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Thermal insulation for building equipment and industrial installations — Calculation rules

Isolation thermique des équipements de bâtiments et des installations industrielles — Méthodes de calcul

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 89, *Thermal performance of buildings and building components*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 12241:2008), which has been technically revised.

The main changes are as follows:

- how to calculate the convective part of the external surface coefficient of heat transfer;
- how to introduce thermal bridges in the general heat loss calculation;
- provides detailed data along with the method for calculating fittings (thermal bridges), only informative.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Methods relating to conduction are direct mathematical derivations from Fourier’s law of heat conduction, so no significant difference in the formulae used in the member countries exists. For convection and radiation, however, there are no methods in practical use that are mathematically traceable to Newton’s law of cooling or the Stefan-Boltzman law of thermal radiation, without some empirical element. For convection in particular, many different formulae have been developed, based on laboratory data. Different formulae have become popular in different countries, and no exact means are available to select between these formulae.

Within the limitations given below, these methods can be applied to most types of industrial, thermal-insulation, heat-transfer problems.

a) These methods do not take into account the permeation of air and the transmittance of thermal radiation through transparent media.

b) The formulae in these methods require for their solution that some system variables be known, given, assumed or measured. In all cases, the accuracy of the results depends on the accuracy of the input variables. This document contains no guidelines for accurate measurement of any of the variables. However, it does contain guides that have proven satisfactory for estimating some of the variables for many industrial thermal systems.

c) When the steady-state calculations are used in a changing thermal environment (process equipment operating year-round, outdoors, for example), it is necessary to use local weather data based on yearly averages or yearly extremes of the weather variables (depending on the nature of the particular calculation) for the calculations in this document.

d) In particular, the user should not infer from the methods of this document that either insulation quality or avoidance of dew formation can be reliably assured based on minimal, simple measurements and application of the basic calculation methods given here. For most industrial heat flow surfaces, there is no isothermal state (no one, homogeneous temperature across the surface), but rather a varying temperature profile. Furthermore, the heat flow through a surface at any point is a function of several variables that are not directly related to insulation quality. Among others, these variables include ambient temperature, movement of the air, roughness and emissivity of the heat flow surface, and the radiation exchange with the surroundings (which often vary widely). For calculation of dew formation, variability of the local humidity is an important factor.

e) Except inside buildings, the average temperature of the radiant background seldom corresponds to the air temperature, and measurement of background temperatures, emissivity and exposure areas is beyond the scope of this document. For these reasons, neither the surface temperature nor the temperature difference between the surface and the air can be used as a reliable indicator of insulation performance or avoidance of dew formation.

Clauses 4 and 5 of this document give the methods used for industrial thermal insulation calculations not covered by more specific standards.

Clauses 6 and 7 of this document are adaptations of the general formula for specific applications of calculating heat flow, temperature drop, and freezing times in pipes and other vessels. Thermal insulation to heating/cooling systems such as a boiler and refrigerator are not dealt with by this document.

Annexes A and B of this document are for information only.

Thermal insulation for building equipment and industrial installations — Calculation rules

1 Scope

This document gives rules for the calculation of heat-transfer-related properties of building equipment and industrial installations, predominantly under steady-state conditions. This document also gives a simplified approach for the calculation of thermal bridges.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 7345, *Thermal performance of buildings and building components — Physical quantities and definitions*

ISO 9346, *Hygrothermal performance of buildings and building materials — Physical quantities for mass transfer — Vocabulary*

ISO 13787, *Thermal insulation products for building equipment and industrial installations — Determination of declared thermal conductivity*

ISO 13788, *Hygrothermal performance of building components and building elements — Internal surface temperature to avoid critical surface humidity and interstitial condensation — Calculation methods*

ISO 23993, *Thermal insulation products for building equipment and industrial installations — Determination of design thermal conductivity*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345, ISO 9346, ISO 13787 and ISO 23993 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

3.1.1
thermally separated end disc
end disc used so that the extremities and end caps are not in contact with the object

Note 1 to entry: This construction is used to avoid thermal bridges and the risk of damaging vapour retarders or pipe tracing [15].

3.2 Symbols

Table 1 gives the definition and unit of symbols used in this document.

Table 1 — Definition and unit of symbol

Symbol	Definition	Unit
A	area	$\mathrm{m^2}$
A_s	solar absorption coefficient	
a	length of a rectangle	m
a_r	temperature factor	$\mathrm{K^3}$
b	width of a rectangle	m
C_r	radiation coefficient	$\mathrm{W/(m^2 \cdot K^4)}$
c_p	specific heat capacity at constant pressure	$\mathrm{J/(kg \cdot K)}$
D	diameter	m
d	thickness	m
d_R	insulation layer thickness of the pipe	m
F	overall conversion factor for thermal conductivity	
Gr	Grashof number	
H	height	m
h	surface coefficient of heat transfer	$\mathrm{W/(m^2 \cdot K)}$
J_s	solar radiation	$\mathrm{W/m^2}$
K	thermal bridge coefficient	W/K
L	length	m
l	characteristic length	m
l_i	insulation box inside length	m
m	mass	kg
$\dot{m}$	mass flow rate	kg/s
Nu	Nusselt number	
P	perimeter	m
p	pressure	Pa
p_a	water vapour pressure	Pa
Pr	Prandtl number	
q	density of heat flow rate	$\mathrm{W/m^2}$ or W/m
R	thermal resistance	$\mathrm{m^2 \cdot K/W}$ or $\mathrm{m \cdot K/W}$ or K/W
Re	Reynolds number	
S	space inside the insulation box	
T	thermodynamic temperature	K
t	time	s
U	thermal transmittance	$\mathrm{W/(m^2 \cdot K)}$ or $\mathrm{W/(m \cdot K)}$ or W/K
w	velocity of the air or other fluid	m/s
x	Bolt length + 20 mm	mm
α	coefficient of longitudinal temperature drop	$\mathrm{m^{-1}}$
α'	coefficient of cooling time	$\mathrm{s^{-1}}$
Δh	latent heat	J/kg
ε	emissivity	
Φ	heat flow rate	W
λ	thermal conductivity	$\mathrm{W/(m \cdot K)}$
λ_d	declared thermal conductivity	$\mathrm{W/(m \cdot K)}$
λ_D	design thermal conductivity	$\mathrm{W/(m \cdot K)}$

Table 1 *(continued)*

Symbol	Definition	Unit
θ	Celsius temperature	°C
θ_b	point of measurement of the temperature at the fin base	°C
ρ	density	kg/m^3
φ	relative humidity	%
σ	Stefan-Boltzmann constant (see Reference [8])	$W/(m^2 \cdot K^4)$
v	kinematic viscosity of air or other fluid	m^2/s
Δ	difference	
ΔA	equivalent area	m^2
ΔL	equivalent length	m
$\Delta\lambda$	extra conductivity due to regularly placed components in the insulation system	$W/(m \cdot K)$

3.3 Subscripts

Table 2 gives the definition of subscripts used in this document.

Table 2 — Definition of subscripts

A	valve	i	interior (internal)
a	ambient,	in	initial
anc	anchor	Ka	insulation box
av	average	l	linear
B	thermal bridge	lab	laboratory
c	cooling	lam	laminar flow
cv	convection	MRT	mean radiant temperature
cr	critical	P	pump
cs	cross section	p	pipe
d	duct	r	radiation
E	soil	ref	reference
e	exterior (external)	s	surface
ef	effective	sat	saturated vapour
en	entrance	se	exterior surface
ex	exit	si	interior surface
f	fluid	sph	spherical
fa	frontal of the fin	sq	per square
fas	fastener	T	total
FEM	Finite Element Method	tb	insulation related thermal bridge
fi	final	tur	turbulent flow
fin	fin	V	vertical
fl	flange	v	vessel
forced	forced	W	wall
fr	freezing	w	water
free	free	wp	start freezing
H	horizontal		

4 Calculation rules and formulae of heat transfer

4.1 Fundamental formulae for heat transfer

4.1.1 General

The formulae given in Clause 4 apply only to the case of heat transfer in steady state, i.e. to the case where temperatures remain constant in time at any point of the medium considered. The design thermal conductivity is temperature-dependent; see Figure 1, dashed line. However, in this document, the design value for the mean temperature for each layer shall be used.

4.1.2 Thermal conduction

Thermal conduction normally describes molecular heat transfer in solids, liquids, and gases under the effect of a temperature gradient.

It is assumed in the calculation that a temperature gradient exists in one direction only and that the temperature is constant in planes perpendicular to it.

The density of heat flow rate, q, for a plane wall in the x-direction is given by Formula (1):

$$q = \lambda_D \cdot \frac{d\theta}{dx} \qquad (1)$$

For a single layer, Formulae (2), (3) and (4) are given:

$$q = \frac{\lambda_D}{d} \cdot (\theta_{\text{si}} - \theta_{\text{se}}) \qquad (2)$$

or

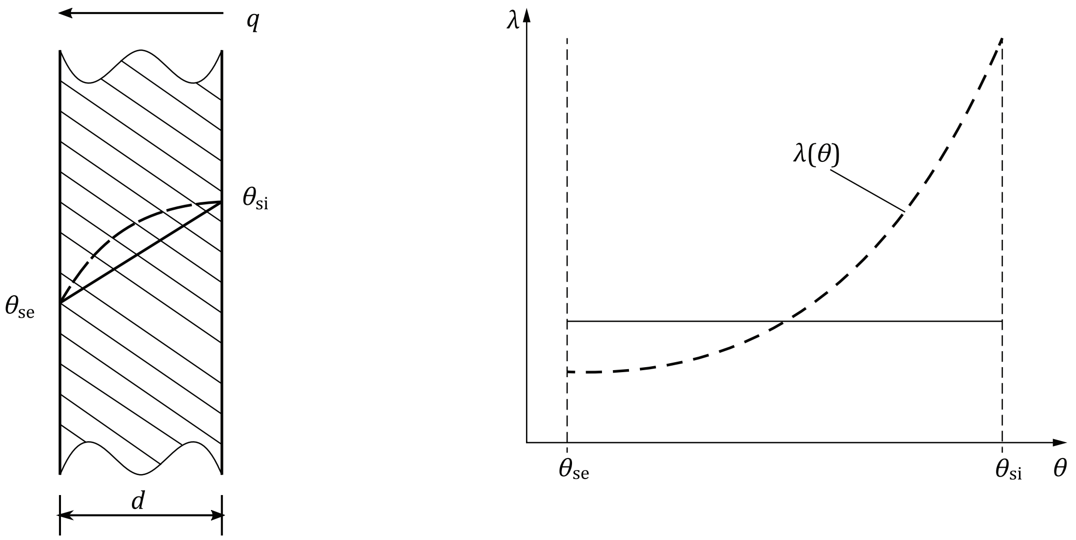
$$q = \left(\frac{\theta_{\text{si}} - \theta_{\text{se}}}{R} \right) \qquad (3)$$

and

$$R = \frac{d}{\lambda_D} \qquad (4)$$

where

λ_D	is the design thermal conductivity of the insulation product or system, expressed in W/(m·K);
d	is the thickness of the plane wall, expressed in m;
θ_{si}	is the temperature of the internal surface, expressed in °C;
θ_{se}	is the temperature of the external surface, expressed in °C;
R	is the thermal resistance of the wall, expressed in $m^2 \cdot K/W$.



a) Temperature distribution in a single-layer

b) Thermal conductivity as function of the temperature

NOTE The dashed curve in Figure 1a), represents the temperature variation in a wall, considering that the thermal conductivity depends on the temperature, such as the dashed curve in Figure 1b). In case that the thermal conductivity is considered as temperature-independent (the solid line in Figure 1b), the variation of the temperature inside a wall is represented by the straight line in Figure 1a).

Figure 1 — Temperature distribution

For a multi-layer wall (see Figure 2), q is calculated according to Formula (3), where R is the thermal resistance of the multi-layer wall, as given in Formula (5):

$$R = \sum_{j=1}^{n} \frac{d_j}{\lambda_{D_j}} \tag{5}$$

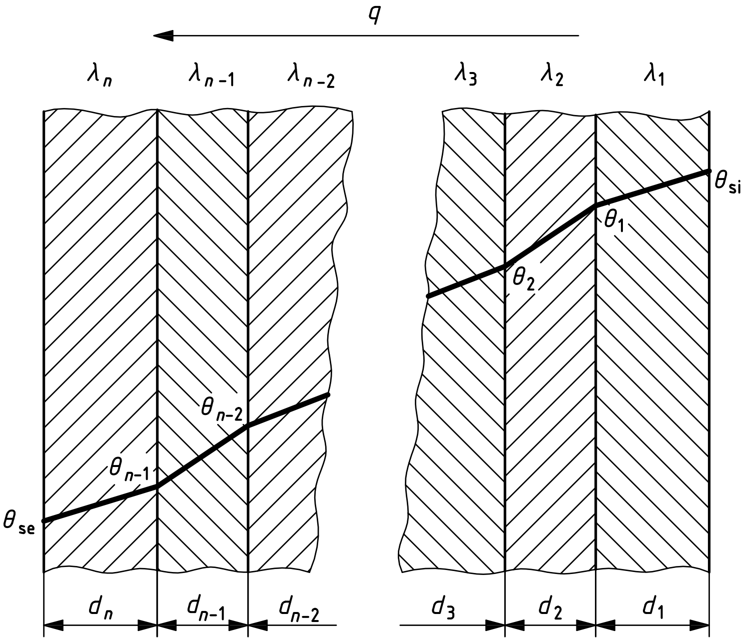


Figure 2 — Temperature distribution in a multi-layer wall

The linear density of heat flow rate, q_l, of a single-layer hollow cylinder (see Figure 3) is given in Formula (6):

$$q_l = \frac{\theta_{si} - \theta_{se}}{R_l} \tag{6}$$

where R_l is the linear thermal resistance of a single-layer hollow cylinder [m·K/W], as given in Formula (7):

$$R_l = \frac{\ln \frac{De}{D_i}}{2 \cdot \pi \cdot \lambda_D} \tag{7}$$

where

D_e is the outer diameter of the layer, expressed in m;

D_i is the inner diameter of the layer, expressed in m.

a) **Temperature distribution in a single layer-hollow cylinder**

b) **Front view of a hollow cylinder**

Figure 3 — Temperature distribution in a single-layer hollow cylinder

For a multi-layer hollow cylinder (see Figure 4), the linear density of heat flow rate, q_l, is given in Formula (6), where R_l is given by Formula (8)

$$R_l = \frac{1}{2 \cdot \pi} \sum_{j=1}^{n} \left(\frac{1}{\lambda_{D_j}} \ln \frac{D_{e,j}}{D_{i,j}} \right) \tag{8}$$

where

$D_{i,1} = D_i$

$D_{e,n} = D_e$

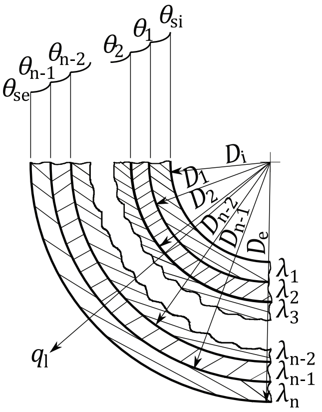


Figure 4 — Temperature distribution in a multi-layer hollow cylinder

For curved surfaces with a diameter larger than 1 200 mm, it is recommended to use formulae for a plane wall.

The heat flow rate of a sphere, Φ_{sph}, of a single-layer hollow sphere (see Figure 5) is given by Formula (9):

$$\Phi_{sph} = \frac{\theta_{si} - \theta_{se}}{R_{sph}} \tag{9}$$

where R_{sph} is the thermal resistance of a single-layer hollow sphere [K/W], as given in Formula (10):

$$R_{sph} = \frac{1}{2 \cdot \pi \cdot \lambda_D} \left(\frac{1}{D_i} - \frac{1}{D_e} \right) \tag{10}$$

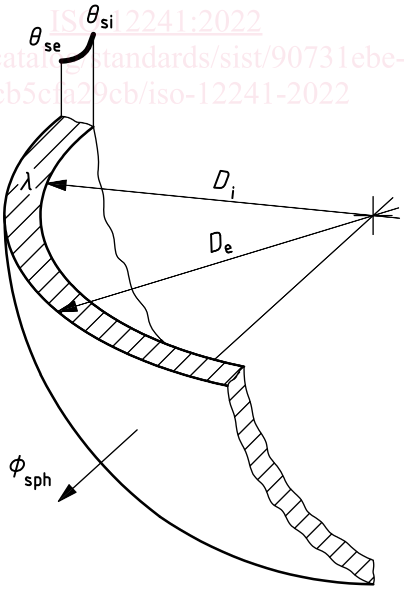


Figure 5 — Temperature distribution in a single-layer hollow sphere

For a multi-layer hollow sphere (see Figure 6), the heat flow rate of a sphere, Φ_{sph}, is given in Formula (9), where R_{sph} is given by Formula (11):

$$R_{sph} = \frac{1}{2 \cdot \pi} \cdot \sum_{j=1}^{n} \frac{1}{\lambda_{D_j}} \cdot \left(\frac{1}{D_{j-1}} - \frac{1}{D_j} \right) \tag{11}$$

where

$D_0 = D_i$

$D_n = D_e$

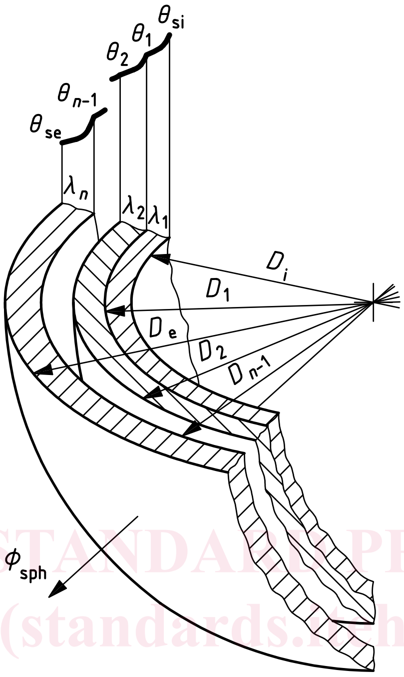


Figure 6 — Temperature distribution in a multi-layer hollow sphere

The linear density of heat flow rate, q_l, through the wall of a duct with rectangular cross-section (see Figure 7) is given by Formula (12):

$$q_l = \frac{\theta_{si} - \theta_{se}}{R_l} \tag{12}$$

The linear thermal resistance of a duct, R_l [m·K/W], of the wall of such a duct can be approximately calculated by Formula (13):

$$R_l = \frac{2 \cdot d}{\lambda_D \cdot (P_e + P_i)} \tag{13}$$

where

d is the thickness of the insulating layer, expressed in m;

P_i is the inner perimeter of the duct, expressed in m;

P_e is the external perimeter of the duct, expressed in m, as given in Formula (14):

$$P_e = P_i + (8 \cdot d) \tag{14}$$

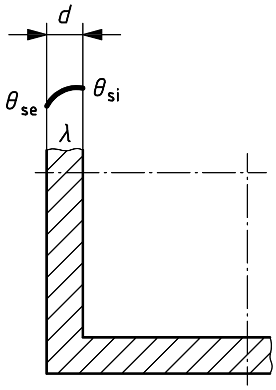


Figure 7 — Temperature distribution in a wall of a duct with rectangular cross-section with temperature-dependent thermal conductivity

4.1.3 Surface coefficient of heat transfer

In general, the radiative and convective heat transfer at the surface area given by Formulae (15) and (16) occurs at the surface:

$$q_{\mathrm{r}} = h_{\mathrm{r}} \cdot (\theta_1 - \theta_{\mathrm{MRT}}) \tag{15}$$

$$q_{\mathrm{cv}} = h_{\mathrm{cv}} \cdot (\theta_1 - \theta_{\mathrm{a}}) \tag{16}$$

where

q_{r}	is the density of radiative heat flow, expressed in W/m^2;
q_{cv}	is the density of convective heat flow, expressed in W/m^2;
h_{r}	is the radiative part of the surface coefficient of heat transfer, expressed in W/(m^2·K);
h_{cv}	is the convective part of the surface coefficient of heat transfer, expressed in W/(m^2·K);
θ_1	is the surface temperature of surface 1, expressed in °C;
θ_{MRT}	is the mean radiant temperature of the surrounding, expressed in °C;
θ_{a}	is the ambient air temperature, expressed in °C.

NOTE 1 h_{r} is dependent on the temperature and the emissivity of the surface. Emissivity is defined as the ratio between the radiation coefficient of the surface and the black body radiation constant (see ISO 9288).

NOTE 2 h_{cv} is, in general, dependent on a variety of factors, such as air movement, temperature, the relative orientation of the surface, the material of the surface and other factors.

The combined surface heat transfer can be given by Formula (17):

$$q = q_{\mathrm{r}} + q_{\mathrm{cv}} = h_{\mathrm{r}} \cdot (\theta_1 - \theta_{\mathrm{MRT}}) + h_{\mathrm{cv}} \cdot (\theta_1 - \theta_{\mathrm{a}}) \tag{17}$$

When the mean radiant temperature is almost equal to the ambient air temperature, the combined heat transfer at the surface is given by Formula (18):

$$q = h_{\mathrm{r}} \cdot (\theta_1 - \theta_{\mathrm{a}}) + h_{\mathrm{cv}} \cdot (\theta_1 - \theta_{\mathrm{a}}) = (h_{\mathrm{r}} + h_{\mathrm{cv}}) \cdot (\theta_1 - \theta_{\mathrm{a}}) = h_{\mathrm{se}} \cdot (\theta_{\mathrm{se}} - \theta_{\mathrm{a}}) \tag{18}$$