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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

Reference number
ISO 12241:2008(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

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

ISO 12241 was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*.

This second edition cancels and replaces the first edition (ISO 12241:1998), which has been technically revised, including methods to determine the correction terms for thermal transmittance and linear thermal transmittance for pipes that are added to the calculated thermal transmittance to obtain the total thermal transmittance to calculate the total heat losses for an industrial installation.

Introduction

Methods relating to conduction are direct mathematical derivations from Fourier's law of heat conduction, so international consensus is purely a matter of mathematical verification. No significant difference in the equations 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 equations have been developed, based on laboratory data. Different equations have become popular in different countries, and no exact means are available to select between these equations.

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

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

The equations 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 International Standard 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.

It should be noted that the steady-state calculations are dependent on boundary conditions. Often a solution at one set of boundary conditions is not sufficient to characterize a thermal system that operates in a changing thermal environment (process equipment operating year-round, outdoors, for example). In such cases, 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 International Standard.

In particular, the user should not infer from the methods of this International Standard 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. This condition suggests the requirement for numerous calculations to properly model thermal characteristics of any one surface. 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.

Except inside buildings, the average temperature of the radiant background seldom corresponds to the air temperature, and measurement of background temperatures, emissivities and exposure areas is beyond the scope of this International Standard. 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 International Standard give the methods used for industrial thermal insulation calculations not covered by more specific standards. In applications where it is not necessary to assure precise values of heat energy conservation or (insulated) surface temperature, or where critical temperatures for dew formation are either not approached or not a factor, these methods can be used to calculate heat flow rates.

Clauses 6 and 7 of this International Standard are adaptations of the general equation for specific applications of calculating heat flow temperature drop and freezing times in pipes and other vessels.

Annexes B and C of this International Standard are for information only.

Thermal insulation for building equipment and industrial installations — Calculation rules

1 Scope

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

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7345, *Thermal insulation — Physical quantities and definitions*

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

ISO 10211, *Thermal bridges in building construction — Heat flows and surface temperatures — Detailed calculations*

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

ISO 23993, *Thermal insulation 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 apply.

3.2 Definition of symbols

Symbol	Definition	Unit
A	area	m^2
a_r	temperature factor	K^3
C'	thickness parameter (see 4.2.2)	m
C_r	radiation coefficient	W/(m^2·K^4)
c_p	specific heat capacity at constant pressure	kJ/(kg·K)
D	diameter	m, mm
d	thickness	m, mm
H	height	m
h	surface coefficient of heat transfer	W/(m^2·K)
l	length	m
m	mass	kg
$\dot{m}$	mass flow rate	kg/h
P	perimeter	m
q	density of heat flow rate	W/m^2
q_d	linear density of heat flow rate for ducts	W/m
q_l	linear density of heat flow rate	W/m
R	thermal resistance	m^2·K/W
R_d	linear thermal resistance of ducts	m·K/W
R_l	linear thermal resistance	m·K/W
R_le	linear thermal surface resistance	m·K/W
R_s	surface resistance of heat transfer	m^2·K/W
R_sph	thermal resistance for hollow sphere	K/W
t_fr	freezing time	h
t_v	cooling time	h
t_wp	time until freezing starts	h
T	thermodynamic temperature	K
U	thermal transmittance	W/(m^2·K)
U_l	linear thermal transmittance	W/(m·K)
U_sph	thermal transmittance for hollow sphere	W/K
U_B	thermal transmittance of thermal bridge	W/(m^2·K)
ΔU_B	additional term corresponding to installation-related and/or irregular insulation-related thermal bridges	W/(m^2·K)
U_T	total thermal transmittance for plane wall	W/(m^2·K)
$U_\mathrm{T,l}$	total linear thermal transmittance	W/(m·K)
$U_\mathrm{T,sph}$	total thermal transmittance for hollow sphere	W/K
v	air velocity	m/s

Symbol	Definition	Unit
z, y	correction terms for irregular insulation-related thermal bridges	—
z^*, y^*	correction terms for installation-related thermal bridges	—
α	coefficient of longitudinal temperature drop	m^{-1}
α'	coefficient of cooling time	h^{-1}
Δh_{fr}	specific enthalpy; latent heat of freezing	kJ/kg
ε	emissivity	—
Φ	heat flow rate	W
λ	design thermal conductivity	W/(m·K)
λ_{d}	declared thermal conductivity	W/(m·K)
θ	Celsius temperature	°C
$\Delta\theta$	temperature difference	K
ρ	density	$\mathrm{kg/m^3}$
φ	relative humidity	%
σ	Stefan-Boltzmann constant (see Reference [8])	$\mathrm{W/(m^2 \cdot K^4)}$

3.3 Subscripts

a	ambient	lab	laboratory
av	average	l	linear
B	thermal bridge	p	pipe
c	cooling	r	radiation
cv	convection	ref	reference
d	design, duct, dew point	s	surface
E	soil	sph	spherical
e	exterior, external	se	surface, exterior
ef	effective	si	surface, interior
fm	final temperature of the medium	T	total
fr	freezing	V	vertical
H	horizontal	v	vessel
i	interior, internal	W	wall
im	initial temperature of the medium	w	water

4 Calculation methods for heat transfer

4.1 Fundamental equations for heat transfer

4.1.1 General

The equations given in Clause 4 apply only to the case of heat transfer in a steady-state, i.e. to the case where temperatures remain constant in time at any point of the medium considered. Generally, the design thermal conductivity is temperature-dependent; see Figure 1, dashed line, which is derived by iterative calculations. However, in this International Standard, 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 Equation (1):

$$q = -\lambda \frac{\mathrm{d}\theta}{\mathrm{d}x} \qquad (1)$$

For a single layer, Equations (2) and (3) hold:

$$q = \frac{\lambda}{d} (\theta_{\mathrm{si}} - \theta_{\mathrm{se}}) \qquad (2)$$

or

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

where

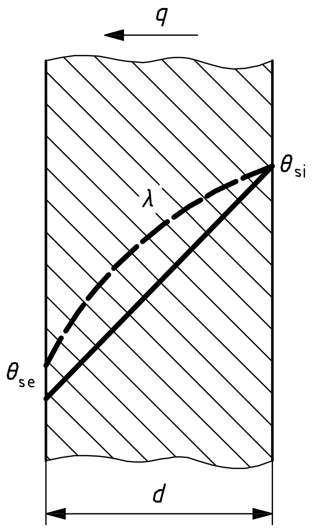
λ is the design thermal conductivity of the insulation product or system;

d is the thickness of the plane wall;

θ_{si} is the temperature of the internal surface;

θ_{se} is the temperature of the external surface;

R is the thermal resistance of the wall.



NOTE The straight line shows a negligible temperature dependence on λ and the dashed curve a strong dependence.

Figure 1 — Temperature distribution in a single-layer wall

For multi-layer insulation (see Figure 2), q is calculated according to Equation (4):

$$q = \frac{\theta_{\mathrm{si}} - \theta_{\mathrm{se}}}{R'} \qquad (4)$$

where R' is the thermal resistance of the multi-layer wall, as given in Equation (5):

$$R' = \sum_{j=1}^{n} \frac{d_j}{\lambda_j} \tag{5}$$

NOTE The prime denotes a multi-layer quantity.

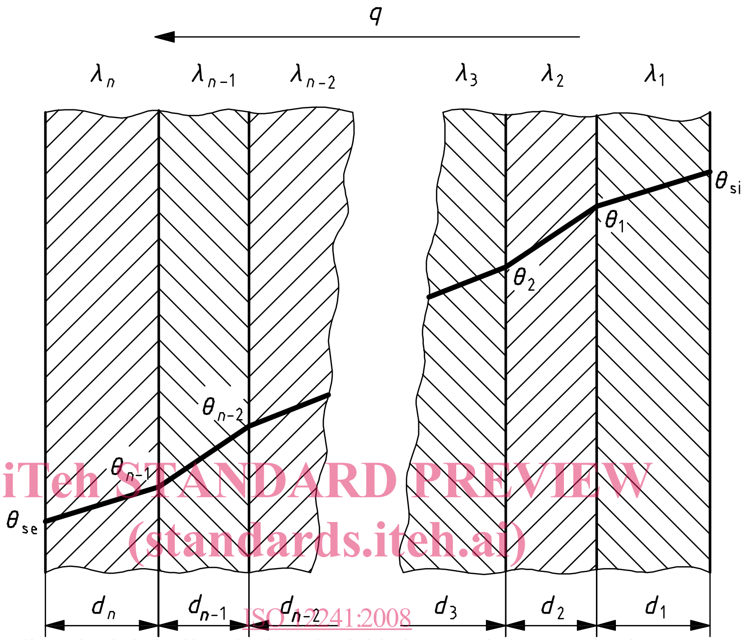


Figure 2 — Temperature distribution in a multi-layer wall

The linear density of heat flow rate, q_l, of a single-layer hollow cylinder (see Figure 3) is given in Equation (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, as given in Equation (7):

$$R_l = \frac{\ln \frac{D_e}{D_i}}{2\pi\lambda} \tag{7}$$

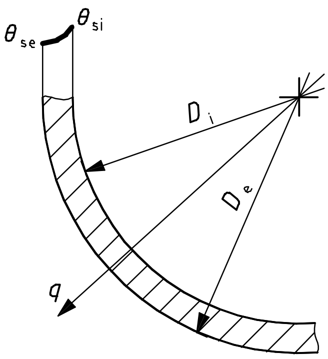


Figure 3 — Temperature distribution in a single-layer hollow cylinder

For multi-layer hollow cylinder (see Figure 4), the linear density of heat flow rate, q_l, is given in Equation (8):

$$q_\mathrm{l} = \frac{\theta_\mathrm{si} - \theta_\mathrm{se}}{R'_\mathrm{l}} \tag{8}$$

where R'_l is given by Equation (9)

$$R'_\mathrm{l} = \frac{1}{2\pi} \sum_{j=1}^{n} \left(\frac{1}{\lambda_j} \ln \frac{D_{\mathrm{e}j}}{D_{\mathrm{i}j}} \right) \tag{9}$$

where

$D_0 = D_\mathrm{i}$

$D_n = D_\mathrm{e}$

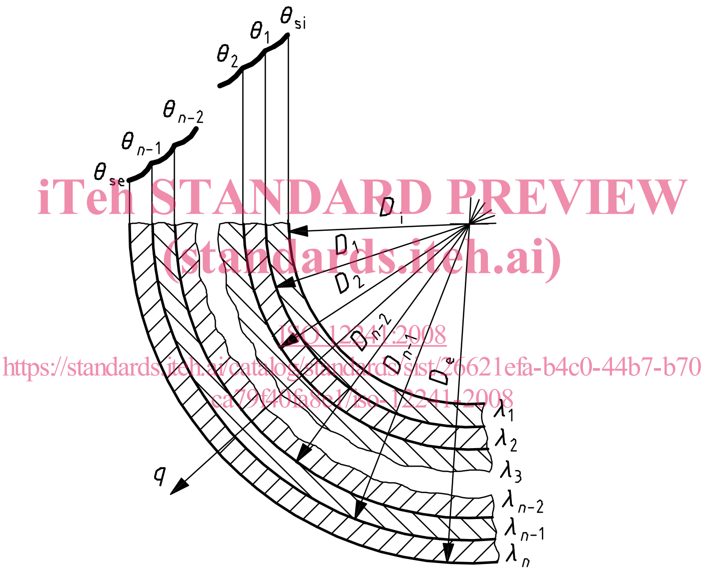


Figure 4 — Temperature distribution in a multi-layer hollow cylinder

The heat flow rate, Φ_sph, of a single-layer hollow sphere (see Figure 5) is as given in Equation (10):

$$\Phi_\mathrm{sph} = \frac{\theta_\mathrm{si} - \theta_\mathrm{se}}{R_\mathrm{sph}} \tag{10}$$

where R_sph is the thermal resistance of a single-layer hollow sphere, as given in Equation (11):

$$R_\mathrm{sph} = \frac{1}{2\pi\lambda} \left(\frac{1}{D_\mathrm{i}} - \frac{1}{D_\mathrm{e}} \right) \tag{11}$$

where

D_e is the outer diameter of the layer;

D_i is the inner diameter of the layer.

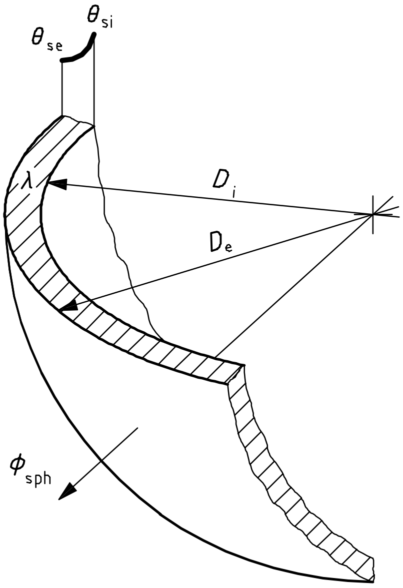


Figure 5 — Temperature distribution in a single-layer hollow sphere

The heat flow rate, Φ_{sph}, of a multi-layer hollow sphere (see Figure 6) is as given in Equation (12):

$$\Phi_{\mathrm{sph}} = \frac{\theta_{\mathrm{si}} - \theta_{\mathrm{se}}}{R'_{\mathrm{sph}}} \tag{12}$$

where R'_{sph} is as given in Equation (13):

$$R'_{\mathrm{sph}} \frac{1}{2\pi} \sum_{j=1}^{n} \frac{1}{\lambda_j} \left(\frac{1}{D_{j-1}} - \frac{1}{D_j} \right) \tag{13}$$

$$D_0 = D_{\mathrm{i}}$$

$$D_n = D_{\mathrm{e}}$$

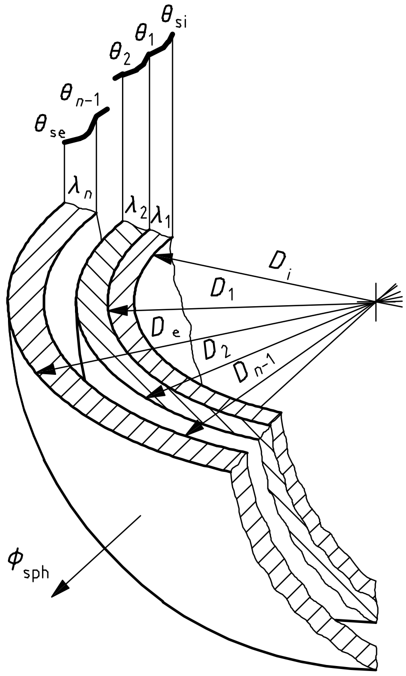


Figure 6 — Temperature distribution in a multi-layer hollow sphere

The linear density of heat flow rate, q_d, through the wall of a duct with rectangular cross-section (see Figure 7) is as given in Equation (14):

$$q_d = \frac{\theta_{si} - \theta_{se}}{R_d} \tag{14}$$

The linear thermal resistance, R_d, of the wall of such a duct can be approximately calculated as given in Equation (15):

$$R_d = \frac{2d}{\lambda\,(P_e + P_i)} \tag{15}$$

where

d is the thickness of the insulating layer;

P_i is the inner perimeter of the duct;

P_e is the external perimeter of the duct, as given in Equation (16):

$$P_e = P_i + (8 \times d) \tag{16}$$

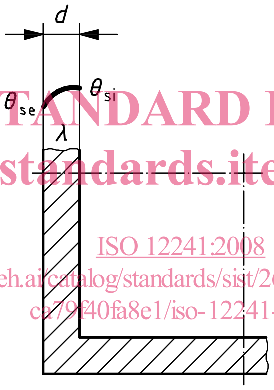


Figure 7 — Temperature distribution in a wall of a duct with rectangular cross-section at temperature-dependent thermal conductivity

4.1.3 Surface coefficient of heat transfer

In general, the surface coefficient of heat transfer, h, is given by Equation (17):

$$h = h_r + h_{cv} \tag{17}$$

where

h_r is the radiative part of the surface coefficient of heat transfer;

h_{cv} is the convective part of the surface coefficient of heat transfer.

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.

4.1.3.1 Radiative part of surface coefficient, h_r

h_r is given by Equation (18):

$$h_\mathrm{r} = a_\mathrm{r}\, C_\mathrm{r} \tag{18}$$

where

a_r is the temperature factor;

C_r is the radiation coefficient, as given by Equation (21).

The temperature factor, a_r, is given by Equation (19):

$$a_\mathrm{r} = \frac{(T_1)^4 - (T_2)^4}{T_1 - T_2} \tag{19}$$

and can be approximated up to a temperature difference of 200 K by Equation (20):

$$a_\mathrm{r} \approx 4 \times (T_\mathrm{av})^3 \tag{20}$$

where T_av is the arithmetic mean of the surface temperature and the mean radiant temperature of the surroundings.

The radiation coefficient, C_r, is given by Equation (21):

$$C_\mathrm{r} = \varepsilon\, \sigma \tag{21}$$

where σ is the Stefan-Boltzmann constant [$5{,}67 = 10^{-8}$ W/(m^2·K^4)].

4.1.3.2 Convective part of surface coefficient, h_cv

4.1.3.2.1 General

For convection, it is necessary to make a distinction between the surface coefficient inside buildings and that in open air. For pipes and containers, there is a difference as well between the internal surface coefficient, h_i, and the external surface coefficient, h_se.

NOTE In most cases, h_i can be neglected by assuming that the inner surface temperature equals the temperature of the medium.

4.1.3.2.2 Inside buildings

In the interior of buildings, h_cv can be calculated for plane vertical walls and vertical pipes for laminar, free convection ($H^3 \Delta\theta \leqslant 10$ m^3·K) by Equation (22):

$$h_\mathrm{cv} = 1{,}32 \times \sqrt[4]{\frac{\Delta\theta}{H}} \tag{22}$$

where

$\Delta\theta = |\theta_\mathrm{se} - \theta_\mathrm{a}|$;

θ_se is the surface temperature of the wall;

θ_a is the temperature of the ambient air inside the building;

H is the height of the wall or diameter of a pipe.