor	–
ρ_a	density of air	kg/m³
ρ_s	density of solid material matrix	kg/m³
ρ_l	density of liquid water	kg/m³
σ_s	Stefan-Boltzmann constant	W/(m²·K⁴)

4 Hygrothermal formulae and material properties

4.1 Assumptions

The hygrothermal Formulae (1) to (16) contain the following assumptions:

— geometry remains constant with no swelling or shrinkage;

— no chemical reactions are occurring;

— local equilibrium exists between liquid and vapour, without hysteresis; and

— moisture storage function is not dependent on temperature.

4.2 Balance formulae

4.2.1 General

The development of the formulae is based on the conservation of energy and moisture mass. The mathematical expressions of the conservation laws are the balance formulae. Heat conservation shall be expressed by the change of internal energy u over time in accordance with Formula (1).

$$\frac{\partial u}{\partial t} = -\frac{\partial \left(q + h_{\mathrm{v}} g_{\mathrm{v}} + h_{\mathrm{l}} g_{\mathrm{l}}\right)_k}{\partial x_k} + S_{\mathrm{u}} \qquad (1)$$

The moisture mass conservation shall be expressed in accordance with Formula (2)

$$\frac{\partial w}{\partial t} = -\frac{\partial \left(g_{\mathrm{v}} + g_{\mathrm{l}}\right)_k}{\partial x_k} + S_{\mathrm{w}} \qquad (2)$$

The subscript k denotes the directions x, y, z, both for the coordinates and the corresponding flux quantities q and g. Removing the index k from the formulae yields the formulation for one-dimensional problems. q and g are vectors and the derivative of vector q, for example, expands for two-dimensional problems to formula (3).

$$\frac{\partial q_k}{\partial x_k} = \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} \qquad (3)$$

4.2.2 Internal energy density

A reference state shall be selected when defining the internal energy density and associated enthalpies. Then u is defined as energy density relative to some reference energy density u_{ref} at the reference temperature, $T_{\mathrm{ref.}}$

$$u = \rho_{\mathrm{s}} \cdot c_{\mathrm{s}} \cdot \left(T - T_{\mathrm{ref}}\right) + w_{\mathrm{l}} \cdot c_{\mathrm{l}} \cdot \left(T - T_{\mathrm{ref}}\right) + w_{\mathrm{ice}} \cdot \left(c_{\mathrm{ice}} \left(T = T_{\mathrm{ref}}\right) - h_{\mathrm{ice}}\right) \qquad (4)$$

NOTE 1 The internal energy, u, of a dry building material depends on its temperature. It is possible to use a linear relation for this purpose within temperature ranges that can occur in buildings. The internal energy of water as liquid and/or ice is additionally present in moist materials. The internal energy stored in the gas phase, i.e. dry air and water vapour, can be neglected.

In the time scales relevant to application of this document, freezing and thawing processes are considered to be fast enough to treat freezing and thawing of ice inside the porous material as equilibrium processes. Macroscopically, still a time delay in thawing/freezing can be observed, which is then mainly governed by the ability of the material to transport heat to or from the freezing zone.

Depending on the choice of the reference temperature, T_{ref} (0 K or 273,15 K) the corresponding freezing enthalpy h_{ice} shall be inserted into Formula (4) (see Table 1).

NOTE 2 A consistent model can ensure that in the presence of ice the sum of the volumetric contents of liquid water and ice will not exceed the available porosity of the material.

4.2.3 Additional source terms

When additional source terms are used they shall be integrated by using the Auxiliary models in Annex E.

NOTE Additional heat sources, S_{u}, and moisture sources, S_{w}, allow the consideration of special effects, for instance building component ventilation or additional moisture sources due to rain water penetration. The use of source terms makes it possible to integrate auxiliary models into the balance formulae which can be tailored to the effects to be factored in.

4.3 Relations between driving potentials and conserved quantities

The primary state variables or conserved quantities are the internal energy density *u* and the water content (moisture mass density) *w*, defined through the balance equations for energy and moisture mass. The calculation of the energy and mass flows of the individual transport processes requires additional state variables or driving potentials: capillary pressure, p_{c}, partial pressure of water vapour, p_{v} and temperature, *T*.

The relative humidity shall be calculated in accordance with Formula (5):

$$\psi = \frac{P_{\text{v}}}{P_{\text{v,sat}}(T)} \tag{5}$$

The capillary pressure of the pore water is related to the relative humidity of the surrounding air by the Kelvin Formula (6):

$$P_{\text{c}} = \rho_{\text{l}} R_{\text{v}} T \ln(\varphi) \tag{6}$$

The consideration of moisture transfer in capillary active materials requires a sufficiently well defined sorption isotherm in the humidity range $92\% \le \varphi \le 100\%$.

4.4 Transport of heat and moisture

In transport Formulae (7) to (9) one-dimensional flux density expressions are used. 2D and 3D formulations are obtained through use of directional indexes, *k*, for the vector flux quantities (see 7.2).

4.4.1 Heat and enthalpy transport inside materials

Heat transport shall be composed of sensible and latent components. Heat transport by thermal conduction q shall be calculated with Fourier's law (Formula (7)) with a thermal conductivity which depends on moisture content. If ice is considered in the calculation, the thermal conductivity $\lambda(w, w_{\text{ice}})$ also depends on the ice content w_{ice} (see A.3).

$$q = \lambda(w) \cdot \frac{\partial T}{\partial x} \tag{7}$$