
**Hygrothermal performance of building
components and building elements —
Internal surface temperature to avoid
critical surface humidity and interstitial
condensation — Calculation methods**

*Performance hygrothermique des composants et parois de bâtiments —
Température superficielle intérieure permettant d'éviter l'humidité
superficielle critique et la condensation dans la masse — Méthodes de
calcul*



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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 13788 was prepared by the European Committee for Standardization (CEN) in collaboration with ISO Technical Committee TC 163, *Thermal insulation*, Subcommittee SC 2, *Calculation methods*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Throughout the text of this standard, read "...this European Standard..." to mean "...this International Standard...".

Annexes A to F of this International Standard are for information only.

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Foreword

The text of EN ISO 13788:2001 has been prepared by Technical Committee CEN/TC 89 "Thermal performance of buildings and building components", the secretariat of which is held by SIS, in collaboration with Technical Committee ISO/TC 163 "Thermal insulation".

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of an identical text or by endorsement, at the latest by January 2002, and conflicting national standards shall be withdrawn at the latest by January 2002.

This standard is one of a series of standards, which specify test methods for the thermal and moisture related properties of building materials and products.

The annexes A, B, C, D, E and F are informative.

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

Introduction

Moisture transfer is a very complex process and the knowledge of moisture transfer mechanisms, material properties, initial conditions and boundary conditions is often insufficient, inadequate and still under development. Therefore this standard lays down simplified calculation methods, based on experience and commonly accepted knowledge. The standardisation of these calculation methods does not exclude use of more advanced methods. The calculations will normally lead to designs well on the safe side and if a construction fails a specified design criterion according to this procedure, more accurate methods may be used to show that the design will pass.

This standard deals with critical surface humidity and interstitial condensation, and does not cover other aspects of moisture, e.g. ground water, precipitation, built-in moisture and moisture convection, which can be considered in the design of a building component.

1 Scope

This standard gives calculation methods for:

- a) The internal surface temperature of a building component or building element below which mould growth is likely, given the internal temperature and relative humidity – the method can also be used to assess the risk of other surface condensation problems.
- b) The assessment of the risk of interstitial condensation due to water vapour diffusion. The method used assumes built-in water has dried out and does not take account of a number of important physical phenomena including:
 - the dependence of thermal conductivity on moisture content;
 - the release and absorption of latent heat;
 - the variation of material properties with moisture content;
 - capillary suction and liquid moisture transfer within materials;
 - air movement through cracks or within air spaces;
 - the hygroscopic moisture capacity of materials.

Consequently the method is applicable only to structures where these effects are negligible.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 12524	<i>Building materials and products – Hygrothermal properties - Tabulated design values</i>
ISO 6946	<i>Building components and building elements – Thermal resistance and thermal transmittance - Calculation method</i>
ISO 9346	<i>Thermal insulation - Mass transfer - Physical quantities and definitions</i>
ISO 10211-1	<i>Thermal bridges in building construction – Calculation of heat flows and surface temperatures - Part 1: General methods</i>
ISO 10456	<i>Building materials and products – Procedures for determining declared and design thermal values</i>
ISO 12572	<i>Hygrothermal performance of building materials and products - Determination of water vapour transmission properties</i>

ISO 15927-1¹ *Hygrothermal performance of buildings – Calculation and presentation of climatic data - Part 1: Monthly means of single meteorological elements*

3 Definitions, symbols and units

3.1 Terms and definitions

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

3.1.1

temperature factor at the internal surface

difference between the temperature of the internal surface and the external air temperature, divided by the difference between the internal air temperature and the external air temperature, calculated with a surface resistance at the internal surface R_{si} :

$$f_{Rsi} = \frac{\theta_{si} - \theta_e}{\theta_i - \theta_e} \quad (1)$$

Methods of calculating the temperature factor in complex constructions are given in ISO 10211-1.

3.1.2

design temperature factor at the internal surface

minimum acceptable temperature factor at the internal surface:

$$f_{Rsi,min} = \frac{\theta_{si,min} - \theta_e}{\theta_i - \theta_e} \quad (2)$$

3.1.3

minimum acceptable temperature

lowest internal surface temperature before mould growth starts

3.1.4

internal moisture excess

rate of moisture production in a space divided by the air change rate and the volume of the space:

$$\Delta v = v_i - v_e = G/(n V) \quad (3)$$

3.1.5

water vapour diffusion-equivalent air layer thickness

thickness of a motionless air layer which has the same water vapour resistance as the material layer in question:

$$s_d = \mu d \quad (4)$$

3.1.6

relative humidity

ratio of the vapour pressure to the saturated vapour pressure at the same temperature:

¹ To be published

$$\varphi = \frac{p}{p_{\text{sat}}} \quad (5)$$

3.1.7

critical surface humidity

relative humidity at the surface that leads to deterioration of the surface, specifically mould growth

3.2 Symbols and units

Symbol	Quantity	Unit
D	water vapour diffusion coefficient in a material	m^2/s
D_0	water vapour diffusion coefficient in air	m^2/s
G	internal moisture production rate	kg/h
M_a	accumulated moisture content per area at an interface	kg/m^2
R	thermal resistance	$\text{m}^2 \cdot \text{K}/\text{W}$
R_v	gas constant for water vapour = 462	$\text{Pa} \cdot \text{m}^3/(\text{K} \cdot \text{kg})$
T	temperature	K
U	thermal transmittance of component or element	$\text{W}/(\text{m}^2 \cdot \text{K})$
V	internal volume of building	m^3
Z_p	water vapour resistance with respect to partial vapour pressure	$\text{m}^2 \cdot \text{s} \cdot \text{Pa}/\text{kg}$
Z_v	water vapour resistance with respect to humidity by volume	s/m^2
d	material layer thickness	m
$f_{R\text{si}}$	temperature factor at the internal surface	-
$f_{R\text{si,min}}$	design temperature factor at the internal surface	-
g	density of water vapour flow rate	$\text{kg}/(\text{m}^2 \cdot \text{s})$
n	air change rate	h^{-1}
p	water vapour pressure	Pa
q	density of heat flow rate	W/m^2
s_d	water vapour diffusion-equivalent air layer thickness	m
t	time	s
w	moisture content mass by volume	kg/m^3
δ_p	water vapour permeability of material with respect to partial vapour pressure	$\text{kg}/(\text{m} \cdot \text{s} \cdot \text{Pa})$
δ_0	water vapour permeability of air with respect to partial vapour pressure	$\text{kg}/(\text{m} \cdot \text{s} \cdot \text{Pa})$
v	humidity of air by volume	kg/m^3
Δv	internal moisture excess, $v_i - v_e$	kg/m^3
Δp	internal vapour pressure excess, $p_i - p_e$	Pa
φ	relative humidity of air	-
λ	thermal conductivity	$\text{W}/(\text{m} \cdot \text{K})$
μ	water vapour resistance factor	-
θ	Celsius temperature	$^{\circ}\text{C}$
$\theta_{\text{si,min}}$	minimum acceptable surface temperature	$^{\circ}\text{C}$

3.3 Subscripts

c	condensation	n	interface
cr	critical value	s	surface
e	external air	sat	value at saturation
ev	evaporation	se	external surface
i	internal air	si	internal surface
min	minimum value	T	total over whole component or element

4 Input data for the calculations

4.1 Material and product properties

For the calculations, design values shall be used. Design values in product or material specifications or the tabulated design values given in the standards referred to in Table 1 may be used.

Table 1 - Material and product properties

Property	Symbol	Design values
Thermal conductivity thermal resistance	λ R	Obtained from EN 12524 or determined in accordance with ISO 10456.
Water vapour resistance factor water vapour diffusion-equivalent air layer thickness	μ s_d	Obtained from EN 12524 or determined in accordance with ISO 12572.

Thermal conductivity, λ , and water vapour resistance factor, μ , are applicable to homogenous materials and thermal resistance, R , and water vapour diffusion-equivalent air layer thickness, s_d , primarily to composite products or products without well-defined thickness.

For air layers, R is taken from ISO 6946; s_d is assumed to be 0,01 m, independent of air layer thickness and inclination.

4.2 Climatic conditions

4.2.1 Location

Unless otherwise specified, the external conditions used shall be representative of the location of the building.

4.2.2 Time period

For the calculation of the risk of surface mould growth or the assessment of structures for the risk of interstitial condensation, monthly mean values, derived using the methods described in ISO 15927-1, shall be used.

For calculations of the risk of surface condensation on low thermal inertia elements such as, for example, windows and their frames, the mean annual minimum temperature on a daily basis and corresponding relative humidity shall be used.

NOTE This implies that there will be some condensation on one day in half the years.

4.2.3 Temperatures

The following temperatures shall be used for the calculations.

- a) External air temperature as specified in 4.2.2.
- b) Ground temperature adjacent to building components.
The annual mean value of the external air temperature shall be used.
- c) Internal air temperature.
Use values according to the expected use of the building. Internal air temperatures to be used in this standard may be specified nationally.

4.2.4 Humidity conditions

- a) To define the external air humidity conditions, use humidity by volume, v_e , or vapour pressure, p_e .

Monthly mean vapour pressure or humidity by volume may be calculated from the mean temperature and relative humidity using equations (6) or (7).

$$\overline{p_e} = \overline{\varphi_e} p_{\text{sat}}(\overline{\theta_e}) \quad (6)$$

$$\overline{v_e} = \overline{\varphi_e} v_{\text{sat}}(\overline{\theta_e}) \quad (7)$$

Due to the non-linear relationship between temperature and saturation humidity, these equations become inaccurate in hot climates.

For calculations of the risk of surface condensation on low thermal inertia elements such as, for example windows and their frames, the external relative humidity corresponding to the mean annual minimum temperature on a daily basis shall be used.

- b) Humidity conditions in the ground

Assume saturation ($\varphi = 1$).

- c) Internal air humidity

The internal air humidity can be derived:

- 1) by either of the expressions

$$p_i = p_e + \Delta p \quad (8)$$

$$v_i = v_e + \Delta v \quad (9)$$

Take values of Δp and Δv according to the expected use of the building and multiply them by 1,10 to provide a safety margin. Values to be used in this standard may be specified nationally.

or

- 2) given as a constant ϕ_i when the internal relative humidity is known and kept constant e.g. by air-conditioning. To provide a safety margin add 0,05 to the relative humidity.

NOTE 1 The introduction of a factor 1,10 (or a margin of 0,05 RH) is intended to allow for inaccuracies in the method. The calculation method as described in this standard is a steady state calculation. In reality, however, external air temperature variations, changing solar radiation, hygroscopic inertia and intermittent heating can influence surface humidity conditions. This is especially the case for a thermal bridge area consisting of building materials with high thermal inertia. The factor does not include the behaviour of the occupants, which can have a significant effect on ventilation.

NOTE 2 Internal humidities can be classified in five humidity classes, see annex A.

4.3 Surface resistances

4.3.1 Heat transfer

The values of R_{se} and R_{si} given in Table 2 shall be used for the assessment of mould growth and interstitial condensation.

Table 2 - Surface thermal resistances

	Resistance $\text{m}^2 \cdot \text{K/W}$
External surface resistance R_{se}	0,04
Internal surface resistance R_{si}	
On glazing and frames	0,13
All other internal surfaces	0,25

NOTE An internal surface resistance of 0,25 is taken to represent the worst case of condensation risk in a corner.

4.3.2 Water vapour transfer

The surface water vapour resistance is assumed to be negligible in the calculations in accordance with this standard.

5 Calculation of surface temperature to avoid critical surface humidity

5.1 General

This clause specifies a method to design the building envelope to prevent the adverse effects of critical surface humidity, e.g. mould growth.

NOTE Surface condensation can cause damage to unprotected building materials that are sensitive to moisture. It can be accepted temporarily and in small amounts, e.g. on windows and tiles in bathrooms, if the surface does not absorb the moisture and adequate measures are taken to prevent its contact with adjacent sensitive materials.

There is a risk for mould growth at surface relative humidities above 0,8 for several days.

5.2 Determining parameters

Besides the external climate (air temperature and humidity) three parameters govern surface condensation and mould growth:

- a) the “thermal quality” of each building envelope element, represented by thermal resistance, thermal bridges, geometry and internal surface resistance. The thermal quality can be characterised by the temperature factor at the internal surface, f_{Rsi} ;

NOTE ISO 10211-1 gives a method for calculating weighting factors, when there is more than one inside boundary temperature.

- b) the internal moisture supply, see 4.2.4;
- c) internal air temperature and heating system.

NOTE A lower room temperature is in general more critical. This is especially the case for rooms with reduced, intermittent or no heating where water vapour may enter from adjacent warmer rooms. The heating system will influence air movement and temperature distribution in the rooms and therefore locally cooler areas of the building envelope may become more critical.

5.3 Design for avoidance of mould growth

To avoid mould growth the relative humidity at the surface should not exceed 0,8 for several days. The principal steps in the design procedure are to determine the internal air humidity and then, based on the required relative humidity at the surface, to calculate the acceptable saturation humidity, by volume, v_{sat} , or vapour pressure, p_{sat} , at the surface. From this value, a minimum surface temperature and hence a required “thermal quality” of the building envelope (for a given internal air temperature and expressed by f_{Rsi}) is established.

For each month of the year, go through the following steps:

- a) define the external air temperature in accordance with 4.2.3;
- b) define the external humidity in accordance with 4.2.4;
- c) define the internal temperature in accordance with national practice;
- d) calculate the internal relative humidity from Δv or Δp (defined in 4.2.4) or take a constant relative humidity for a conditioned environment, including the corrections for safety margin defined in 4.2.4;
- e) with a maximum acceptable relative humidity at the surface, $\varphi_{si} = 0,8$, calculate the minimum acceptable saturation humidity by volume, v_{sat} , or vapour pressure, p_{sat} .

$$v_{sat}(\theta_{si}) = \frac{v_i}{0,8} \quad (10)$$

or

$$p_{sat}(\theta_{si}) = \frac{p_i}{0,8} \quad (11)$$

NOTE 1 The criterion $\varphi_{si} \leq 0,8$ is selected with regard to the risk of mould growth. Other criteria, e.g. $\varphi_{si} \leq 0,6$ to avoid corrosion, can be used, if appropriate.

- f) Determine the minimum acceptable surface temperature, $\theta_{si,min}$, from the minimum acceptable saturation humidity.

NOTE 2 The temperature as a function of saturation humidity can be found from equation (E.10) or (E.11) in annex E. Another option is to prepare a table or a graph, based on equation (E.8), indicating the relationship between p_{sat} and θ , to find θ from p_{sat} .

- g) From the minimum acceptable surface temperature, $\theta_{si,min}$, assumed internal air temperature, θ_i (see 4.2.3) and external temperature, θ_e , the minimum temperature factor, $f_{Rsi,min}$, is calculated according to equation (2).

The month with the highest required value of $f_{Rsi,min}$ is the critical month. The temperature factor for this month is $f_{Rsi,max}$ and the building element shall be designed so that $f_{Rsi,max}$ is always exceeded; i.e. $f_{Rsi} > f_{Rsi,max}$.

Examples of this procedure are given in annex B.

NOTE 3 For a given building design effective values of f_{Rsi} can be derived:

- for plane elements, from $f_{Rsi} = (U^{-1} - R_{si})/U^{-1}$
- Where multidimensional heat flow occurs, from a finite element or similar programme in accordance with ISO 10211, *Thermal bridges in building construction – Calculation of heat flows and surface temperatures – Part 1: General methods, or Part 2: Linear thermal bridges*.

5.4 Design for avoidance of surface condensation on lightweight constructions

In the case of lightweight constructions, which respond to temperature changes in periods much less than a day, the following procedure shall be used.

- Define the external temperature as the mean annual minimum temperature.
- Define the external relative humidity as 0,95 and calculate the vapour pressure or humidity by volume with equation 6) or 7).
- Define the internal temperature according to national practice.
- Convert Δv or Δp (defined in 4.2.2) into the internal relative humidity.
- With a maximum acceptable relative humidity at the surface, $\varphi_s = 1,0$, calculate the minimum acceptable saturation humidity, by volume, v_{sat} , or vapour pressure, p_{sat} .

$$v_{\text{sat}}(\theta_{\text{si}}) = v_i \quad (12)$$

$$\text{or} \quad p_{\text{sat}}(\theta_{\text{si}}) = p_i \quad (13)$$

- Determine the minimum acceptable surface temperature, $\theta_{\text{si,min}}$, from the minimum acceptable saturation humidity.

NOTE The temperature as a function of saturation humidity can be found from equation (E.10) or (E.11) in annex E. Another option is to prepare a table or a graph, based on equation (E.8), indicating the relationship between p_{sat} and θ , to find θ from p_{sat} .

- From the minimum acceptable surface temperature $\theta_{\text{si,min}}$, assumed internal air temperature, θ_i (see 4.2.3) and external temperature, θ_e , the required temperature factor of the building envelope, $f_{\text{Rsi,min}}$, is calculated according to equation (2).

6 Calculation of interstitial condensation

6.1 General

This clause gives a method to establish the annual moisture balance and to calculate the maximum amount of accumulated moisture due to interstitial condensation. The method assumes that any built-in moisture has dried out.

The method should be regarded as an assessment rather than as an accurate prediction tool. It is suitable for comparing different constructions and assessing the effects of modifications. It does not provide an accurate prediction of moisture conditions within the structure under service conditions, and is not suitable for calculation of drying out of built-in moisture.

6.2 Principle

Starting with the first month in which any condensation is predicted, the monthly mean external conditions are used to calculate the amount of condensation or evaporation in each of the twelve months of a year. The accumulated mass of condensed water at the end of those months when condensation has occurred is compared with the total evaporation during the rest of the year. One-dimensional, steady-state conditions are assumed. Air movements through or within the building elements are not considered.

Moisture transfer is assumed to be pure water vapour diffusion, described by the following equation

$$g = \frac{\delta_0}{\mu} \frac{\Delta p}{\Delta x} = \delta_0 \frac{\Delta p}{s_d} \quad (14)$$

where $\delta_0 = 2 \times 10^{-10} \text{ kg}/(\text{m}\cdot\text{s}\cdot\text{Pa})$.

NOTE 1 δ_0 depends on temperature and barometric pressure, but these influences are neglected in this standard. Other equations for water vapour transfer are given in annex E.

The density of heat flow rate is given by

$$q = \lambda \frac{\Delta \theta}{d} = \frac{\Delta \theta}{R} \quad (15)$$

NOTE 2 The thermal conductivity, λ , and the thermal resistance, R , are assumed constant and the specific heat capacity of the materials not relevant. For parallel sided homogeneous materials, $R = d/\lambda$. Heat sinks/sources due to phase changes are neglected.

NOTE 3 Calculation methods according to this principle are often called “Glaser methods”. More advanced methods are briefly described in annex F.

6.3 Limitations and sources of error

There are several sources of error caused by the simplifications described in 6.2.

- a) The thermal conductivity depends on the moisture content, and heat is released/absorbed by condensation/evaporation. This will change the temperature distribution and saturation values and affect the amount of condensation/drying.
- b) The use of constant material properties is an approximation.
- c) Capillary suction and liquid moisture transfer occur in many materials and this may change the moisture distribution.
- d) Air movements through cracks or within air spaces may change the moisture distribution by moisture convection. Rain or melting snow may also affect the moisture conditions.
- e) The real boundary conditions are not constant over a month.
- f) Most materials are at least to some extent hygroscopic and can absorb water vapour.
- g) One-dimensional moisture transfer is assumed.
- h) The effects of solar and long-wave radiation are neglected.

NOTE Due to the many sources of error, this calculation method is less suitable for certain building components and climates. Neglecting moisture transfer in the liquid phase normally results in an overestimate of the risk of interstitial condensation.

In building elements where there is air flow through or within the element the calculated results can be very unreliable and great caution shall be used when interpreting the results.

6.4 Calculation

6.4.1 Material properties

Divide the building element into a series of parallel-sided homogeneous layers and define the material properties of each layer and the surface coefficients in accordance with 4.1 and 4.3. Each layer in multi-layer products or components, including any products with facings or coatings, shall be treated as an individual layer, taking full account of their respective thermal and moisture vapour transmission properties. Calculate the thermal resistance, R , and the water vapour diffusion-equivalent air layer thickness, s_d , of each individual layer of the building element. Subdivide high thermal resistance elements, such as insulants, into a number of layers each with the same thermal resistance not exceeding $0,25 \text{ m}^2 \cdot \text{K/W}$; these subdivisions are treated as separate material layers in all calculations.

Some materials, such as sheet metals, effectively prevent the passage of any water vapour and therefore have an infinite value of μ . However, as a finite value of μ for a material is required for the calculation procedure, a value of 100 000 should be taken for these materials. This can lead to the prediction of negligibly small amounts of condensation, which should be disregarded as due to the inaccuracy of the calculation method.

Calculate the accumulated thermal resistance and the water vapour diffusion-equivalent air layer thickness from the outside to each interface n :

$$R'_n = R_{se} + \sum_{j=1}^n R_j \quad (16)$$

$$s'_{d,n} = \sum_{j=1}^n s_{d,j} \quad (17)$$

The total thermal resistance and the water vapour diffusion-equivalent air layer thickness are given by equations (18) and (19):

$$R'_T = R_{si} + \sum_{j=1}^N R_j + R_{se} \quad (18)$$

$$s'_{d,T} = \sum_{j=1}^N s_{d,j} \quad (19)$$

6.4.2 Boundary conditions

Define internal and external temperature and humidity according to 4.2.

6.4.3 Starting month

Starting with any month of the year (the trial month), calculate the temperature, saturated vapour pressure and vapour distributions through the component as specified in 6.4.4 and 6.4.5. Determine whether any condensation is predicted.

If no condensation is predicted in the trial month, repeat the calculation with successive following months until either:

- a) no condensation has been found in any of the twelve months, then report the component as free from condensation; or
- b) a month is found with condensation, this is the starting month.

If condensation is predicted in the trial month, repeat the calculation with successively earlier months until either:

- a) condensation is predicted in all twelve months; then, starting in any month, calculate the total annual accumulation of condensation as specified in 6.4.4, 6.4.5 and 6.4.6; or
- b) a month is found with no condensation; then take the following month as the starting month.

NOTE In climates outside the tropics, with well defined seasons, choosing a trial month two or three months before the coldest period of the year will normally allow the starting month to be found rapidly.

If a starting month has been determined, carry out the calculations specified in clauses 6.4.4, 6.4.5 and 6.4.6 for each month of the year, starting with the starting month.

6.4.4 Temperature and saturated vapour pressure distribution

Calculate the temperature at each interface between materials according to:

$$\theta_n = \theta_e + \frac{R'_n}{R'_T} (\theta_i - \theta_e) \quad (20)$$

The temperature distribution in each layer is linear given the assumption of steady state conditions, see Figure 1.

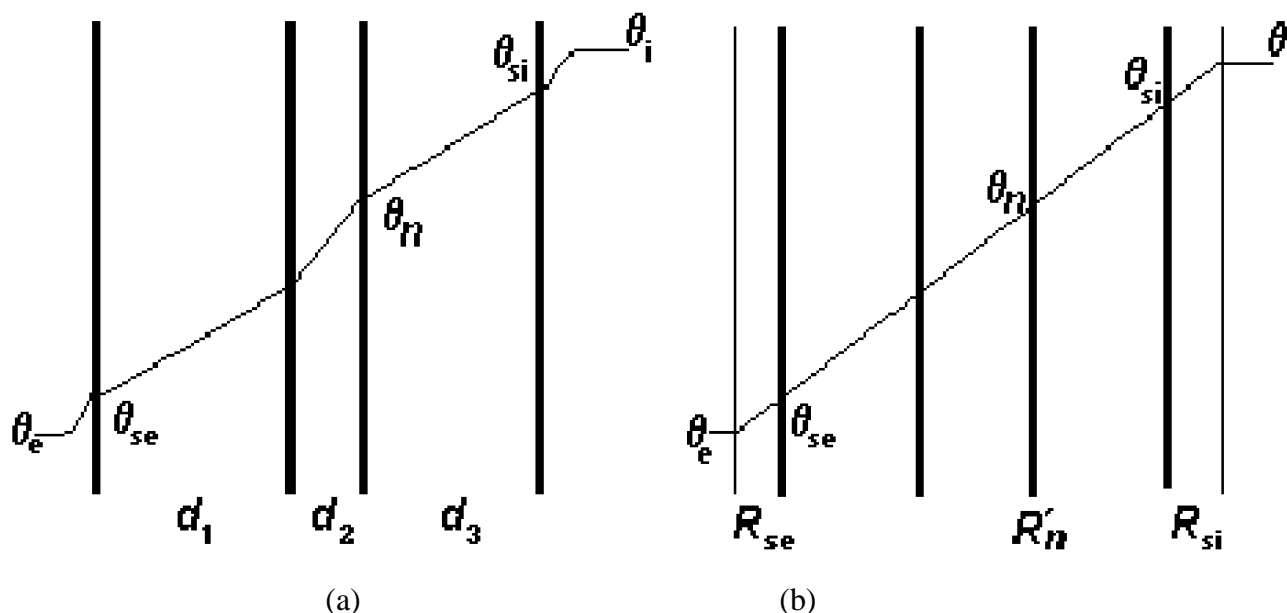


Figure 1 - Temperature distribution in a multi-layer building element:

(a) plotted against the width of each layer, (b) plotted against thermal resistance of each layer

Calculate the saturation vapour pressure from the temperature at each interface between material layers.

NOTE Expressions for saturation vapour pressure as a function of temperature are given in annex E.

6.4.5 Vapour pressure distribution

Draw a cross section of the building element with the thicknesses of each layer equivalent to its water vapour diffusion-equivalent air layer thickness, s_d , see Figure 2. Draw straight lines joining the saturation vapour pressures at each interface between materials.

If there is no accumulated condensate from the previous month, draw the vapour pressure profile as a straight line between the internal and external vapour pressure (p_i and p_e). If this line does not exceed the saturation pressure at any interface, condensation does not occur; see Figure 2, in which the water vapour pressure in the building component is lower at every point in the component than the vapour saturation pressure.

The vapour flow rate through the building element may be calculated as

$$g = \delta_0 \frac{p_i - p_e}{s'_{d,T}} \quad (21)$$

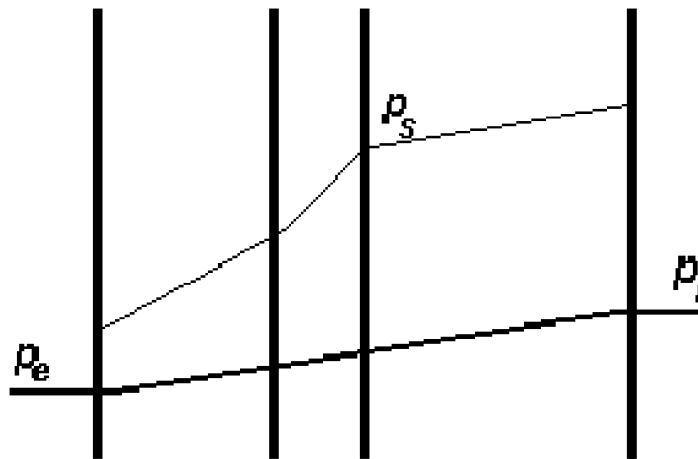


Figure 2 - Water vapour diffusion in a multi-layer building element without any interstitial condensation

If the vapour pressure exceeds the saturation pressure at any interface, redraw the vapour pressure as a series of lines which touch, but do not exceed, the saturation vapour pressure profile at as few points as possible, see examples in Figures 3 and 4. These points are the condensation interfaces.

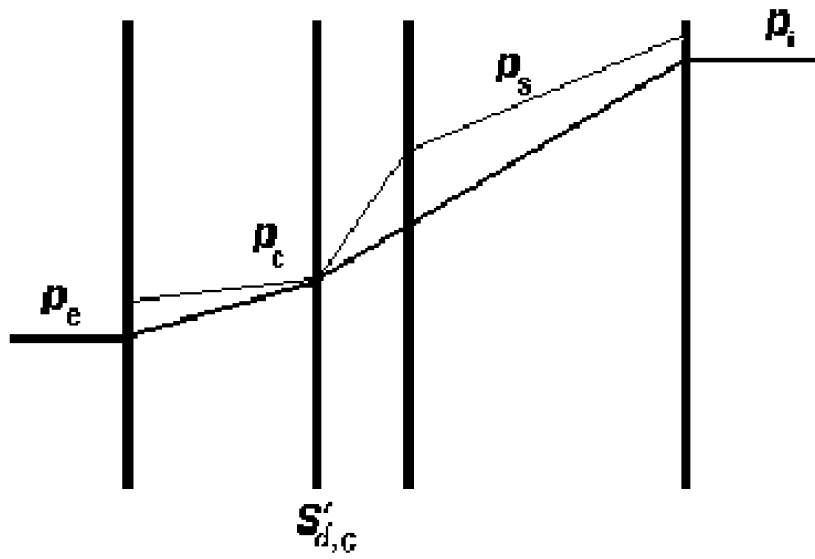


Figure 3 - Water vapour diffusion with interstitial condensation in one interface plane

6.4.6 Condensation rate

The rate of condensation is the difference between the amount of moisture transported to and the amount of moisture transported from the condensation interface:

$$g_c = \delta_0 \left(\frac{p_i - p_c}{s'_{d,T} - s'_{d,c}} - \frac{p_c - p_e}{s'_{d,c}} \right) \quad (22)$$

In a building component with **more than one** condensation interface, maintain a record of the amount of condensation in each interface.

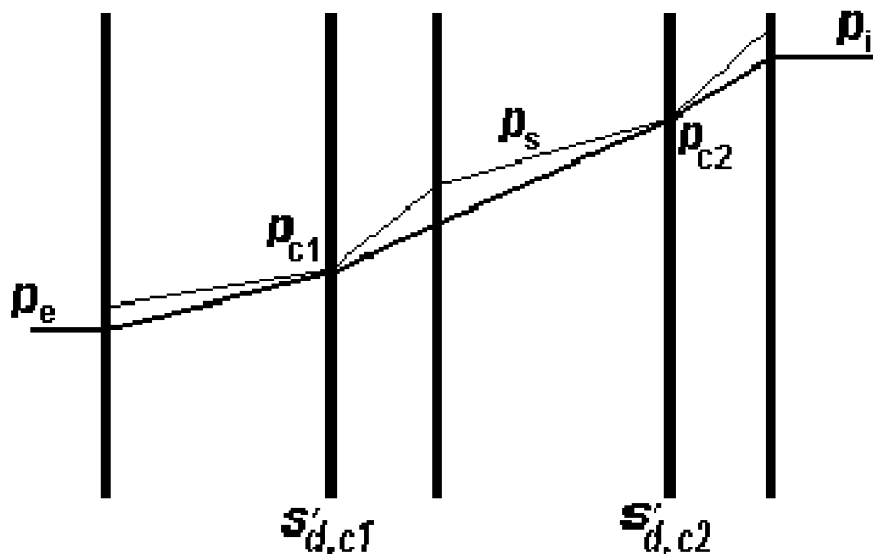


Figure 4 - Water vapour diffusion with interstitial condensation in two interface planes

The rate of condensation is calculated for each condensation interface from the difference in slope between successive straight lines, that is, in the case of two condensation interfaces (see Figure 4).

$$\text{Interface c1: } g_{c1} = \delta_0 \left(\frac{P_{c2} - P_{c1}}{s'_{d,c2} - s'_{d,c1}} - \frac{P_{c1} - P_e}{s'_{d,c1}} \right) \quad (23)$$

$$\text{Interface c2: } g_{c2} = \delta_0 \left(\frac{P_i - P_{c2}}{s'_{d,T} - s'_{d,c2}} - \frac{P_{c2} - P_{c1}}{s'_{d,c2} - s'_{d,c1}} \right) \quad (24)$$

6.4.7 Evaporation

When there is condensate, accumulated from previous months, at one or more interfaces, the vapour pressure shall be equal to the saturation pressure and the vapour pressure profile shall be drawn as straight lines between the values representing internal vapour pressure, condensation interfaces and external vapour pressure, see Figure 5. If the vapour pressure values exceed the saturation values at any interface, redraw the vapour pressure lines as specified in 6.4.4.

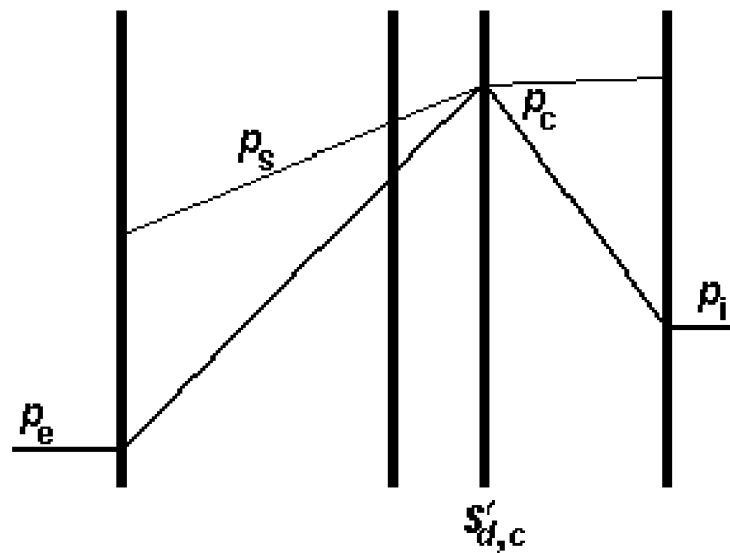


Figure 5 - Evaporation from an interface in the building component

The rate of evaporation is calculated as

$$g_{ev} = \delta_0 \left(\frac{P_i - P_c}{s'_{d,T} - s'_{d,c}} - \frac{P_c - P_e}{s'_{d,c}} \right) \quad (25)$$

NOTE The expressions for the rate of evaporation and condensation are the same. By convention condensation occurs if the expression is positive and evaporation if the expression is negative.

In a building component with **more than one** condensation interface the rate of evaporation is calculated for each interface separately, see Figure 6.

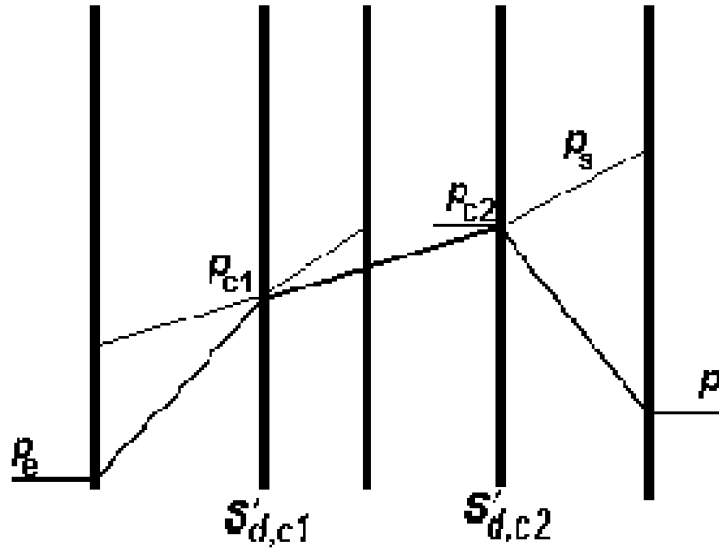


Figure 6 - Evaporation from a building component, when condensation has occurred in two interfaces

The rates of evaporation, for two evaporation interfaces, are calculated as (see Figure 6):

$$\text{At interface c1: } g_{ev1} = \delta_0 \left(\frac{p_{c2} - p_{c1}}{s'_{d,c2} - s'_{d,c1}} - \frac{p_{c1} - p_e}{s'_{d,c1}} \right) \quad (26)$$

$$\text{At interface c2: } g_{ev2} = \delta_0 \left(\frac{p_i - p_{c2}}{s'_{d,T} - s'_{d,c2}} - \frac{p_{c2} - p_{c1}}{s'_{d,c2} - s'_{d,c1}} \right) \quad (27)$$

If the accumulated amount of condensate at an interface at the end of the month is calculated as a negative value, put it to zero.

6.4.8 Evaporation and condensation

In a building component with more than one condensation interface there could be months with condensation in one interface and evaporation in another, see Figure 7.

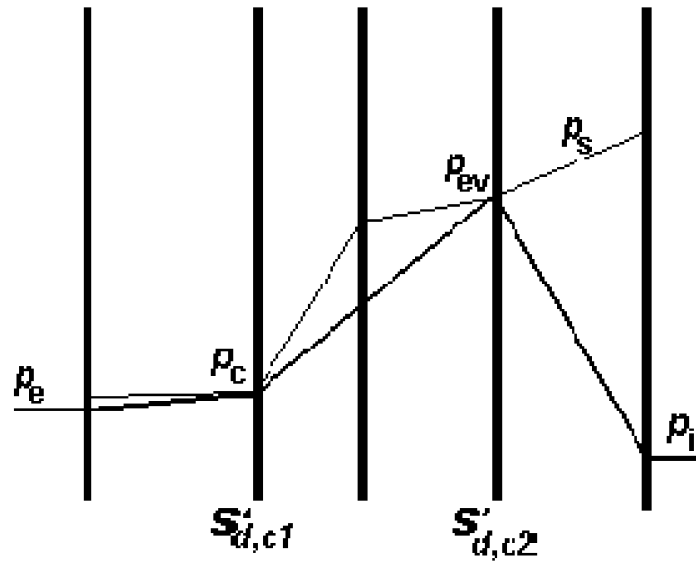


Figure 7 - Evaporation in one interface and condensation in another in a building component, where condensation has occurred in two interfaces

The rate of condensation, g_c , or evaporation, g_{ev} , are calculated for each interface separately:

$$\text{condensation between layer 1 and 2: } g_c = \delta_0 \left(\frac{p_{c2} - p_{c1}}{s'_{d,c2} - s'_{d,c1}} - \frac{p_{c1} - p_e}{s'_{d,c1}} \right) \quad (28)$$

$$\text{evaporation between layer 3 and 4: } g_{ev} = \delta_0 \left(\frac{p_i - p_{c2}}{s'_{d,T} - s'_{d,c2}} - \frac{p_{c2} - p_{c1}}{s'_{d,c2} - s'_{d,c1}} \right) \quad (29)$$

Examples of interstitial condensation calculations are given in annex C.

6.5 Criteria used to assess structures

Report the results of the calculations according to a), b) or c) as applicable.

- a) No condensation predicted at any interface in any month.

In this case report the structure as being free of interstitial condensation.

- b) Condensation occurs at one or more interfaces but, for each interface concerned, all the condensate is predicted to evaporate during the summer months.

In this case report the maximum amount of condensation that occurred at each interface, and the month during which the maximum occurred. Also, the risk of degradation of building materials and deterioration of thermal performance as a consequence of the calculated maximum amount of moisture shall be considered according to regulatory requirements and other guidance in product standards.

- c) Condensation at one or more interfaces does not completely evaporate during the summer months.

In this case report that the structure has failed the assessment, and state the maximum amount of moisture that occurred at each interface together with the amount of moisture remaining after 12 months at each interface.

Annex A (informative)

Classes of internal humidity load

Internal humidity load can be described by five humidity classes. Figure A.1 shows limit values of Δv and Δp for each class. For the calculations, it is recommended that the upper limit value for each class is used unless the designer can demonstrate that conditions are less severe. The data in Figure A.1 are derived from buildings in Western Europe. Measured data may be used to derive values applicable to other climates.

Table A.1 gives some guidance regarding selection of humidity class.

Table A.1 - Internal humidity classes

Humidity class	Building
1	Storage areas
2	Offices, shops
3	Dwellings with low occupancy
4	Dwellings with high occupancy, sports halls, kitchens, canteens; buildings heated with un-flued gas heaters
5	Special buildings, e.g. laundry, brewery, swimming pool

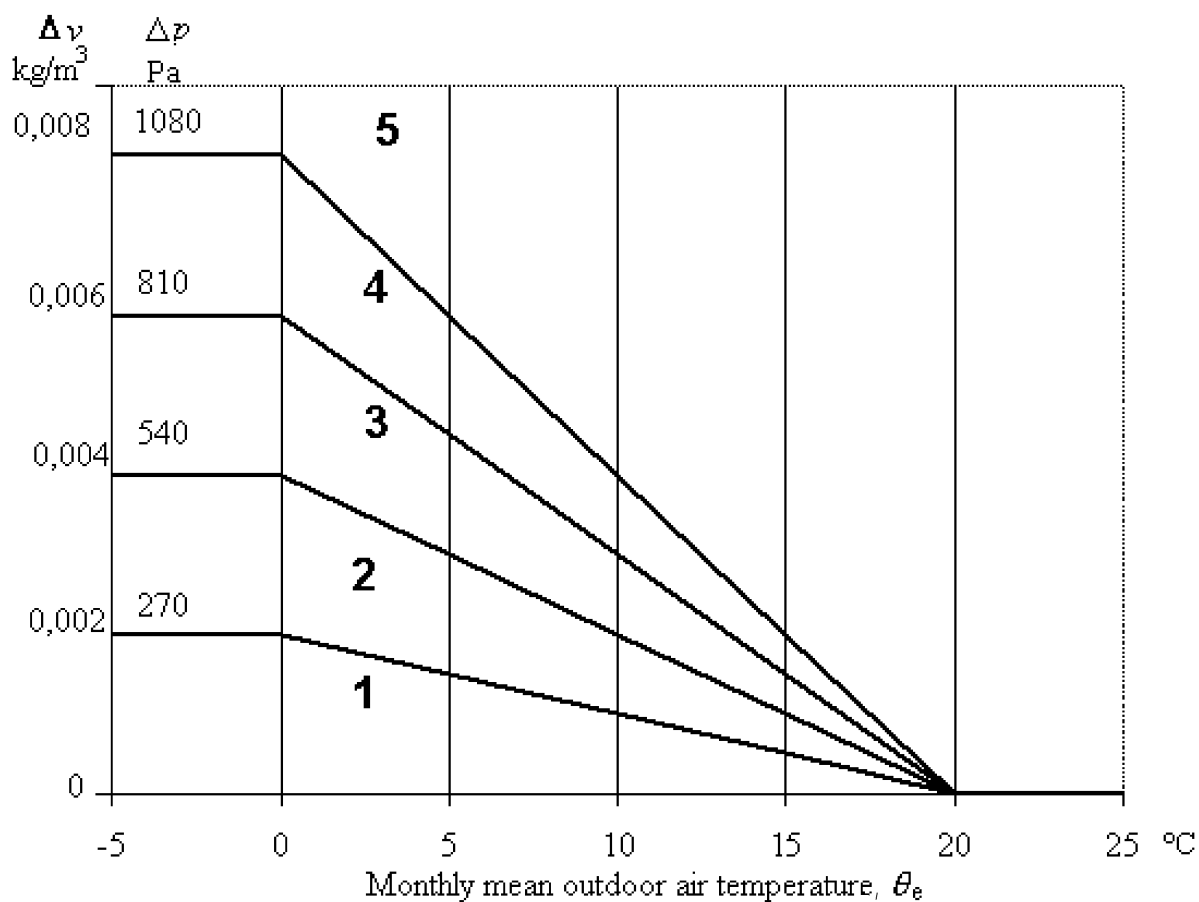


Figure A.1 - Variation of internal humidity classes with external temperature

Annex B (informative)

Examples of calculation of the temperature factor at the internal surface to avoid critical surface humidity

B.1 Example 1, using internal humidity classes

- 1) The monthly mean external temperature, θ_e , and relative humidity (φ_e) for the location of the building are defined (columns 1 and 2 in Table B.1).
- 2) The monthly external saturated vapour pressure, $p_{\text{sat},e}$, calculated from the temperature using equations (E.7) or (E.8), where appropriate, or Table E.1, and the relative humidity are used to calculate the external vapour pressure, p_e , (column 3 in Table B.1).
- 3) The internal vapour pressure excess, Δp_{sat} , for the selected humidity class of the building, is derived as a function of temperature from Figure A.1 (column 4, derived from the boundary between classes 3 and 4 in Figure A.1), multiplied by 1,10, and added to p_e to give the internal vapour pressure (column 5 of Table B.1).
- 4) The minimum acceptable saturation vapour pressure, $p_{\text{sat}}(\theta_{\text{si}})$, is calculated as specified in 5.3 e) and the minimum acceptable surface temperature, $\theta_{\text{si,min}}$, calculated from equation (E.10) or (E.11) to give the values in columns 6 and 7 of Table B.1.
- 5) The internal temperatures, θ_i , are defined in column 8 of Table B.1 and equation (1) is used to calculate f_{Rsi} , giving the values shown in column 9 of Table B.1

With the conditions assumed in Table B.1, January is the critical month and $f_{\text{Rsi,max}} = 0,766$.

Table B.1 - Calculation of $f_{\text{Rsi,max}}$ using internal humidity classes

Month	1 θ_e °C	2 φ_e	3 p_e Pa	4 Δp Pa	5 p_i Pa	6 $p_{\text{sat}}(\theta_{\text{si}})$ Pa	7 $\theta_{\text{si,min}}$ °C	8 θ_i °C	9 f_{Rsi}
January	2,8	0,92	683	698	1 451	1 813	16,0	20	0,766
February	2,8	0,88	657	697	1 423	1 779	15,7	20	0,748
March	4,5	0,85	709	630	1 402	1 752	15,4	20	0,706
April	6,7	0,80	788	538	1 380	1 725	15,2	20	0,638
May	9,8	0,78	941	415	1 398	1 747	15,4	20	0,550
June	12,6	0,80	1 162	299	1 491	1 864	16,4	20	0,513
July	14,0	0,82	1 302	244	1 571	1 963	17,2	20	0,538
August	13,7	0,84	1 317	256	1 598	1 998	17,5	20	0,602
September	11,5	0,87	1 183	343	1 560	1 950	17,1	20	0,659
October	9,0	0,89	1 017	446	1 507	1 884	16,6	20	0,688
November	5,0	0,91	788	610	1 458	1 823	16,1	20	0,738
December	3,5	0,92	719	670	1 456	1 820	16,0	20	0,759

B.2 Example 2, assuming a constant internal relative humidity

In the case of an air conditioned building, where the temperature and relative humidity are controlled at 20 °C and 0,50:

- 1) The monthly mean external temperature, θ_e , and internal temperature, θ_i , and relative humidity, ϕ_i , are defined for the building under investigation (columns 1, 2 and 3 in Table B.2).
- 2) The internal saturated vapour pressure, $p_{\text{sat},i}$, is derived from the temperature using equation (E.7) or Table E.1; this is combined with the internal relative humidity, increased by 0,05, to give the internal vapour pressure, p_i , shown in column 4 of Table B.2.
- 3) The minimum acceptable saturation vapour pressure, $p_s(\theta_{si})$, is calculated as specified in 5.3 e) and the minimum acceptable surface temperature, $\theta_{si,\text{min}}$, calculated from equation (E.9) to give the values in columns 5 and 6 of Table B.2.
- 4) Equation (1) is used to calculate f_{Rsi} giving the values shown in column 7 of Table B.2.

With the conditions assumed in Table B.2, January and February are the critical months and $f_{Rsi,\text{max}} = 0,656$.

Table B.2 - Calculation of $f_{Rsi,\text{max}}$ using controlled internal humidity

Month	1 θ_e °C	2 θ_i °C	3 ϕ_i	4 p_i Pa	5 $p_{\text{sat}}(\theta_{si})$ Pa	6 $\theta_{si,\text{min}}$ °C	7 f_{Rsi}
January	2,8	20	0,55	1 285	1 607	14,1	0,656
February	2,8	20	0,55	1 285	1 607	14,1	0,656
March	4,5	20	0,55	1 285	1 607	14,1	0,618
April	6,7	20	0,55	1 285	1 607	14,1	0,555
May	9,8	20	0,55	1 285	1 607	14,1	0,420
June	12,6	20	0,55	1 285	1 607	14,1	0,201
July	14,0	20	0,55	1 285	1 607	14,1	0,014
August	13,7	20	0,55	1 285	1 607	14,1	0,061
September	11,5	20	0,55	1 285	1 607	14,1	0,304
October	9,0	20	0,55	1 285	1 607	14,1	0,462
November	5,0	20	0,55	1 285	1 607	14,1	0,606
December	3,5	20	0,55	1 285	1 607	14,1	0,642

B.3 Example 3, with a known moisture supply and constant ventilation rate

- 1) The monthly mean external temperature, θ_e , and relative humidity, ϕ_e , for the location of the building are defined (columns 1 and 2 in Table B.3).
- 2) The monthly external saturated vapour pressure, $p_{\text{sat},e}$, calculated from the temperature using equations (E.7) or (E.8), where appropriate, or Table E.1, and the relative humidity are used to calculate the external vapour pressure, p_e , (column 3 in Table B.3).

3) The internal moisture supply vapour pressure excess, Δp , is calculated from the assumed air change rate, n , moisture production rate, G , and volume of the building, V , using equation (3) and converted into a vapour pressure excess, Δp , using equation (E.6). This is added to p_e to give the internal vapour pressure (columns 5 and 6 of Table B.3)

4) The minimum acceptable saturation vapour pressure, $p_{\text{sat}}(\theta_{\text{si}})$, is calculated as specified in 5.3 e) and the minimum acceptable surface temperature, $\theta_{\text{si,min}}$, calculated from equation (E.9) to give the values in columns 8 and 9 of Table B.3.

5) Equation (1) is used to calculate f_{rsi} giving the values shown in column 10 of Table B.3.

With the conditions assumed in Table B.3, August is the critical month and $f_{\text{rsi,max}} = 0,832$.

Table B.3 - Calculation of $f_{\text{rsi,max}}$ using a constant ventilation rate

Month	1 θ_e °C	2 ϕ_e	3 p_e Pa	4 n h ⁻¹	5 Δp Pa	6 p_i Pa	7 $p_{\text{sat}}(\theta_{\text{si}})$ Pa	8 $\theta_{\text{si,min}}$ °C	9 θ_i °C	10 f_{rsi}
January	2,8	0,92	683	0,5	433	1 116	1 395	11,9	20	0,531
February	2,8	0,88	657	0,5	433	1 090	1 363	11,6	20	0,510
March	4,5	0,85	709	0,5	433	1 142	1 428	12,3	20	0,502
April	6,7	0,8	788	0,5	433	1 221	1 527	13,3	20	0,496
May	9,8	0,78	941	0,5	433	1 374	1 718	15,1	20	0,522
June	12,6	0,8	1 162	0,5	433	1 595	1 994	17,5	20	0,657
July	14,0	0,82	1 302	0,5	433	1 735	2 169	18,8	20	0,800
August	13,7	0,84	1 317	0,5	433	1 750	2 188	18,9	20	0,832
September	11,5	0,87	1 183	0,5	433	1 616	2 020	17,7	20	0,726
October	9,0	0,89	1 017	0,5	433	1 450	1 813	16,0	20	0,633
November	5,0	0,91	788	0,5	433	1 221	1 527	13,3	20	0,553
December	3,5	0,92	719	0,5	433	1 152	1 440	12,4	20	0,540

NOTE $G = 0,4 \text{ kg/h}$, $V = 250 \text{ m}^3$

B.4 Example 4, with a known moisture supply and variable ventilation rate

In practice, buildings are ventilated less in colder weather. If a relationship between the air change rate and temperature is known or can be assumed, the values of f_{rsi} can be calculated as in example 3 but using the variable air change rate in step 3).

The values in Table B.4 were calculated assuming that $n = 0,2 + 0,04 \theta_e$. With these conditions, January is the critical month and $f_{\text{rsi,max}} = 0,718$.

Table B.4 - Calculation of $f_{Rsi,max}$ using a variable ventilation rate

Month	1 θ_e °C	2 φ_e	3 p_e Pa	4 n h ⁻¹	5 Δp Pa	6 p_i Pa	7 $p_{sat}(\theta_{si})$ Pa	8 $\theta_{si,min}$ °C	9 θ_i °C	10 f_{Rsi}
January	2,8	0,92	683	0,31	694	1 377	1 722	15,2	20	0,718
February	2,8	0,88	657	0,31	694	1 351	1 689	14,9	20	0,701
March	4,5	0,85	709	0,38	570	1 279	1 599	14,0	20	0,614
April	6,7	0,8	788	0,47	463	1 251	1 564	13,7	20	0,524
May	9,8	0,78	941	0,59	366	1 307	1 634	14,3	20	0,445
June	12,6	0,8	1 162	0,70	308	1 470	1 837	16,2	20	0,483
July	14,0	0,82	1 302	0,76	285	1 587	1 984	17,4	20	0,563
August	13,7	0,84	1 317	0,75	290	1 607	2 008	17,6	20	0,615
September	11,5	0,87	1 183	0,66	328	1 511	1 889	16,6	20	0,601
October	9,0	0,89	1 017	0,56	387	1 404	1 755	15,5	20	0,587
November	5,0	0,91	788	0,40	542	1 330	1 662	14,6	20	0,641
December	3,5	0,92	719	0,34	637	1 356	1 695	14,9	20	0,692

NOTE $G = 0,4 \text{ kg/h}$, $V = 250 \text{ m}^3$

Annex C (informative)

Examples of calculation of interstitial condensation

C.1 Environmental conditions

Table C.1 shows the internal and external environmental conditions used in the two examples in C.2 and C.3.

Table C.1 - Internal and external conditions used for analysis

Month	Internal		External	
	θ_i °C	φ_i	θ_e °C	φ_e
October	20	0,57	10	0,83
November	20	0,57	5	0,88
December	20	0,59	1	0,88
January	20	0,57	-1	0,85
February	20	0,58	0	0,84
March	20	0,54	4	0,78
April	20	0,51	9	0,72
May	20	0,51	14	0,68
June	20	0,50	18	0,69
July	20	0,56	19	0,73
August	20	0,52	19	0,75
September	20	0,56	15	0,79

C.2 Example 1: Building component with condensation in one interface plane

In this example, the flat roof with an impermeable weather proofing layer over the insulation, shown in Figure C.1 is analysed using the internal and external climates shown in Table C.1 and the material properties shown in Table C.2.

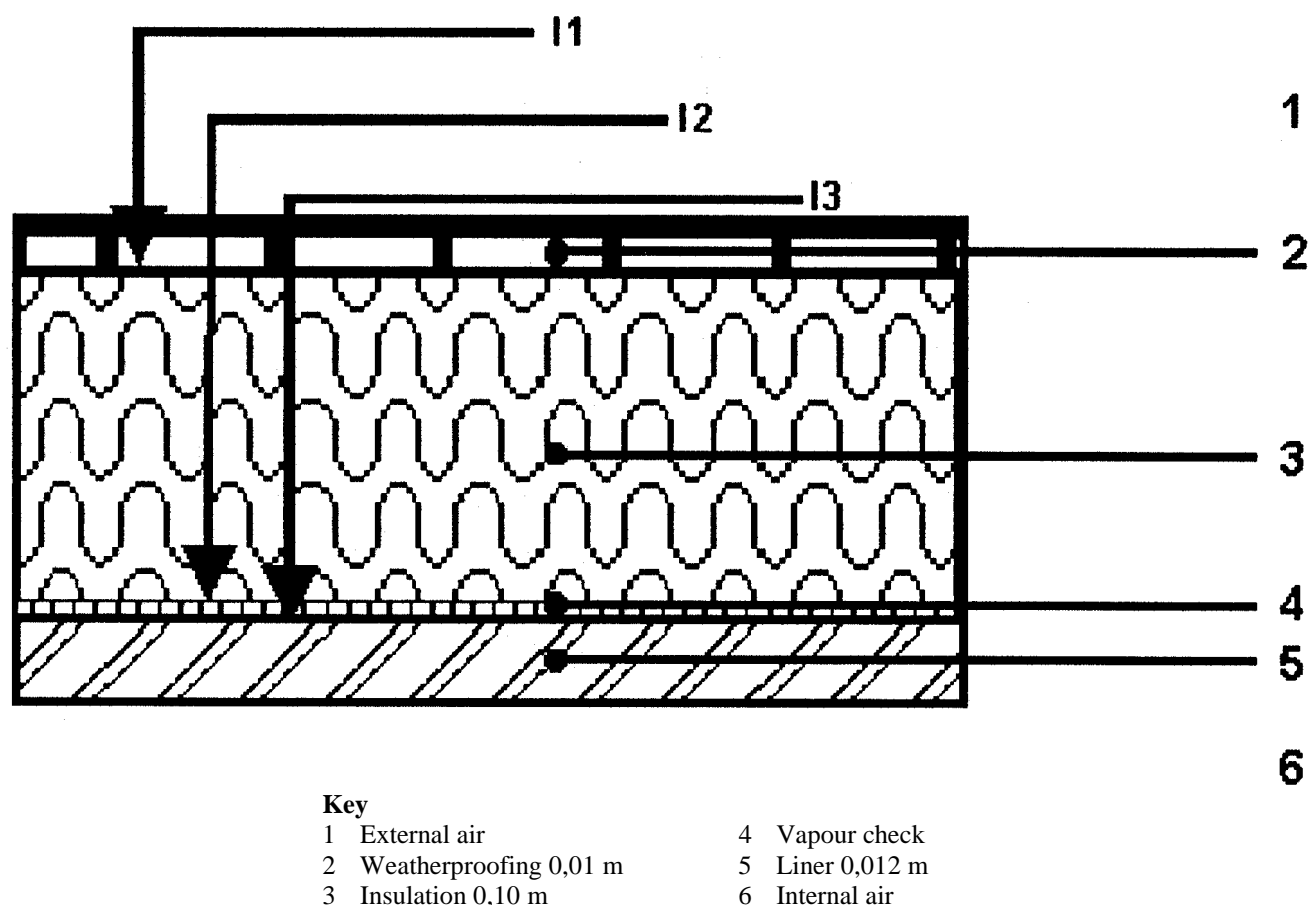


Figure C.1 - Material properties for flat roof in example 1

Table C.2 - Material properties for flat roof

	d m	R $\text{m}^2 \cdot \text{K/W}$	μ	s_d m
External resistance		0,04		
Weatherproofing	0,010	0,05	500000	5000
Insulation	0,100	3	150	15
Vapour check				1000
Liner	0,012	0,075	10	0,12
Internal resistance		0,13		

NOTE The material properties shown in the examples refer to generic material types, not specific materials.

The three interfaces at the intersections between the material layers shown in Figure C.1 are analysed. At the beginning of the calculation, it is assumed that the accumulated moisture content, M_a , in all three interfaces is zero.

Using the environmental data in Table C.1, October is determined as the starting month as described in 6.4.3, 6.4.4 and 6.4.5, with the vapour pressure exceeding the saturated vapour pressure at interface 1, the interface between the insulation and weatherproofing. The rate of condensation, g_c , is calculated from equation (22). This makes up the accumulated moisture content, M_a , at the end of October shown in the left part of Table C.3.

This procedure is then repeated using the environmental conditions for each month from Table C.1. In each month, no condensation is predicted at interfaces 2 and 3. As shown in Table C.3, the rate of condensation at interface 1 rises to a peak in the coldest month of January and then falls towards zero in March.

Table C.3 - Monthly condensation rate and accumulation at interface 1

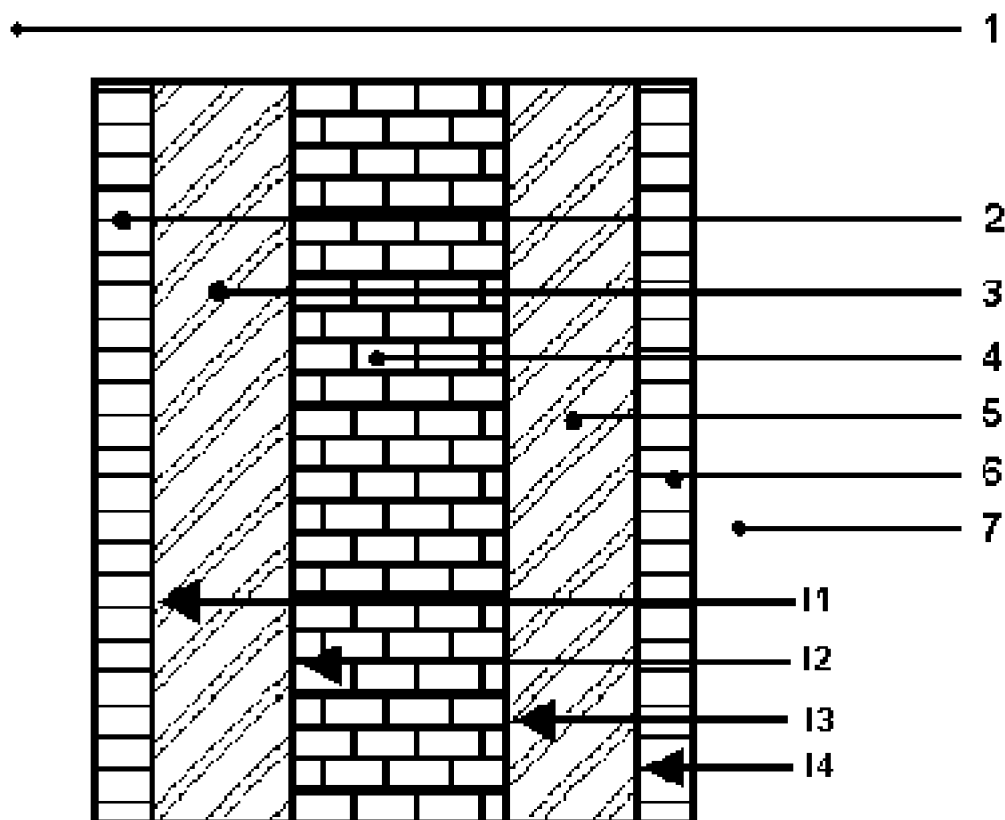
Month	With vapour check		With no vapour check	
	g_c kg/m ²	M_a kg/m ²	g_c kg/m ²	M_a kg/m ²
October	0,00002	0,00002	0,00288	0,00288
November	0,00021	0,00023	0,01490	0,01778
December	0,00036	0,00058	0,02470	0,04248
January	0,00038	0,00096	0,02621	0,06869
February	0,00033	0,00129	0,02304	0,09173
March	0,00020	0,00150	0,01499	0,10672
April	-0,00003	0,00147	0,00068	0,10740
May	-0,00028	0,00119	-0,01504	0,09236
June	-0,00053	0,00066	-0,03097	0,06139
July	-0,00053	0,00013	-0,03164	0,02975
August	-0,00058	0	-0,03494	0
September	0	0	0	0

From April onwards, the rate of condensation becomes negative, i.e. evaporation is occurring as specified in 6.4.6, and the accumulated moisture falls until it is close to zero in June. During August, the accumulated moisture dries out, and is set to zero.

If the vapour barrier is eliminated, see the right part of Table C.3, condensation again starts in October and persists until August, but the rate of condensation and the total accumulated moisture are much higher than with the vapour barrier.

C.3 Example 2: Building component with condensation in two interfaces

In this example an internally insulated masonry wall which has had an external insulated render added to, for example, eliminate a rain penetration problem, shown in Figure C.2 is analysed using the material properties shown in Table C.4 and the internal and external climates shown in Table C.1.

**Key**

1 External air

2 Render 0,01 m

3 Insulation 0,08 m

4 Masonry 0,15 m

5 Insulation 0,08 m

6 Lining 0,01 m

7 Internal air

Figure C.2 - Materials in external wall in example 2**Table C.4 - Material properties for insulated wall**

	<i>d</i> m	<i>R</i> m ² ·K/W	<i>μ</i>	<i>s_d</i> m
External resistance		0,04		
Rendering	0,010	0,01	100	1,00
Insulation	0,080	2,5	2,0	0,16
Masonry	0,130	0,6	22,0	2,86
Insulation	0,080	2,5	2,0	0,16
Lining	0,010	0,05	10	0,10
Internal resistance		0,13		

The four interfaces at the intersections between the material layers shown in Figure C.2 are analysed. At the beginning of the calculation, it is assumed that the accumulated moisture content, M_a , in all four interfaces is zero.

Using the environmental data in Table C.1, November is determined as the starting month as described in 6.4.3, 6.4.4 and 6.4.5, with the vapour pressure exceeding the saturated vapour pressure at interface 1, the interface between the render and the external insulation. The rate of condensation, g_c , is calculated from equation (22). This makes up the accumulated moisture content, M_a , at the end of November shown in Table C.5.

This situation persists in December, with further accumulation at interface 1. In January, however, condensation also starts at interface 3, between the masonry and internal insulation. The rates at both interfaces are calculated with equations (23) and (24). This persists in February, but during March, all the condensate at interface 3 dries out. Condensation continues to accumulate at interface 1 until March but evaporation starts in April with complete drying during May.

Table C.5 - Monthly condensation rates and accumulation within the insulated wall

Month	Interface 1		Interface 3	
	g_c kg/m ²	M_a kg/m ²	g_c kg/m ²	M_a kg/m ²
November	0,013	0,013	0	0
December	0,070	0,084	0	0
January	0,071	0,155	0,036	0,036
February	0,058	0,212	0,004	0,039
March	0,014	0,226	-0,527	0
April	-0,164	0,062	0	0
May	-0,344	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0

Annex D (informative)

The assessment of the risk of condensation on window frames

Condensation on the inside surface of window frames can be an inconvenience if the water runs onto adjacent decorations, but, more importantly, it can cause corrosion in metal frames or rot in wooden ones by penetrating joints e.g. between the frame and glass. Because of their impermeable surface finish, mould growth is rarely a problem on window frames. The maximum acceptable relative humidity at the frame surface is therefore $\phi_s = 1$. This is used in the procedure for the calculation of the minimum acceptable surface temperature of the frame $\theta_{si,min}$, specified in 5.4.

Owing to the complex form and variety of materials used in window frames and the interactions between the glass, frame and wall containing the window, heat flows and surface temperatures cannot, generally, be calculated by simple one dimensional methods. Care therefore needs to be taken linking the minimum acceptable surface temperature of the frame to the internal and external air temperatures.

Two - or if necessary - three dimensional finite element calculations on complete window systems including the glazing, give surface temperatures that can be scaled to any combination of internal or external temperatures. Calculations carried out with an insulation material, such as expanded polystyrene, substituted for the glazing, used to obtain an equivalent thermal transmittance of the frame, will not give accurate surface temperatures.

Details of appropriate calculation methods are given in ISO 10077-2¹, *Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 2: Numerical method for frames*.

Various simplified methods have been developed to allow the calculation of realistic thermal transmittances of complete windows taking account of multi-dimensional heat flows through the frame and the spacer between the panes of double glazing. While these will give accurate heat flows, surface temperatures will be seriously in error and they should not be used to estimate the risk of condensation.

¹ To be published

Annex E (informative)

Relationships governing moisture transfer and water vapour pressure

E.1 Moisture transfer

Equations (E.1) to (E.4) can be used for the calculation of moisture diffusion, provided relevant material properties are used:

$$g = \delta_p \frac{\Delta p}{d} = \frac{\Delta p}{Z_p} \quad (\text{E.1})$$

$$g = \frac{\delta_0}{\mu} \frac{\Delta p}{d} = \delta_0 \frac{\Delta p}{s_d} \quad (\text{E.2})$$

$$g = \delta_v \frac{\Delta v}{d} = \frac{\Delta v}{Z_v} \quad (\text{E.3})$$

$$g = \frac{D_0}{\mu} \frac{\Delta v}{d} = D_0 \frac{\Delta v}{s_d} \quad (\text{E.4})$$

E.2 Vapour pressure and humidity by volume

Vapour pressure and humidity by volume are related by equation (E.5):

$$p = v R_v T \quad (\text{E.5})$$

where

R_v is the gas constant for water = 462 Pa·m³/(K·kg);

T is the absolute temperature in kelvins.

The difference between internal and external water vapour pressure Δp is calculated as

$$\Delta p = \Delta v R_v (T_i + T_e) / 2 = \frac{G}{n V} R_v (T_i + T_e) / 2 \quad (\text{E.6})$$

E.3 Water vapour saturation pressure as a function of temperature

The following empirical formulae give the saturated vapour pressure of water as a function of temperature

$$p_{\text{sat}} = 610,5 \, e^{\frac{17,269 \, \theta}{237,3 + \theta}} \quad \text{for } \theta \geq 0 \, ^\circ\text{C} \quad (\text{E.7})$$

$$p_{\text{sat}} = 610,5 \, e^{\frac{21,875 \, \theta}{265,5 + \theta}} \quad \text{for } \theta < 0 \, ^\circ\text{C} \quad (\text{E.8})$$

These may be inverted to allow the calculation of the temperature corresponding to any saturated vapour pressure.

$$\theta = \frac{237,3 \log_e \left(\frac{p_{\text{sat}}}{610,5} \right)}{17,269 - \log_e \left(\frac{p_{\text{sat}}}{610,5} \right)} \quad \text{for } p_{\text{sat}} \geq 610,5 \text{ Pa} \quad (\text{E.9})$$

$$\theta = \frac{265,5 \log_e \left(\frac{p_{\text{sat}}}{610,5} \right)}{21,875 - \log_e \left(\frac{p_{\text{sat}}}{610,5} \right)} \quad \text{for } p_{\text{sat}} < 610,5 \text{ Pa} \quad (\text{E.10})$$

Table E.1 - Saturated vapour pressure and humidity by volume

θ °C	p_{sat} Pa	v_{sat} kg/m ³	θ °C	p_{sat} Pa	v_{sat} kg/m ³
-20	103	0,00088	11	1312	0,00999
-19	113	0,00096	12	1402	0,01064
-18	124	0,00105	13	1497	0,01132
-17	137	0,00115	14	1598	0,01204
-16	150	0,00126	15	1704	0,01280
-15	165	0,00138	16	1817	0,01360
-14	181	0,00151	17	1937	0,01444
-13	198	0,00165	18	2063	0,01533
-12	217	0,00180	19	2196	0,01626
-11	237	0,00196	20	2337	0,01725
-10	259	0,00213	21	2486	0,01828
-9	283	0,00232	22	2642	0,01937
-8	309	0,00252	23	2808	0,02051
-7	338	0,00274	24	2982	0,02171
-6	368	0,00298	25	3166	0,02297
-5	401	0,00324	26	3359	0,02430
-4	437	0,00351	27	3563	0,02568
-3	475	0,00381	28	3778	0,02714
-2	517	0,00413	29	4003	0,02866
-1	562	0,00447	30	4241	0,03026
0	611	0,00484	31	4490	0,03194
1	656	0,00518	32	4752	0,03369
2	705	0,00555	33	5027	0,03552
3	757	0,00593	34	5316	0,03744
4	813	0,00634	35	5619	0,03945
5	872	0,00678	36	5937	0,04155
6	935	0,00724	37	6271	0,04374
7	1001	0,00773	38	6621	0,04603
8	1072	0,00825	39	6987	0,04843
9	1147	0,00880	40	7371	0,05092
10	1227	0,00938			

Annex F (informative)

More advanced calculation methods

F.1 Computer models

A number of computer models for more advanced calculations have been developed. Such models can be expected to yield a much better accuracy than that described in this standard. One problem is, however, that input data such as material properties and climatic conditions are often not sufficiently well known.

Computer models are often based on finite differences with time steps in the order of minutes or hours and distance between grid points in the order of centimetres. They can normally deal with moisture transfer in both liquid phase and vapour phase and the absorption of moisture in non-hygroscopic materials.

Most models allow material properties to be given as functions of, for example, moisture content or temperature. External and internal climatic data are given as hourly values or as mathematical functions. Some models deal with the coupled effects of heat and moisture transfer, others calculate the temperature and moisture fields independently of each other.

F.2 Methods of Glaser type which can consider moisture redistribution in the liquid phase

The method in this standard assumes that condensation occurring at an interface between material layers remains at that interface. In practice the condensate may migrate into the layers on either side of the interface.

The extent of such moisture migration can be estimated on the basis of a critical moisture content of the material, w_{cr} , which is the moisture content above which moisture transfer in liquid phase starts; below w_{cr} only moisture transfer in the vapour phase is assumed. Typical values of w_{cr} for some building materials are given in Table F.1.

Table F.1 - Typical values of critical moisture content

Material	Critical moisture content w_{cr} kg/m ³
Autoclaved aerated concrete	120
Brick	60 - 130
Cement mortar	180
Concrete	125
Sandlime brick	80 - 110

When a certain amount of water M_a is added to a surface of a material layer, the thickness over which the moisture is distributed, d_w , is calculated as

$$d_w = \frac{M_a}{w_{cr}}$$

The normal Glaser calculation is then carried out with the relative humidity equal to 1,0 ($p = p_{sat}$) in the zone with thickness d_w .

