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Hygrothermal performance of building equipment and industrial installations — Calculation of water vapour diffusion — Cold pipe insulation systems

Performance hygrothermique des équipements de bâtiments et installations industrielles — Calcul de la diffusion de vapeur d'eau — Systèmes d'isolation de tuyauteries froides

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Foreword

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The main task of technical committees is to prepare International Standards. 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 the member bodies casting a vote.

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ISO 15758 was prepared by the European Committee for Standardization (CEN) (as EN 14114:2002) and was adopted, under a special “fast-track procedure”, by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*, in parallel with its approval by the ISO member bodies.

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Foreword

This document (EN 10264-1:2002) 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of an identical text or by endorsement, at the latest by September 2002, and conflicting national standards shall be withdrawn at the latest by September 2002.

The enquiry version was designated prEN ISO 15758. However, as a result of the enquiry, ISO decided to decouple from the Vienna Agreement; CEN and ISO will proceed to publication on their own.

This standard is one of a series of standards which specify calculation methods for the design and evaluation of the thermal and moisture related performance properties of buildings and building components.

The Annexes A and B 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, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

If the thermal insulation of a cold pipe system is not completely water vapour tight, there will be a flow of water vapour from the warm environment to the surface of the pipe, whenever the temperature of the surface of the cold pipe is below the dew point of the ambient air. This flow of water vapour leads to an interstitial condensation in the insulation layer and/or dew formation on the surface of the pipe itself. Interstitial condensation may cause the insulation material to deteriorate and dew formation on the surface of a metal pipe may cause corrosion over time. If the temperature is below 0 °C ice will be formed and the methods of this standard will not apply.

In periods where the dew point of the ambient air is higher than the temperature of the outer surface of the insulation surface condensation will occur. This is dealt with in EN ISO 12241.

Different measures are available to control water vapour transfer and reduce the amount of condensation. The following are normally applied:

a) Installation of a vapour retarder;
b) Use of insulation materials with a high water vapour resistance factor (low permeability);
c) Use of a vapour retarder and a capillary active fabric to continuously remove condensed water from the pipe surface to the environment.

Which protection measure is chosen depends on the ambient climate, the temperature of the medium in the pipe and the water vapour diffusion resistance of the insulation layer. The success of any system is strongly dependent on workmanship and maintenance. In any case anti-corrosion measures should be applied to a metal pipe in severe conditions.

The expected economic lifetime of an insulation system, assuming a maximum acceptable accumulated moisture content, can be calculated using the methods in this standard.

1 Scope

This standard specifies a method to calculate the density of water vapour flow rate in cold pipe insulation systems, and the total amount of water diffused into the insulation over time. This calculation method presupposes that water vapour can only migrate into the insulation system by diffusion, with no contribution from airflow. It also assumes the use of homogeneous, isotropic insulation materials so that the water vapour partial pressure is constant at all points equidistant from the axis of the pipe.

The standard is applicable when the temperature of the medium in the pipe is above 0 °C. It applies to pipes inside buildings as well as in the open air.

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 (including amendments).

ISO 9346 *Thermal insulation - Mass transfer - Physical quantities and definitions (ISO 9346:1987)*

ISO 12241 *Thermal insulation for building equipment and industrial installations - Calculation rules (ISO 12241:1998)*

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

ISO 13788 *Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation – Calculation methods (ISO 13788:2001)*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this standard, the terms and definitions given in ISO 9346, ISO 12572, ISO 13788 and the following apply.

3.1.1
exposed moist area
surface area of a capillary active fabric that is exposed to the ambient atmosphere

3.1.2
vapour retarder
material with high resistance to the flow of water vapour

3.1.3
corrected water vapour diffusion equivalent air layer thickness
thickness of an imaginary plane layer with μ =1, and an area of πD_j which has the same diffusion resistance as the layer j with $\mu = \mu_j$

NOTE See Equation (18).

3.2 Symbols and units

Symbol	Quantity	Unit
A'_e	surface area from which evaporation takes place per linear metre of the pipe	m^2/m
D_j	outside diameter of *j*th layer of an insulation system	m
D_0	outside diameter of cold pipe	m
G'	total moisture uptake over a period per linear metre of pipe	kg/m
P	actual atmospheric pressure	Pa
P_0	standard atmospheric pressure = 101325	Pa
R_v	gas constant for water vapour = 461,5	J/(kg·K)
T	thermodynamic temperature	K
Z'_P	water vapour resistance of insulation system per linear metre of pipe	m·s·Pa/kg
Z'_j	water vapour resistance of *j*th layer of an insulation system per linear metre of pipe	m·s·Pa/kg
Z'_{f1}	water vapour resistance of one thin foil, cladding or skin per linear metre of pipe.	m·s·Pa/kg
d	thickness of an insulation layer	m
f_e	evaporation factor	kg/(m²·s·Pa)
g'	water vapour flow rate within the insulation per linear metre of pipe	kg/(m·s)
g'_c	rate of condensation per linear metre of pipe	kg/(m·s)
g'_e	evaporation rate per linear metre of pipe	kg/(m·s)
h_c	convection heat transfer coefficient	W/(m²·K)
p	partial water vapour pressure	Pa
p_a	partial water vapour pressure of air	Pa
p_{sat}	saturated water vapour pressure	Pa
s_d	water vapour diffusion equivalent air layer thickness	m
s_{df}	water vapour diffusion equivalent air layer thickness of foils	m
t	period of calculation (month or year)	month, year
x	distance	m
δ	water vapour permeability	kg/(m·s·Pa)
δ_0	water vapour permeability of air	kg/(m·s·Pa)
μ	water vapour resistance factor	-
$\sigma_{d,j}$	corrected water vapour diffusion equivalent air layer thickness of layer *j*	m
$\tilde{\sigma}_{d,j}$	total corrected water vapour diffusion equivalent air layer thickness from surface of cold pipe to the outside of layer *j*	m
θ_0	temperature of the medium in the pipe	°C

NOTE For practical reasons, hours or days are often used instead of seconds as time units.

4 Calculation equations

4.1 General

The density of water vapour flow rate, g, through a material is calculated by the following equation:

$$g = -\delta \frac{dp}{dx} \tag{1}$$

where δ is the water vapour permeability of the material.

The total moisture uptake during a period, G, is given by:

$$G = \int_0^t g \, dt \tag{2}$$

In calculations the diffusion resistance factor, μ, is commonly used instead of the permeability

$$\mu = \frac{\delta_0}{\delta} \tag{3}$$

where δ_0 is the water vapour permeability of still air, which can be calculated from:

$$\delta_0 = \frac{0{,}083 \; P_0}{R_v \; T \; P} \left(\frac{T}{273} \right)^{1{,}81} \tag{4}$$

For approximate calculations, δ_0 can be assumed to be constant in the temperature range under consideration; the following value can therefore be used:

$$\delta_0 = 2{,}0 \times 10^{-10} \tag{5}$$

4.2 Homogeneous insulation

In the case of a cold pipe with a single homogeneous layer of insulation, the density of water vapour flow per metre of an insulated cold pipe is given by replacing the differential expression by the vapour pressure difference in Equation (1):

$$g' = \frac{p_a - p_{sat}(\theta_0)}{Z'_P} \tag{6}$$

where

p_a is the vapour pressure of the ambient air, in Pa;

$p_{sat}(\theta_0)$ is the saturation vapour pressure at the outside surface of the pipe, in Pa;

Z'_P is the water vapour resistance per linear metre of the pipe insulation, in m·s·Pa/kg, defined by Equation (7):

$$Z'_P = \frac{\ln \frac{D_1}{D_0}}{2\,\pi\,\delta} \quad (7)$$

There will only be a vapour flow and hence condensation at the surface of the cold pipe when the vapour pressure of the ambient air is higher than the saturation vapour pressure at the cold surface of the pipe.

The total water uptake over a period t is then given by:

$$G' = \int_0^t \frac{p_a(t) - p_{sat}(\theta_0(t))}{Z'_P} \mathrm{d}t \quad (8)$$

4.3 Multi-layer insulation systems

The water vapour resistance, Z'_P, of an insulation system with n different layers is given by:

$$Z'_P = \sum_{j=1}^{n} \frac{\ln \frac{D_j}{D_{j-1}}}{2\pi\delta_j} \quad (9)$$

which gives,

$$Z'_P = \frac{1}{2\pi\delta_0} \sum_{j=1}^{n} \mu_j \ln \frac{D_j}{D_{j-1}} \quad (10)$$

where

$$\mu_j = \frac{\delta_0}{\delta_j}$$

j = 1 to n defines the layers from the cold pipe outwards.

Equation (10) can also be used for a homogeneous insulation material with water vapour resistance highly dependent on temperature.

NOTE See Example A.2.

If the outer layer, n, is a vapour retarder jacket, foil or skin, with negligible thickness, but with large water vapour diffusion-equivalent air layer thickness s_{df}, the water vapour resistance of the retarder will be:

$$Z'_n = \frac{1}{\pi\delta_0 D_n} s_{df} = \frac{1}{2\,\pi\delta_0} \frac{2s_{df}}{D_n} \quad (11)$$

The water vapour resistance of the whole system is then:

$$Z'_P = \frac{1}{2\pi\delta_0} \left(\sum_{j=1}^{n-1} \mu_j \ln \frac{D_j}{D_{j-1}} + \frac{2s_{df}}{D_n} \right) \quad (12)$$

The total water uptake over a period *t* is then given by Equation (8).

4.4 Systems with capacity for drying

For cold pipe systems with drying-out capacities the total water uptake *G'* in the system is given by:

$$G' = \int_0^t (g' - g'_e)\,\mathrm{d}t \quad (13)$$

where g'_e is the drying capacity per linear metre of pipe, in kg/(m·s).

For insulation systems, where the drying capacity is obtained by utilising the wicking action of a capillary active fabric, the capacity is determined by the evaporation from the freely exposed moist area of the fabric per metre length of pipe, A'_e:

$$g'_e = f_e\left(p_{sat}(\theta_a) - p_a\right)A'_e \quad (14)$$

where $p_{sat}(\theta_a)$ is the saturation vapour pressure at the ambient temperature, in Pa.

The evaporation factor, f_e, can be determined by measurement or calculation:

$$f_e = \frac{h_c}{R_v\,T\,\rho\,c_p} \quad (15)$$

where

- h_c is the convection heat transfer coefficient, in W/(m^2·K);
- R_v is the gas constant for water vapour = 461,5 J/(kg·K);
- ρ is the density of air = 1,205 kg/m^3 at 20 °C;
- c_p is the specific heat capacity at constant pressure of air = 1005 J/(kg·K) at 20 °C.

NOTE A method of measurement is given in Annex B. Further information regarding Equation (15) is to be found in reference [5] in the Bibliography.

For horizontal and vertical pipes in still air h_c =10 W/(m^2·K), giving $f_e = 6\times10^{-8}$ kg/(m^2·s·Pa).

The total water uptake over a time, *t*, is then given by:

$$G' = \int_0^t \left[\frac{p_a - p_{sat}(\theta_0)}{Z'_P} - f_e\left(p_{sat}(\theta_a) - p_a\right)A'_e\right]\mathrm{d}t \quad (16)$$

5 Boundary conditions

The following boundary conditions for temperature and vapour pressure shall be used to evaluate the equations given in Clause 4.

a) At the surface of the cold pipe
The surface temperature of the cold pipe shall be taken as the temperature of the medium in the pipe. The vapour pressure at the surface shall be taken as the saturated vapour pressure at that temperature, i.e. a relative humidity of 1,0.

b) Ambient air
Outside buildings, use either the annual mean temperature and vapour pressure or the monthly mean temperature and vapour pressure of the warmest month.

Inside buildings, use the temperature and vapour pressure representative of the use of the building in the warmest month of the year. Methods for deriving internal conditions are given in ISO 13788.

NOTE Use of the monthly mean vapour pressure gives results which are on the safe side.

6 Calculation procedure

6.1 General

The equations given in Clause 4 allow the calculation of the total amount of water condensing within the cold pipe insulation and determination of whether condensation occurs within the insulation material or only on the pipe surface.

For the evaluation of the amount of water vapour transported into an insulated cold pipe system the following procedures shall be followed step by step.

6.2 Calculation of the rate of condensation in a single homogenous insulation layer

a) Define the service temperature of the cooling medium and the temperature and relative humidity of the environment.

b) Determine the vapour pressure corresponding to the given climatic conditions.

c) Calculate the amount of water uptake using Equation (8).

6.3 Calculation of the rate of condensation in a multi-layer insulation system

a) Define the service temperature of the cooling medium and the temperature and relative humidity of the environment.

b) Calculate the temperature distribution through the insulation in accordance with ISO 12241.

c) Calculate the saturation pressure distribution as a function of temperature in accordance with ISO 13788.

d) Calculate the value of the corrected water vapour diffusion equivalent air layer thickness, $\sigma_{d,j}$, for the boundaries between each layer j of the insulation. $\sigma_{d,j}$ is defined as the thickness of an imaginary plane layer with μ =1, and an area of $\pi\, D_j$ which has the same diffusion resistance as the layer j with $\mu = \mu_j$:

$$\frac{\sigma_{d,j}}{\delta_0 \pi D_j} = \frac{\ln \frac{D_j}{D_{j-1}}}{2\pi\delta_0 / \mu_j} \quad (17)$$

which gives

$$\sigma_{d,j} = \mu_j \frac{D_j}{2} \ln \frac{D_j}{D_{j-1}} \quad (18)$$

e) Calculate the total corrected water vapour diffusion equivalent air layer thickness, $\tilde{\sigma}_{d,j}$, from the outside surface of the cold pipe to each interface between materials:

$$\tilde{\sigma}_{d,j} = \sum_{i=1}^{j} \sigma_{d,i} \quad (19)$$

f) Draw the saturated vapour pressure as a function of $\tilde{\sigma}_{d,j}$, for each layer of the cold pipe system elements. Then draw the actual vapour pressure profile as a straight line between the vapour pressure of the environment and that at the outer surface of the pipe.

1) If the actual vapour pressure p does not cross the saturation pressure p_{sat}, condensation will occur only on the outer surface of the pipe. The condensation rate is then given by Equation (6).

2) If p crosses p_{sat} then condensation will occur within the insulation material as well as on the outer surface of the pipe. Determine the tangent to the condensation point and calculate the condensation rate in the insulation material and at the pipe surface from:

$$g'_c = \delta_0 \left(\frac{p_a - p_{sat}(\theta_c)}{\tilde{\sigma}_{d,T} - \tilde{\sigma}_{d,c}} - \frac{p_{sat}(\theta_c) - p_{sat}(\theta_0)}{\tilde{\sigma}_{d,c}} \right) \quad (20)$$

where

θ_c is the temperature at the interface where the condensation is occurring, in °C;

$\tilde{\sigma}_{d,c}$ is the sum of the $\sigma_{d,j}$ values from the pipe to the interface between materials where condensation is occurring;

$\tilde{\sigma}_{d,T}$ is the sum of the $\sigma_{d,j}$ values from the pipe to outside of the insulation.

3) If p crosses p_{sat} in two places condensation will occur at these two locations within the insulation as well as on the cold pipe, see Figure 1:

$$g'_{c1} = \delta_0 \left(\frac{p_{sat}(\theta_{c2}) - p_{sat}(\theta_{c1})}{\tilde{\sigma}_{d,c2} - \tilde{\sigma}_{d,c1}} - \frac{p_{sat}(\theta_{c1}) - p_{sat}(\theta_0)}{\tilde{\sigma}_{d,c1}} \right) \quad (21)$$

$$g'_{c2} = \delta_0 \left(\frac{p_a - p_{sat}(\theta_{c2})}{\tilde{\sigma}_{d,T} - \tilde{\sigma}_{d,c2}} - \frac{p_{sat}(\theta_{c2}) - p_{sat}(\theta_{c1})}{\tilde{\sigma}_{d,c2} - \tilde{\sigma}_{d,c1}} \right) \quad (22)$$

where

θ_{c1} is the temperature at the condensation interface closer to the cold pipe, in °C;

θ_{c2} is the temperature at the condensation interface closer to the outside air, in °C;

$\tilde{\sigma}_{d,c1}$ is the sum of the $\sigma_{d,j}$ values from the pipe to the condensation interface closer to the cold pipe;

$\tilde{\sigma}_{d,c2}$ is the sum of the $\sigma_{d,j}$ values from the pipe to the condensation interface closer to the outside air.

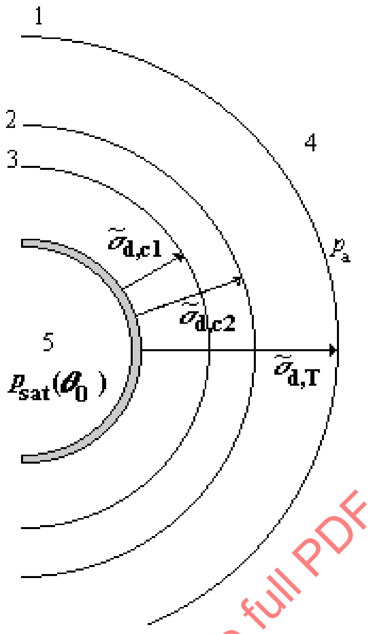
g) If the water vapour resistance factor of an insulation material is strongly temperature dependent, the insulation layer should be divided into sublayers with different water vapour resistance factors.

NOTE An example of the calculation is given in Annex A, A.2.

h) Calculate the total accumulation on the pipe and in the insulation system by integrating the individual condensation rates over time:

$$G' = \int_0^t \sum_{i=0}^{N_p} g'_i(t)\,dt \quad (23)$$

where N_p is the number of condensation interfaces within the insulation system.



Key

1 Outside surface of insulation system
2 Condensation interface 2
3 Condensation interface 1
4 Ambient air
5 Cold pipe

Figure 1 – Cross section of insulated cold pipe with two condensation interfaces within the insulation system

Annex A
(informative)

Examples

A.1 Water uptake in an insulated cold pipe with a vapour retarder on the outside

Water vapour resistance factor of the insulation $\mu_1 = 50$;
Insulation thickness $d_1 = 0{,}05$ m;
Pipe diameter without insulation $D_0 = 0{,}1$ m;
Water vapour equivalent air layer thickness of vapour retarder $s_{df} = 100$ m;
Climatic conditions:

Ambient temperature 20 °C, relative humidity 0,7, giving $p_a = 1638$ Pa
Pipe medium temperature 5 °C, giving $p_{sat}(\theta_0) = 872$ Pa.

The vapour resistance of the whole insulation system is given by Equation (12):

$$Z'_P = \frac{1}{2\pi \times 2 \times 10^{-10}} \left[50 \;\ln \frac{0{,}2}{0{,}1} + \frac{2 \times 100}{0{,}2} \right] = 8{,}23 \times 10^{11} \text{ m} \cdot \text{Pa} \cdot \text{s/kg} \qquad \text{(A.1)}$$

The density of water vapour flow rate is given by Equation (6):

$$g' = \frac{1638 - 872}{8{,}23 \times 10^{11}} = 9{,}31 \times 10^{-10} \text{ kg/(m} \cdot \text{s)} \qquad \text{(A.2)}$$

The mass accumulated over a year is $G'_a = 0{,}029$ kg/m.

A.2 Cold pipe insulated with one layer of a material with a highly temperature dependent water vapour resistance factor

In this example it is assumed that a cold pipe is insulated by a 30 mm thick material with a water vapour resistance factor that varies linearly from 2000 at 0 °C to 500 at 25 °C. This is treated as three layers of equal thickness with resistance factors of 1750, 1250, and 750.

Pipe diameter without insulation: $D_0 = 0{,}088$ m;
Insulation layer 1: $\mu_1 = 1750$, $d_1 = 0{,}010$ m, $D_1 = 0{,}108$ m;
Insulation layer 2: $\mu_2 = 1250$, $d_2 = 0{,}010$ m, $D_2 = 0{,}128$ m;
Insulation layer 3: $\mu_3 = 750$, $d_3 = 0{,}010$ m, $D_3 = 0{,}148$ m;

Climatic conditions:

Ambient temperature 25 °C, relative humidity 0,7, giving $p_a = 2060$ Pa
Pipe medium temperature 0 °C, giving $p_{sat}(\theta_0) = 611$ Pa.

The total water vapour resistance is given by Equation (10) as: