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

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British Standards

National foreword

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

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Foreword

This document (EN 15026:2007) 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 European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2007, and conflicting national standards shall be withdrawn at the latest by October 2007.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard : Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Introduction

This standard defines the practical application of hygrothermal simulation software used to predict one-dimensional transient heat 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 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 longwave radiation exchange;
- moisture-related heat losses by transmission and moisture evaporation.

The factors relevant to hygrothermal building component simulation are summarised below. 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.

Inputs

- Assembly, orientation and inclination of building components
- Hygrothermal material parameters and functions
- Boundary conditions, surface transfer for internal and external climate
- Initial condition, calculation period, numerical control parameters

Outputs

- Temperature and heat flux distributions and temporal variations
- Water content, relative humidity and moisture flux distributions and temporal variations

Post processing

- Energy use, economy & ecology
- Biological growth, rot and corrosion
- Moisture related damage and degradation

The post processing tools are not part of this standard. As far as possible references to publications dealing with these tools is given.

1 Scope

This standard specifies the equations to be used in a simulation method for calculating the non steady transfer of heat and moisture through building structures.

It also provides a benchmark example intended to be used for validating a simulation method claiming conformity with this standard, together with the allowed tolerances.

The equations in 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;
- latent heat transfer by vapour diffusion;
- moisture storage by vapour sorption and capillary forces;
- moisture transport by vapour diffusion;
- moisture transport by liquid transport (surface diffusion and capillary flow).

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

- internal and external temperature;
- internal and external humidity;
- solar and longwave radiation;
- precipitation (normal and driving rain);
- wind speed and direction.

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

- convection takes place 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 in the component exceed 50 °C.

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 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 12667, *Thermal performance of building materials and products — Determination of thermal resistance by means of guarded hot plate and heat flow meter methods — Products of high and medium thermal resistance*

EN 12939, *Thermal performance of building materials and products — Determination of thermal resistance by means of guarded hot plate and heat flow meter methods — Thick products of high and medium thermal resistance*

EN ISO 7345, *Thermal insulation – Physical quantities and definitions (ISO 7345:1987)*

prEN ISO 9346:2005, *Hygrothermal performance of buildings and building materials - Mass transfer - Physical quantities and definitions (ISO/DIS 9346:2005)*

prEN ISO 10456, *Building materials and products - Hygrothermal properties -Tabulated design values and procedures for determining declared and design thermal values (ISO/DIS 10456:2005)*

EN ISO 12571, *Hygrothermal performance of building materials and products – Determination of hygroscopic sorption properties (ISO 12571:2000)*

EN ISO 12572, *Hygrothermal performance of building materials and products – Determination of water vapour transmission properties (ISO 12572:2001)*

prEN ISO 15927-3, *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/DIS 15927-3:2006)*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in prEN ISO 9346:2005 and EN ISO 7345 apply. Other terms used are defined in the relevant clauses of this standard.

3.2 Symbols and units

Symbol	Quantity	Unit
c_{m}	specific heat capacity of dry material	J/(kg·K)
c_{w}	specific heat capacity of liquid water	J/(kg·K)
D_{w}	moisture diffusivity	m^2/s
E_{sol}	total flux density of incident solar radiation	W/m^2

g	density of moisture flow rate	kg/(m²·s)
g_p	density of moisture flow rate of available water from precipitation	kg/(m²·s)
g_v	density of water vapour flow rate	kg/(m²·s)
g_w	density of liquid water flow rate	kg/(m²·s)
$g_{w,max}$	density of water flow rate which can be absorbed at the surface of a material	kg/(m²·s)
h	surface heat transfer coefficient	W/(m^2·K)
h_c	convective heat transfer coefficient	W/(m^2·K)
h_e	specific latent enthalpy of evaporation or condensation	J/kg
h_r	radiative heat transfer coefficient	W/(m^2·K)
K	liquid conductivity	s/m
p_a	ambient atmospheric pressure	Pa
p_{suc}	suction pressure	Pa
p_v	partial water vapour pressure	Pa
$p_{v,a}$	partial water vapour pressure in the air	Pa
$p_{v,s}$	partial water vapour pressure at a surface	Pa
$p_{v,sat}$	saturated water vapour pressure	Pa
p_w	water pressure inside pores	Pa
q	density of heat flow rate	W/m^2
q_{lat}	density of latent heat flow rate	W/m^2
q_{sens}	density of sensible heat flow rate	W/m^2
R_w	liquid moisture flow resistance of interface	m/s
R_{H2O}	gas constant of water vapour	J/(kg·K)
$s_{d,s}$	equivalent vapour diffusion thickness of a surface layer	m
T	thermodynamic temperature	K
T_a	air temperature of the surrounding environment	K
T_{eq}	equivalent temperature of the surrounding environment	K

T_r	mean radiant temperature of the surrounding environment	K
T_{surf}	surface temperature	K
t	time	s
v	wind speed	m/s
w	moisture content	kg/m^3
x	distance	m
α_{sol}	solar absorptance	-
δ_0	vapour permeability of still air	kg/(m·s·Pa)
δ_p	vapour permeability of material	kg/(m·s·Pa)
ε	longwave emissivity of the external surface	-
λ	thermal conductivity	W/(m·K)
φ	relative humidity	-
μ	diffusion resistance factor	-
ρ_a	density of air	kg/m^3
ρ_m	density of solid matrix	kg/m^3
ρ_w	density of liquid water	kg/m^3
σ_s	Stefan-Boltzmann constant	W/(m^2·K^4)

4 Hygrothermal equations and material properties

4.1 Assumptions

The hygrothermal equations specified in the following clauses contain the following assumptions:

- constant geometry, no swelling and shrinkage;
- no chemical reactions are occurring;
- latent heat of sorption is equal to latent heat of condensation/evaporation;
- no change in material properties by damage or ageing;
- local equilibrium between liquid and vapour without hysteresis;
- moisture storage function is not dependent on temperature;
- temperature and barometric pressure gradients do not affect vapour diffusion.

The development of the equations is based on the conservation of energy and moisture. The mathematical expression of the conservation laws are the balance equations. The conserved quantity changes in time, only if it is transported between neighbouring control volumes.

Heat conservation shall be expressed by

$$\left(c_m \cdot \rho_m + c_w \cdot w\right) \cdot \frac{\partial T}{\partial t} = -\frac{\partial\left(q_{sens} + q_{lat}\right)}{\partial x} \tag{1}$$

The increase of the moisture content of a control volume shall be 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.

$$\frac{\partial w}{\partial t} = -\frac{\partial g}{\partial x} \tag{2}$$

$$g = g_v + g_l \tag{3}$$

The relative humidity shall be defined by the following equation:

$$\varphi = \frac{p_v}{p_{v,sat}(T)} \tag{4}$$

The pressure acting on the water inside a building material due to the capillary forces is different from the pressure of the surrounding air. The difference is called suction.

$$p_{suc} = p_a - p_w \tag{5}$$

The suction of the pore water is related to the relative humidity of the surrounding air by the Kelvin equation:

$$p_{suc} = -\rho_w R_{H2O} T \ln\varphi \tag{6}$$

The relation between the state variables φ, p_v, p_{suc}, T and the moisture content of a building material is defined by the moisture storage function. The moisture storage function of a building material shall be expressed either as the moisture content as a function of suction (suction curve), $w(p_{suc})$, or as the moisture content as a function of the relative humidity (sorption curve), $w(\varphi)$.

4.2 Transport of heat and moisture

4.2.1 Heat transport

4.2.1.1 Heat transport inside materials

Heat transport shall be composed of sensible and latent components. Sensible heat transport shall be calculated with Fourier's law with a thermal conductivity which depends on moisture content.

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

Latent heat transport shall be calculated by the following equation:

$$q_{lat} = h_e\, g_v \tag{8}$$

4.2.1.2 Heat transport across boundaries

The heat flow from the surrounding environment into the construction consists of convection, shortwave radiation from the sun and longwave radiation exchange with sky and surrounding surfaces.

Sensible heat flow from each surrounding environment to the building envelope shall be given by:

$$q_{\text{sens}} = h\left(T_{\text{eq}} - T_{\text{surf}}\right) \tag{9}$$

The heat transfer coefficient and the equivalent temperature are:

$$h = h_{\text{c}} + h_{\text{r}} \tag{10}$$

$$T_{\text{eq}} = T_{\text{a}} + \frac{1}{h}\left(E_{\text{sol}}\,\alpha_{\text{sol}} + \left(T_{\text{r}} - T_{\text{a}}\right)h_{\text{r}}\right) \tag{11}$$

The radiative and convective heat exchanges are represented by an equivalent temperature. Other means of accounting for these effects may be used.

If the surface temperature is known it can be used as a boundary condition.

Latent heat flow to and from the boundaries is proportional to the vapour flow rate at the surfaces (see 4.2.2).

4.2.2 Moisture transport

4.2.2.1 Moisture transport inside materials

Moisture is transported by capillary forces and diffusion. The transport equations shall be formulated using the partial vapour pressure and the suction as the driving potentials.

$$g = g_{\text{v}} + g_{\text{w}} \tag{12}$$

$$g_{\text{v}} = \frac{1}{\mu(\varphi)}\delta_0 \frac{\partial p_{\text{v}}}{\partial x} \tag{13}$$

$$g_{\text{w}} = K\left(p_{\text{suc}}\right)\frac{\partial p_{\text{suc}}}{\partial x} \tag{14}$$

The temperature dependence of the liquid conductivity may be neglected.

NOTE For the liquid transport alternative potentials such as relative humidity, moisture content and temperature may be used, if the transport coefficients are transformed and the interfaces between two materials are handled in such a way that the suction and the partial vapour pressure are still continuous functions across the interface.

4.2.2.2 Moisture transport across material interfaces

Internal interfaces

The details of the contact between two layers of building materials can have a large influence on the liquid moisture transport. Additional coatings, such as adhesives, can also modify the diffusive moisture transport.

Small air gaps between materials and the modification of pore structure at material interfaces, because of chemical reaction products, reduce the capillary water transport across the interface. The influence of the interface on the liquid moisture flow may be described by a moisture resistance, R_{w}, which is defined by:

$$g_{\text{w}} = \frac{\Delta\, p_{\text{suc}}}{R_{\text{w}}} \tag{15}$$

External interfaces

Coatings and paints can cause additional resistance for water uptake and drying. The impact on diffusion can be described by an additional moisture resistance at the surface, $s_{d,s}/\delta_0$, defined by:

$$g_v = \frac{\delta_0}{s_{d,s}}\left(p_{v,a} - p_{v,s}\right) \tag{16}$$

where $s_{d,s}$ is the equivalent vapour diffusion thickness of the interface, in m.

The uptake of driving rain is limited by the amount of water which can be absorbed by the material at the surface:

$$g_{w,max} = \left(K \frac{\partial p_{suc}}{\partial x}\right) \tag{17}$$

so that:

$$g_w = \min(g_p, g_{w,max}) \tag{18}$$

where g_p is the water available for absorption from precipitation.

4.3 Material properties

4.3.1 Necessary material data set and measurement methods

Table 1 provides a list of relevant material properties, together with sources of tabulated values and measurement methods.

4.3.2 Measurement of moisture storage function

The moisture storage function is determined by a combination of sorption tests (EN ISO 12571) and pressure plate measurements [3],[5].

Table 1 — Material data set

Property	Symbol	Tabulated values	Measurement method
Density	ρ_s	prEN ISO 10456	
Specific heat capacity	$c_{p,s}$	prEN ISO 10456	
Thermal conductivity	$\lambda(w)$	prEN ISO 10456	EN 12939 EN 12664 EN 12667
Moisture storage function (sorption curve)	$w(\varphi)$		EN ISO 12571
Moisture storage function (suction curve)	$w(p_{suc})$		Bibliography [5]
Diffusion resistance factor	$\mu(\varphi)$	prEN ISO 10456	EN ISO 12572
Liquid conductivity	K		See 4.3.3.2

4.3.3 Measurement of moisture transport coefficients

4.3.3.1 Vapour transport coefficient

The determination of the vapour transport coefficient is described in EN ISO 12572. A distinction has to be made between dry-cup and wet-cup measurements. Dry-cup tests give information about moisture transfer dominated by vapour diffusion. Wet-cup tests give guidance about the performance under higher humidity conditions when the material pores could be partly filled with water and a combination of vapour and liquid transport is measured.

4.3.3.2 Liquid conductivity

In cases of high water content the liquid transport has a particular influence on the moisture transport behaviour of porous materials. The material property to describe this process is the “liquid diffusivity” or the “liquid conductivity”. Both transport coefficients are linked by the following equation:

$$K(p_{suc}) = -D_w(w)\frac{\partial w}{\partial p_{suc}} \tag{19}$$

These transport coefficients, which are highly dependent on water content, are determined by the measurement of water-content profiles in building materials using different techniques or by approximations using the water absorption coefficient (EN ISO 15148) and drying behaviour as referenced in the Bibliography [1,7,8,9].

NOTE Further information is given in Bibliography [4].

5 Boundary conditions

5.1 Internal conditions

5.1.1 Usage conditions

If the design of a new building is being assessed, internal conditions appropriate to the most severe likely use of the building shall be used. For example it could happen that a building which had a very small internal humidity load (e.g. a warehouse) is turned into one with a high humidity load (e.g. a food processing factory).

5.1.2 Parameters

The following parameters shall be used to specify the internal climate:

- equivalent internal temperature;
- vapour pressure or some other humidity parameter that enables the vapour pressure to be calculated.

5.1.3 Choice of data

Available data shall be chosen in the following order of preference:

1st choice: measured values for similar building in a similar climate or set-values specified by air conditioning systems;

2nd choice: results from hygrothermal building simulations;

3rd choice: specifications of moisture production and ventilation rates and calculation of internal conditions based on specifications of moisture production and ventilation rates

NOTE Annex C and EN ISO 13788 provide information on the calculation of internal humidity.

5.1.4 Surface transfer coefficients

The internal surface transfer coefficients shown in Table 2 shall be used for calculation of heat and vapour transfer at the internal surface.

Table 2 — Internal surface heat transfer coefficients and equivalent vapour diffusion thickness of boundary layer

Direction of heat flow	$h_{c,si}$	$h_{r,si}$	$s_{d,si}$
	W/(m²·K)	W/(m²·K)	m
Horizontal	2,5	5,7 ε	0,008
Upward	5	5,7 ε	0,004
Downward	0,7	5,7 ε	0,03
ε is the longwave emissivity of the surface			

Most surfaces of building constructions have an emissivity of about 0,9.

5.2 External conditions

5.2.1 Sources of data

The external conditions used shall be representative of the location of the building. Test reference years for energy design are generally available; as these are representative of mean conditions they may not be appropriate for moisture design. Reference years containing different variables or representing different extreme cases may be constructed to cover the analysis of specific problems.

If the design of a new building is being assessed, at least one year of external conditions appropriate to the most severe likely location of the building shall be used. The following sources are possible, arranged from the most to least appropriate.

1) At least ten years, preferably more, of measured data.

2) A Reference Year constructed to cause the most severe conditions likely to occur once every ten years (commonly referred as a Design Reference Year). Depending on exposure and composition of the building component, the most severe conditions can occur during a cold or a warm year (e.g. winter or summer condensation).

NOTE 1 Annex B gives details of methods of constructing Reference Years.

3) In the absence of Reference Years, more severe conditions may be simulated by applying an annual temperature shift of ± 2 K to a mean of the whole data set, keeping the relative humidity unchanged, depending whether summer or winter condensation is likely to be the problem.

NOTE 2 A change of 2 K represents the years likely to occur once in ten years.

If a problem in an existing building is being investigated, any data measured at the site of the building shall be used, otherwise the data from a similar location to that of the building shall be used.

In cases where precipitation moisture affects the building component the meteorological data set shall contain at least hourly values for precipitation and wind (velocity and direction).

For constructions below ground level, the ground temperature depends on the ground conditions and the depth observed (see Bibliography [4]). The relative humidity in the ground is assumed to be 99 %. Special care is needed if the construction is facing a wet soil and is able to take up liquid water.

Measured data or simulation results may be necessary to define the external boundary conditions for components adjacent to crawl spaces, attics, vented cavities and green roofs.

5.2.2 Climate parameters

The external climate file shall include the climate parameters necessary for the analysis to be undertaken. A complete set would contain:

- dry bulb temperature;
- vapour pressure, or any other humidity parameter that can be used to calculate vapour pressure;
- global and diffuse solar radiation;
- sky temperature;
- wind speed and direction;
- total atmospheric pressure;
- precipitation (rain, snow, drizzle).

Methods for calculating the moisture load from precipitation are available in prEN ISO 15927-3.

5.2.3 External surface transfer coefficients

5.2.3.1 Heat transfer

Convection: The surface heat transfer coefficient depends on the wind speed and shall be calculated according to the following equation:

$$h_{c,se} = 4 + 4v \tag{20}$$

NOTE The wind speed, v, in Equation (20) should be measured near the building surface.

Radiation: The radiation component of the external heat transfer coefficient shall be calculated as:

$$h_{r,se} = \varepsilon \cdot \sigma_s \cdot 4 \cdot \overline{T}^3 \tag{21}$$

where $\overline{T}$ is the mean of the external surface and the mean radiant external temperature, in K.

5.2.3.2 Vapour transfer

The external equivalent vapour diffusion thickness of the boundary layer at the external surface, $s_{d,se}$, depends on the wind speed and shall be calculated according to the following equation:

$$s_{d,se} = \frac{1}{67 + 90v} \tag{22}$$

NOTE The wind speed, v, in Equation (22) should be measured near the building surface.

6 Documentation of input data and results

6.1 General

The detailed documentation of input and output data of numerical simulations is an essential prerequisite to assess and check the calculation results. As a rule the documentation shall be such that anybody repeating the simulation as documented will obtain identical results. Therefore the documentation shall at least include the following items.

6.2 Problem description

6.2.1 General

The problem description shall contain all the information required prior to the start of the calculation.

6.2.2 Scope and subject of simulation

- Definition of the problem and reason for employing hygrothermal simulation.
- Construction details of the building component under examination.
- Practical background information.
- Output parameters required.
- Duration of simulation.

6.2.3 Initial conditions

- Initial temperature distribution.
- Initial moisture distribution.
- Date and time for the start of the simulation.

6.2.4 Boundary conditions

- Internal and external climate conditions, origin and time interval. The method of constructing the climate data sets shall be specified.
- Transformation of climate data to boundary conditions (e.g. determination of driving rain load).
- Surface heat transfer coefficients.

6.2.5 Material parameters

- Documentation of material properties by tables and graphs.
- Source of material data.
- Assumptions and approximations.
- Practical range of parameters (optional).

6.3 Hygrothermal model and numerical solution

6.3.1 General

The documentation shall contain all information related to the calculation model and the numerical parameters selected for the simulation.

6.3.2 Simulation tool

- Name and version of software.
- Validation of the model for similar benchmark applications (optional).

6.3.3 Numerical simulation

- Discretisation (numerical grid).
- Time intervals (time steps).
- Numerical control parameters (accuracy of solution).

6.3.4 Benchmark example

The benchmark example in Annex A should be solved with the model used and the results reported.

6.4 Calculation report

6.4.1 General

The report of a calculation shall contain all the relevant information about the display, evaluation and interpretation of the calculation results. The report should include:

- method used;
- reference to this standard;
- justification that compliance with the benchmark example is met, within the allowed tolerances.

It is recommended that the format shown below is used.

6.4.2 Display of results

The calculation results shall be documented in a form that conveys all the essential information concerning the hygrothermal performance of the component under study. This may be done by showing graphs and tables of:

- transient distributions (profiles);
- variation with time at specific locations or integrated over material layers;
- peak values (minimum, maximum);
- mean values at points and layers and surfaces of interest of the relevant hygrothermal variables and boundary conditions such as:
  - temperature, heat flow;
  - water content, moisture flow;
  - relative humidity;
  - vapour pressure.

The selection of graphs and tables to be displayed depends on the problem, the analysis and the conclusion.

6.4.3 Interpretation of the results

The documentation of the results may be followed by an interpretation of their practical meaning. This may be done by at least one of the following items:

- Comparing the resulting hygrothermal conditions with specified limits.
- Checking the risk of moisture accumulation by comparing the total moisture content in the construction after one cycle with the initial condition.
- Evaluating the moisture tolerance of the construction (drying potential).
- Feeding the transient results into a post process model (e.g. for mould or algae growth, rot, corrosion).

Annex A
(normative)

Benchmark example – Moisture uptake in a semi-infinite region

A.1 General

This annex defines a normative benchmark test designed to ensure that the software to be used fulfils some basic requirements and gives results which are correct within a specified tolerance. The result of the test is based on an analytical solution for coupled moisture and heat flow in a semi-infinite region.

NOTE Further, more complex benchmark examples are given in the Bibliography [4].

A.2 Problem description

The test deals with thick single homogeneous material in equilibrium with a constant surrounding climate. The material is perfectly airtight. At a certain time the temperature and the relative humidity undergoes a step change. The task is to calculate the temperature and moisture profiles at different times after this change.

- Initial condition: $\varphi = 50$ % , $T = 20$ °C
- After the step change : $\varphi_s = 95$ %, $T_s = 30$ °C
- Boundary resistances and rain impact are not considered.

The objective is to calculate the moisture and temperature distribution after 7 days, 30 days and 365 days.

Properties

a) General data

$T = T_{ref} = 293{,}15$ K

$\rho_w = 1000$ kg/m^3

$R_{H2O} = 462$ J/(kg · K)

b) Material data

Water retention curve:

$$w = \frac{146}{(1+(8\times10^{-8}s)^{1,6})^{0,375}}$$

$$s = 0{,}125\times10^{8}\left((\frac{146}{w})^{\frac{1}{0,375}} - 1\right)^{0,625}$$

Sorption isotherm:

$$w = \frac{146}{(1+(-8\times10^{-8}\cdot R_{H_2O}T\rho_w \ln(\varphi))^{1,6})^{0,375}}$$

$$\varphi = \exp\left(-\frac{1}{R_{H_2O}T\rho_w}0{,}125\times10^{8}\left((\frac{146}{w})^{\frac{1}{0,375}} - 1\right)^{0,625}\right)$$

Vapour diffusion:

$$\delta_p = \frac{M_w}{R_{H2O}\,T}\,\frac{26{,}1\times10^{-6}}{200}\,\frac{1-\frac{w}{146}}{0{,}503(1-\frac{w}{146})^2 + 0{,}497}$$

Liquid water permeability:

$$K = \exp(-39{,}2619 + 0{,}0704\cdot(w-73) - 1{,}7420\times10^{-4}\cdot(w-73)^2 - 2{,}7953\times10^{-6}\cdot(w-73)^3 - 1{,}1566\times10^{-7}\cdot(w-73)^4 + 2{,}5969\times10^{-9}\cdot(w-73)^5)$$

Porosity: equal maximum point of moisture storage function.

Thermal conductivity: $\lambda = 1{,}5 + \frac{15{,}8}{1000}w$

Heat capacity for dry material: $\rho_0 c_0 = 1{,}824\times10^{6}$

A.3 Results

In Figure A.1 and Figure A.2 the solid line is the analytical solution; the dotted lines show the interval of - 2,5 % and + 2,5 %. The calculated results shall be within the limits given in Tables A.1 and A.2.

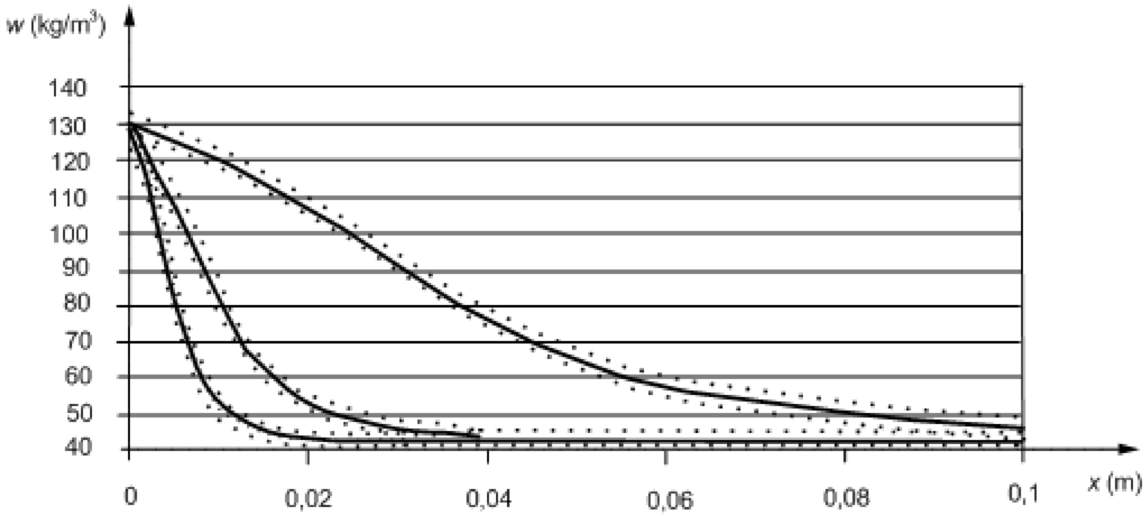


Figure A.1 — The moisture distribution at 7 days, 30 days and 365 days

Table A.1 — The limits of validity for results from the humidity calculations

Days	*x* = 0,01		*x* = 0,02		*x* = 0,03		*x* = 0,04		*x* = 0,05		*x* = 0,06		*x* = 0,08		*x* = 0,10	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
7	50,2	54,5	41,3	45,6	40,8	45,1	40,8	45,1								
30	81,0	85,3	51,1	55,3	43,6	47,9	41,5	45,7	40,9	45,2	40,8	45,1	40,8	45,1		
365	117,5	121,8	104,4	108,7	88,7	93,0	75,6	77,9	62,8	67,1	55,7	60,0	47,9	52,2	44,1	48,4

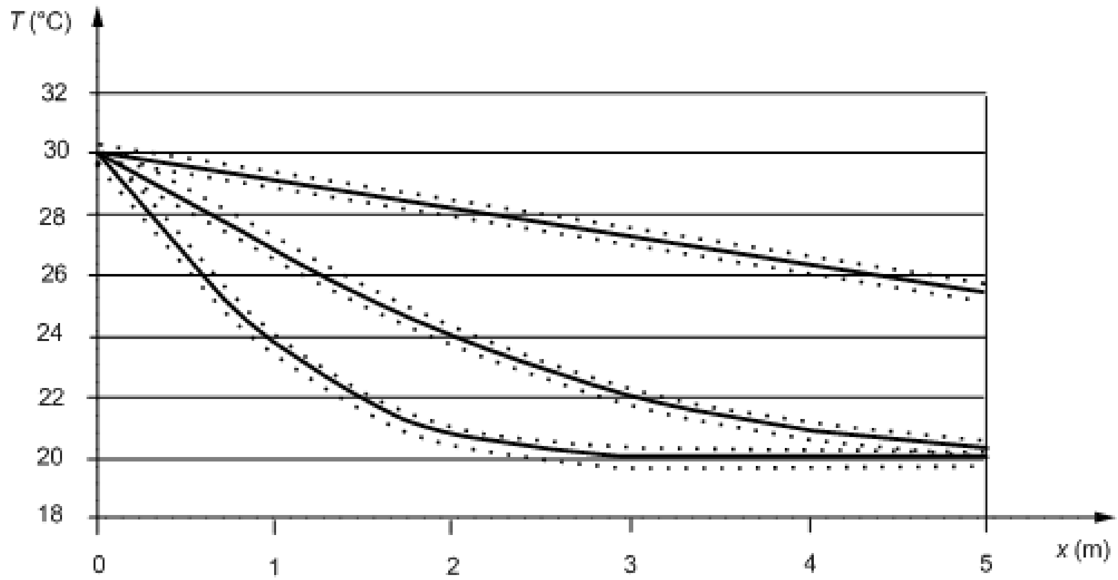


Figure A.2 — The temperature distribution at 7 days, 30 days and 365 days

Table A.2 — The limits of validity for the results from the temperature calculations

Days	x = 0,5		x = 1,0		x = 1,5		x = 2,0		x = 2,5		x = 3,0		x = 4,0		x = 5,0	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
7	26,4	26,9	23,6	24,1	21,7	22,2	20,6	21,1	20,0	20,5	19,8	20,4	19,8	20,3	19,8	20,3
30	28,1	28,6	26,5	27,0	25,0	25,5	23,7	24,3	22,7	23,2	21,8	22,3	20,7	21,2	20,1	20,6
365	29,2	29,8	28,8	29,3	28,3	28,8	27,8	28,4	27,4	27,9	26,9	27,4	26,0	26,6	25,2	25,7

Annex B
(informative)

Design of Moisture Reference Years

Analysis of long term energy use in buildings requires the input of mean external conditions. A number of Test Reference Years of hourly values of the important meteorological parameters have been developed for this purpose; methods for developing Test Reference Years are specified in EN ISO 15927-4, *Hygrothermal performance of buildings - Calculation and presentation of climatic data - Part 4: Hourly data for assessing the annual energy use for heating and cooling (ISO 15927-4:2005).*

When the problems caused by moisture movement within structures are being investigated, a more severe climate is usually required. The type of climate, and the parameters to be included, depends on the nature of the specific problem that is being investigated. The important issues are:

- The degree of risk that is acceptable. In most moisture applications a once in ten years failure rate is usually considered to be acceptable. However, in particularly sensitive applications, such as computer centres, art galleries or hospitals a lower failure rate might be required.

- Whether high or low values of the parameters are relevant to the problem. Most cases require analysis in cold winter weather, however some moisture damage is worst in warm humid summer conditions.

- A considerable amount of research has been carried out to investigate the interaction between semi-extreme values of temperature, relative humidity and solar radiation and the risks of moisture damage. Attempts have been made to design 'Moisture Design Reference Years' which, for climates where the winter situation is the most critical, combine low temperatures and solar radiation with high relative humidities (further details are given in Bibliography [12]). However the process of constructing these years is very complex, requiring information that is not generally available and in any case the results are very little different from using temperature alone as the selection factor.

The following guidelines for selection of external climate data should therefore be followed.

1. The data set should include all the parameters necessary for the operation of the model to be used and to address the specific problem under investigation.

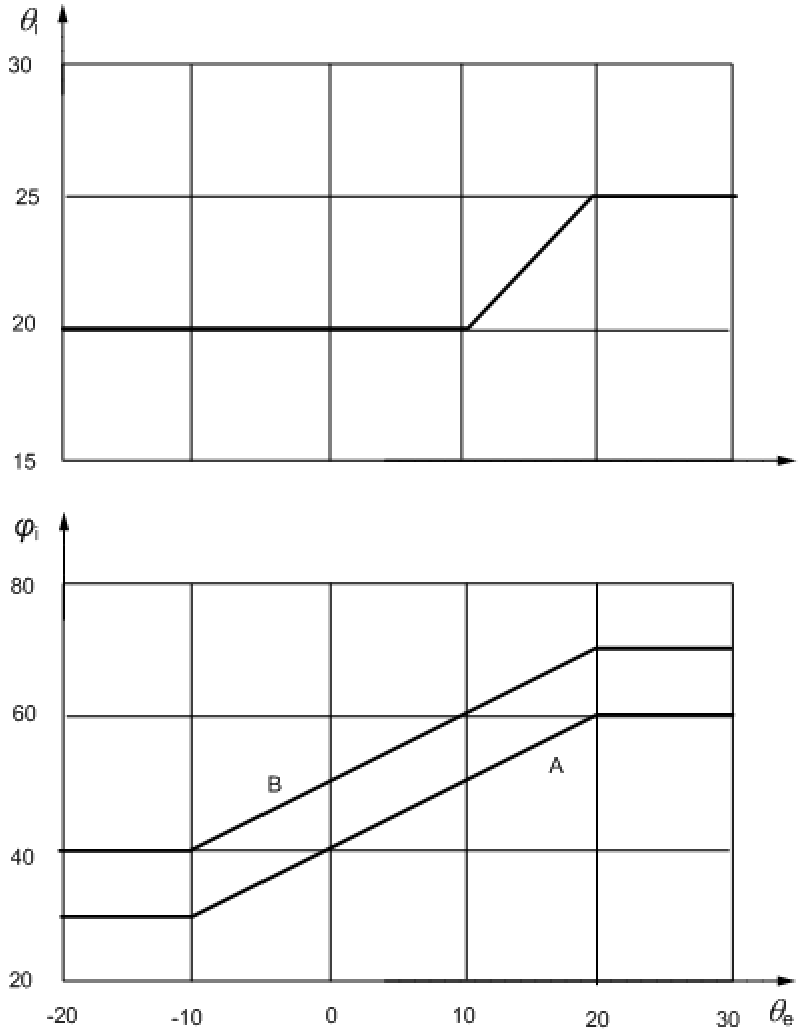
2. A full year of hourly values should be used to analyse structures where liquid water storage and movement are important.

3. If a full year of data is to be used to investigate problems at low temperatures, the year with the mean temperature closest to the 10-percentile value of the distribution of the annual mean temperatures should be selected from all the data available. The 90-percentile temperature value should be selected for investigation of problems associated with high temperatures. The year with the 90-percentile rain fall value should be selected to analyse problems associated with rain penetration.

Annex C
(informative)

Internal boundary conditions

In the absence of well defined - controlled, measured or simulated - internal air conditions, a simplified approach to determine the internal temperature and humidity for heated buildings (only dwellings and offices) based on the external air temperature may be used. The internal air conditions are derived from entering the daily mean of the external air temperature into the graphs in Figure C.1. The internal air humidity level is selected according to the expected occupancy of the building.



Key	φ_i internal relative humidity, %
θ_i internal temperature, °C	A : normal occupancy
θ_e external temperature, °C	B : high occupancy

Figure C.1 — Daily mean internal air temperature and humidity in dwellings and office buildings depending on the daily mean external air temperature

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