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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
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Contents

Page

Foreword

This document (prEN 15026:2004) 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.

Introduction

This standard defines the practical application of hygrothermal simulation software used to predict one-dimensional transient heat, air and moisture transfer in multi-layer building envelope components subjected to non steady 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 models covered in this standard 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, one-dimensional heat and moisture phenomena in building components can be simulated by the models covered by this standard:

- drying of initial construction moisture;
- moisture accumulation by interstitial condensation due to diffusion and convection in winter;
- moisture penetration due to driving rain exposure;
- summer condensation due to migration of moisture from outside to inside;
- exterior surface condensation due to cooling by long wave radiation exchange;
- moisture-related heat losses by transmission and moisture evaporation.

Figure 1 shows the factors relevant to hygrothermal building component simulation. The standard 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. A benchmark case with an analytical solution is given for the assessment of numerical simulation tools. The evaluation, interpretation and documentation of the output form the last part. The post processing tools in Figure 1 are not part of this standard. As far as possible references to publications dealing with these tools are given.

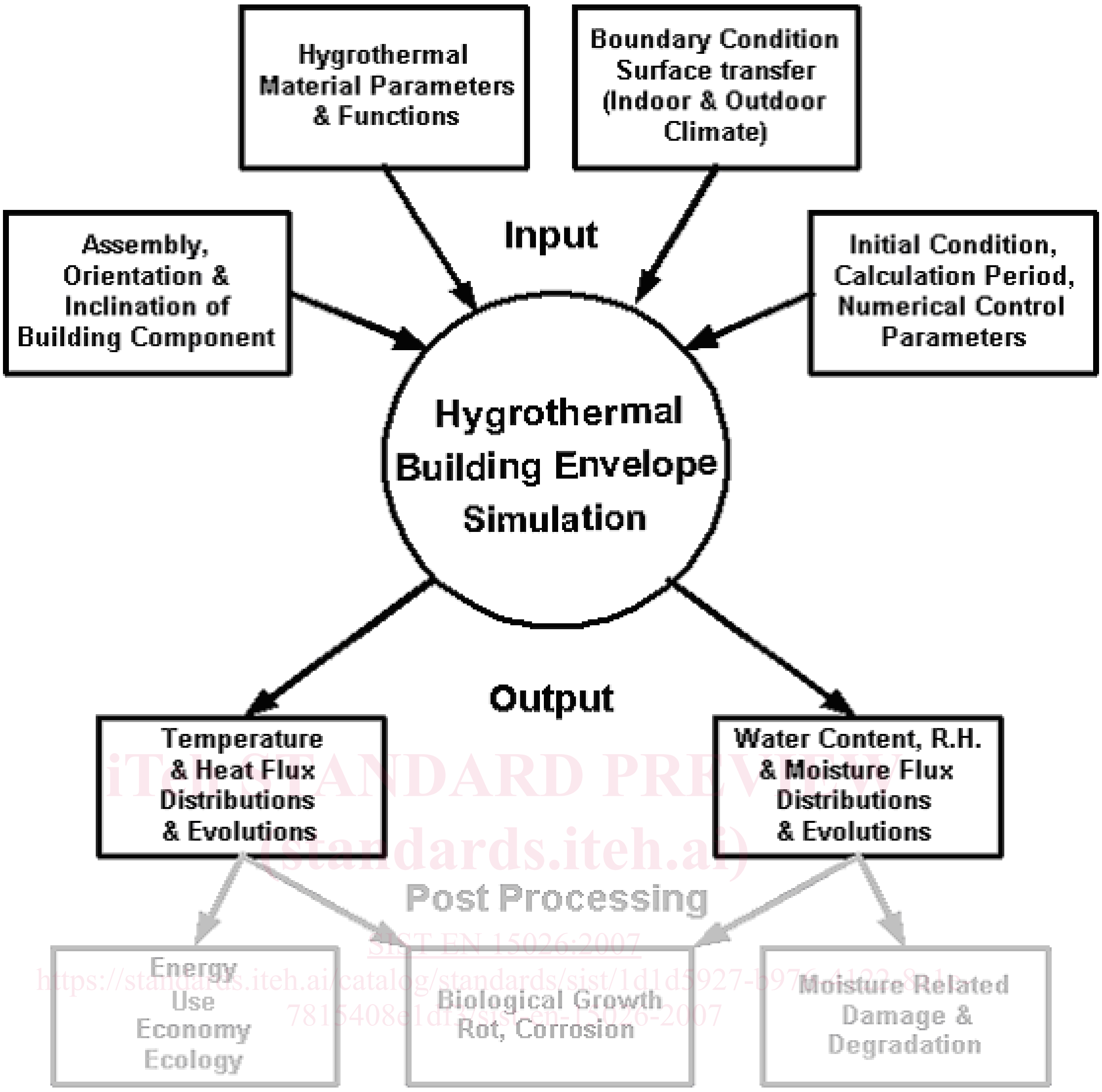

Figure 1 – Flow chart for hygrothermal simulations

1 Scope

This standard specifies a method for calculating the non steady transfer of heat and moisture through building structures. The necessary equations are defined and a benchmark example given.

The hygrothermal simulation models covered by this standard take account of the following storage and one-dimensional transport phenomena:

- heat storage in dry building materials and absorbed water;
- heat transport by moisture-dependent thermal conduction;
- heat transfer by vapour diffusion and air convection, including phase changes;
- moisture storage by vapour absorption and capillary forces;
- moisture transport by vapour diffusion and air convection;
- moisture transport by liquid transport (surface diffusion and capillary flow);

The models described in this standard account for the following climatic variables:

- internal and external temperature;
- internal and external humidity;
- solar and long wave radiation;
- precipitation (normal and driving rain);
- wind speed and direction;
- air pressure differences.

The hygrothermal models described in this standard shall not be applied in cases where:

- convection takes place in a three-dimensional manner through holes and cracks;
- two-dimensional effects play an important part (e.g. rising damp, conditions around thermal bridges, effect of gravitational forces);
- hydraulic, osmotic, electrophoretic forces are present;
- daily mean temperatures exceed 50 °C or in cases of fire;
- the effects of ice formation have to be assessed.

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 12524 *Building materials and products – Hygrothermal properties –Tabulated design values*

EN ISO 7345 *Thermal insulation – Physical quantities and definitions*

EN ISO 9346 *Thermal insulation – Mass transfer – Physical quantities and definitions*

EN ISO 10456 *Building materials and products – Procedures for determining declared and design thermal values*

EN ISO 12572 *Hygrothermal performance of building materials and products – Determination of water vapour transmission properties*

EN ISO 15927-3[1] *Hygrothermal performance of buildings – Calculation and presentation of climatic data – Part 3: Calculation of a driving rain index for vertical surfaces from hourly wind and rain data*

ISO 9053 *Acoustics – Materials for acoustical applications – Determination of airflow resistance*

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

3 Definitions, symbols and units

3.1 Definitions

For the purposes of this standard, the terms and definitions given in EN ISO 9346 and EN ISO 7345 apply. Other terms used are defined in the relevant clause of this standard

3.2 Symbols and units

Symbol	Quantity	Unit
C	flow coefficient per unit area	$m^3/(m^2\ s\ Pa^n)$
D_l	liquid diffusivity	m^2/s
I_{sol}	total flux of incident solar radiation	W/m^2
P_a	pressure of the surrounding air	Pa
ΔP_a	total air pressure difference	Pa
P_l	water pressure inside pores	Pa
R_{H2O}	gas constant of water vapour	J/(kg K)
R_l	liquid moisture flow resistance of interface,	m/s
T	thermodynamic temperature	K

1) To be published.

T_a	air temperature of the surrounding environment	K
T_{eq}	equivalent temperature of the surrounding environment	K
T_r	mean radiation temperature of the surrounding environment	K
T_{ref}	arbitrary reference temperature	K
T_s	surface temperature	K
$c_{p,a}$	specific heat capacity at constant pressure of air	J/(kg K)
$c_{p,l}$	specific heat capacity at constant pressure of liquid water	J/(kg K)
$c_{p,s}$	specific heat capacity at constant pressure of solid matrix	J/(kg K)
d_l	thickness of the layer l	m
g	density of moisture flow rate	kg/(m² s)
g_r	density of air mass flow rate	kg/(m² s)
g_l	density of liquid moisture flow rate	kg/(m² s)
g_p	available water due from to precipitation	kg/(m² s)
g_v	density of vapour flow rate	kg/(m² s)
h_c	convective heat transfer coefficient	W/(m^2·K)
h_e	specific enthalpy of liquid-vapour phase change	J/kg
h_{eff}	effective heat transfer coefficient	W/(m^2·K)
h_r	radiative heat transfer coefficient	W/(m^2·K)
n	flow exponent	-
p_v	partial vapour pressure,	Pa
$p_{v,sat}$	saturated vapour pressure	Pa
q	density of heat flow rate	W/m^2
q_{cond}	density of conduction heat flow rate	W/m^2
q_{conv}	density of convection heat flow rate	W/m^2
s	suction	Pa
Δs	suction difference across interface	Pa
$\bar{s}$	mean suction at interface	Pa
s_d	equivalent vapour diffusion thickness	m
v	wind speed	m/s
w	moisture content	kg/m^3
w_l	water content	kg/m^3
α_{sol}	solar absorptance	-
δ_0	permeability of vapour in air	kg/m s Pa
ε	long-wave emissivity of the external surface	-
λ	thermal conductivity	W/(m·K)

$\lambda_{m,l}$	moisture conductivity for capillary water transport	s
φ	relative humidity	-
μ	diffusion resistance factor	-
ρ_l	liquid water density	kg/m³
ρ_a	density of air	kg/m³
ρ_s	density of solid matrix	kg/m³
σ_s	Stefan-Boltzmann constant	$W/(m^2 \cdot K^4)$

4 Model components and material properties

4.1 Assumptions

The components of the hygrothermal model discussed in the following clauses were developed under the following additional assumptions:

- constant geometry, no swelling and shrinkage;
- no chemical reaction, heat of sorption is neglected;
- no change in material properties by damage or ageing;
- local equilibrium between liquid and vapour without hysteresis;
- the temperature dependence of the moisture storage function is neglected;
- only the partial vapour pressure is used for the calculation of the vapour diffusion; the additional influence of temperature and barometric pressure gradients are neglected;
- the formation of ice is not considered.

The development of the equations is based on the conservation of energy and mass (air and moisture). The mathematical expression of the conservation laws are the balance equations. The conserved quantity changes in time, only if there is a source or sink inside a small representative volume (control volume) or if it is transported between neighbouring control volumes. Considering the restrictions of nearly constant pressure, the heat storage of a control volume can be expressed by the specific heat at constant pressure from the solid matrix and the liquid water inside the pore structure. Phase change between liquid and vapour, i.e. the release of latent heat, is considered as part of the convective heat flow through the structure.

$$\left(c_{p,s} \cdot \rho_s + c_{p,l} \cdot w_l\right) \cdot \frac{\partial T}{\partial t} = -\frac{\partial q}{\partial x} \qquad (1)$$

$$q = q_{cd} + q_{cv} \qquad (2)$$

Conservation of mass can be used to determine the air flow rate. If buoyancy can be neglected the air flow rate is calculated from the total pressure difference over the construction.

$$g_a = \rho_a \, C \, \Delta P_a^{\,n} \qquad (3)$$

NOTE For a whole construction, the coefficients C and n can be measured according to EN 12114. The air flow coefficient per area has to be calculated by division of the flow coefficient by the overall area of the building component.

The increase of the moisture content of a control volume is determined by the net inflow of moisture. The moisture flow rate equals the sum of the vapour flow rate and the flow rate of liquid water.