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Thermal insulation products for building equipment and industrial installations — Determination of design thermal conductivity

Produits isolants thermiques pour l'équipement du bâtiment et les installations industrielles — Détermination de la conductivité thermique utile

Reference number
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Contents

Page

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 23993 was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 89, *Thermal performance of buildings and building components*, in collaboration with ISO Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This International Standard is one of a series of standards on methods for the design and evaluation of the thermal performance of building equipment and industrial installations.

Introduction

The establishment of design values for thermal conductivity for the calculation of the thermal performance of insulation systems for building equipment and industrial installations requires a consideration of various possible influences affecting the thermal properties of the insulation products employed due to the operational conditions of any individual insulation system.

Among these influences could be:

— the non-linearity of the thermal conductivity curve over the temperature range in which the insulant may be employed;

— the thickness effect;

— the effect of moisture in the insulant;

— ageing effects, beyond those already incorporated in the declared value;

— special installation effects such as single- or multi-layered installation.

In this International Standard, the conversion factors F, that need to be used in a variety of applications for a variety of insulation products, are given and the principles and general equations as well as some guidance for the establishment of design values for the calculation of the thermal performance of insulation systems are described. The conversion factors valid for commonly employed insulation products are given in annexes. They are well established in some cases and for some materials. Where experience is lacking and conversion factors cannot be established accurately, they are given in the form of an "educated estimate" so that the calculation result will be on the safe side, i.e. the calculated heat transfer will be greater than that actually occurring when the calculation has obeyed the rules of this International Standard.

Thermal insulation products for building equipment and industrial installations — Determination of design thermal conductivity

1 Scope

This International Standard gives methods to calculate design thermal conductivities from declared thermal conductivities for the calculation of the thermal performance of building equipment and industrial installations.

These methods are valid for operating temperatures from −200 °C to +800 °C.

The conversion factors, established for the different influences, are valid for the temperature ranges indicated in the relevant clauses or annexes.

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 8497, *Thermal insulation — Determination of steady-state thermal transmission properties of thermal insulation for circular pipes*

ISO 9053, *Acoustics — Material for acoustical applications — Determination of airflow resistance*

ISO 9229, *Thermal insulation — Vocabulary*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345, ISO 9229 and the following apply.

3.1
declared thermal conductivity
value of the thermal conductivity of a material or product used for building equipment and industrial installations:

— based on measured data at reference conditions of temperature and humidity;

— given as a limit value, according to the determination method in ISO 13787;

— corresponding to a reasonable expected service lifetime under normal conditions

3.2
design thermal conductivity
value of thermal conductivity of an insulation material or product under specific external and internal conditions which can be considered as typical of the performance of that material or product when incorporated in a building equipment or industrial installation

4 Symbols

Symbol	Quantity	Unit
a_C	compressibility coefficient	$m^3/(kg·K)$
D	internal diameter of the layer	m
d	layer thickness	m
d_g	system thickness including air gap	m
F	overall conversion factor for thermal conductivity	—
F_a	ageing conversion factor	—
F_C	compression conversion factor	—
F_c	convection conversion factor	—
F_d	thickness conversion factor	—
f_d	thickness conversion coefficient	—
F_j	joint factor	—
F_m	moisture conversion factor	—
f_ψ	moisture conversion coefficient volume by volume	m^3/m^3
$F_{\Delta\theta}$	temperature difference conversion factor	—
u	moisture content mass by mass	kg/kg
θ	Celsius temperature	°C
λ_d	declared thermal conductivity	W/(m·K)
λ	design thermal conductivity	W/(m·K)
$\bar{\lambda}$	integrated thermal conductivity	W/(m·K)
$\Delta\lambda$	additional thermal conductivity due to thermal bridges, such as spacers, which are regular parts of the insulation	W/(m·K)
ρ	apparent density	kg/m^3
ψ	moisture content volume by volume	m^3/m^3

5 Determination of declared thermal conductivity

Declared thermal conductivities shall be determined according to ISO 13787.

The product shall be described by its characteristics including a clear identification of the materials, the type of facing if any, the structure, the blowing agent, the thickness and any other parameters having a possible influence on thermal conductivity.

The declared thermal conductivity shall be determined either at a thickness large enough to neglect the thickness effect or, for smaller thicknesses, based on measurements at those thicknesses.

6 Determination of the design value of thermal conductivity

The design value of thermal conductivity shall be determined from the declared thermal conductivity for the set of conditions corresponding to the conditions of the expected application. Possible influences include the following:

a) the average operating temperature, together with the hot and cold surface temperatures;

b) the average moisture content expected when the material is in equilibrium with a defined atmosphere (temperature and relative humidity);

c) the ageing effect according to the application, if not included in the declared value;

d) the compression applied in the application;

e) the convection effect in the material;

f) the thickness effect;

g) the open joint effect;

h) the insulation-related thermal bridges, (thermal bridges that are regular part of the insulation system, e.g. spacers), which are taken into account via a term $\Delta\lambda$.

The design value of thermal conductivity shall be obtained either

— from a declared thermal conductivity converted to the conditions of the application using Equation (1):

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where the additional term $\Delta\lambda$ is obtained according to 7.9 and the overall conversion factor F is given by:

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— or from values measured under application conditions.

NOTE Approximate values for F can be found in the informative Annex C.

7 Conversion of available data

7.1 General

Values of the different conversion factors for some insulating materials and operating conditions are given in Annex A. Conversion factors derived from measured values according to the appropriate test methods, e.g. EN 12667 or ISO 8497, may be used instead of the values in Annex A. If the material does not correspond to the conditions for which the factors are given in Annex A, then the conversion factors derived from measured values shall be used.

7.2 Conversion factor for temperature difference

If the design thermal conductivity is requested at the same reference mean temperature and if the hot and cold surface temperatures are the same as for the declared thermal conductivity, no conversion is needed ($F_{\Delta\theta} = 1$).

In the case of thermal conductivity measurement made with the pipe tester (ISO 8497), no conversion is needed when the measurement is carried out with the full temperature difference $\Delta\theta$.

If the design thermal conductivity is to be determined at another temperature from declared thermal conductivities given in the form of a table of values at different temperatures, interpolation between values in the table shall be based on the use of a best-fit equation such as a regression polynomial, of an order sufficient to provide a correlation coefficient, $r \geqslant 0{,}98$.

If the design thermal conductivity is needed at the same reference mean temperature, but for another hot and cold surface temperature difference, than that used for determining the declared thermal conductivity, the conversion factor $F_{\Delta\theta}$ shall be determined according to the procedure given in A.1 of Annex A.

If the thermal conductivity measurement has been carried out with the full temperature difference, $F_{\Delta\theta} = 1$. If the thermal conductivity measurement has been carried out with a $\Delta\theta$ not exceeding 50 K, the procedure for non-linearity applies.

If the design thermal conductivity is needed at another mean temperature than that of the declared thermal conductivity and with another temperature difference, the procedures outlined above shall be followed successively. As an alternative, the influence of the non-linearity of the thermal conductivity curve may be taken into account by integrating the measured curve as given by Equation (3):

$$\bar{\lambda} = \frac{1}{\theta_2 - \theta_1} \int_{\theta_1}^{\theta_2} \lambda(\theta)\,\mathrm{d}\theta \tag{3}$$

The temperature difference conversion factor is given by:

$$F_{\Delta\theta} = \frac{\bar{\lambda}}{\lambda(\theta)} \tag{4}$$

where $\lambda(\theta)$ is the value read on the curve at the reference temperature.

7.3 Conversion factor for moisture

The conversion factor F_m for volume-related moisture content shall be determined as follows:

$$F_\mathrm{m} = \mathrm{e}^{f_\psi(\psi_2 - \psi_1)} \tag{5}$$

where

f_ψ is the moisture content conversion coefficient volume by volume;

ψ_1 is the moisture content volume by volume for the determination of declared value of thermal conductivity;

ψ_2 is the moisture content volume by volume for the actual application.

The content of moisture in a given application shall be determined either

— by measurements carried out in the conditions of the expected application, or

— by theoretical calculations using proven methods such as those given in ISO 15758 based on measured values as described in ISO 12572, provided the assumptions on which they are based are met.

NOTE A possible test method to determine moisture content is given in EN 12088. If needed for the application, the time period indicated in EN 12088 can be extended.

Some values of the coefficient f_ψ are given in A.2 of Annex A.

7.4 Conversion factor for ageing

The ageing depends upon the material type, facings, structures, the blowing agent, the temperature and the thickness of the material. For a given material, the ageing effect can be obtained from theoretical models validated by experimental data (see procedure in the product standard, where applicable).

No conversion is needed when the declared thermal conductivity or resistance already takes account of ageing or when the ageing effect has been determined in conditions which do not significantly differ from the design set of conditions.

If the set of conditions for the design thermal conductivities significantly differs from that in which the ageing effect of the declared thermal conductivity has been determined, an ageing test in the set of conditions of the design thermal conductivities shall be carried out.

If a conversion factor F_a is used, it shall allow for the calculation of the aged value of the thermal property corresponding to a time not less than half the working lifetime of the product in the application concerned.

NOTE 1 The working lifetime for building equipment is often taken as 50 years.

NOTE 2 No conversion coefficients are given in this International Standard to derive the ageing conversion factor F_a.

No ageing conversion factor shall be used for mineral wool, ceramic fibre, calcium-magnesium silicate fibre, calcium silicate, flexible elastomeric foam and cellular glass.

7.5 Conversion factor for compression

For compressible insulation products, the apparent density may change when the product is subject to load. The influence on the thermal conductivity shall be taken into account by the factor F_C, which shall be calculated according to A.3.

7.6 Conversion factor for convection

The effect of convection in the case of vertical insulation layers shall be taken into account by a convection factor F_c.

The factor F_c shall be calculated according to A.4.

7.7 Conversion factor for thickness effect

For insulation materials permeable to radiation, the thermal conductivity changes with increasing thickness. If the design thermal conductivity is needed at other thicknesses than those of the declared thermal conductivity, the factor F_d shall be determined according to A.5.

7.8 Conversion factor for regular joints

The influence of joints on the design thermal conductivity shall be addressed by the conversion factor F_j, which shall be calculated according to A.6.

The conversion factor F_j shall be applied if the thermal conductivity has been measured in accordance with ISO 8497, with a pipe tester having fewer joints than the actual application.

7.9 Additional thermal conductivity for regularly insulation-related thermal bridges, e.g. spacers

7.9.1 General

Components in the insulating layer which are regularly-spaced insulation-related thermal bridges like spacers are taken into account by adding $\Delta\lambda$ to the corrected thermal conductivity λ_d of the installed insulation product according to Equation (1).

Plant-related and irregularly-spaced insulation-related thermal bridges, e.g. pipe mountings, supports, armatures and frontal plates are thermal bridges which have to be considered as additional heat losses, e.g. as described in ISO 12241.

7.9.2 Spacers

7.9.2.1 Spacers for sheet metal pipeline jackets

The additional thermal conductivity depends on a number of variables. The values indicated in the following are approximate values and apply to common insulating layer thicknesses from 100 mm to 300 mm and common insulation systems for heat protection.

NOTE 1 Reference [9] in the Bibliography provides possible procedures for special insulation systems.

Additions to thermal conductivity

for steel spacers	$\Delta\lambda = 0{,}010$ W/(m·K)
for austenitic steel spacers	$\Delta\lambda = 0{,}004$ W/(m·K)
for ceramic spacers	$\Delta\lambda = 0{,}003$ W/(m·K)

NOTE 2 These values can be used in the range of 50 mm to 200 mm, see Reference [10].

7.9.2.2 Spacers for sheet metal jackets for walls

Spacers of steel in the form of a flat bar

30 mm × 3 mm	$\Delta\lambda = 0{,}003\,5$ W/(m·K)/(spacers/m^2)
40 mm × 4 mm	$\Delta\lambda = 0{,}006\,0$ W/(m·K)/(spacers/m^2)
50 mm × 5 mm	$\Delta\lambda = 0{,}008\,5$ W/(m·K)/(spacers/m^2)

7.9.3 Mechanical fasteners penetrating an insulation layer

Additions $\Delta\lambda$ to thermal conductivity to account for fasteners depend on the number of fasteners per square metre (m^2) and on the geometry. The total addition is calculated by:

$$\Delta\lambda = n\,\Delta\lambda_i \tag{6}$$

where $\Delta\lambda_i$ is the additional conductivity due to fastener i ($i = 1 \ldots n$).

For steel fasteners, diameter 4 mm, 9 fasteners/m^2: $\Delta\lambda = 0{,}006$ W(m·K).

For austenitic steel fasteners, diameter 4 mm, 9 fasteners/m^2: $\Delta\lambda = 0{,}004$ W(m·K).

Annex A
(normative)

Conversion factors

A.1 Conversion factors for the influence of the non-linearity of the thermal conductivity versus temperature curve

When not using directly integrated values for the thermal conductivity or calculation based on a polynomial expression of the thermal conductivity, the influence of the non-linearity of the thermal conductivity versus temperature curve for insulation materials shall be taken into account by using the temperature difference conversion factor $F_{\Delta\theta}$ given in Table A.1.

Table A.1 — Temperature difference conversion factor $F_{\Delta\theta}$

Product type	Apparent density kg/m^3	Temperature difference[a] K		
		100	250	450
Stone wool				
mat	50 to 70	1,04	1,08	1,12
board	80 to 120	1,02	1,05	1,1
	130 to 150	1,0	1,02	1,05
	> 160	1,0	1,0	1,02
lamella mat	30 to 40	1,02	1,10	1,15
	50 to 60	1,01	1,08	1,12
Glass wool				
mat	30 to 45	1,03	1,06	1,10
board	50 to 75	1,01	1,04	1,07
lamella mat	30	1,0	1,08	—
Calcium-magnesium silicate				
mat	80 to 110	1,02	1,06	1,10
board				
Cellular glass	120 to 200	1,02	1,04	1,06
Perlite	60 to 80	1,01	1,02	1,05
Calcium silicate	100 to 200	1,01	1,02	1,05
Microporous insulation	300	1,0	1,01	1,02
In the case of a linear curve, $F_{\Delta\theta} = 1$. In the case of a curve of thermal conductivity as a function of temperature presenting an inflexion point, the integrated value shall be used.				
[a] Linear interpolation may be used.				

A.2 Conversion factor for moisture

The conversion coefficient for moisture is given in Table A.2 for the range of moisture content in column 2. It corresponds to the moisture which stays in the products.

The effect of mass transfer by liquid water and water vapour is not covered by these data.

Table A.2 — Conversion coefficients for moisture

Product type	Moisture content ψ m^3/m^3	Conversion coefficient f_ψ m^3/m^3
Mineral wool	< 0,15	4
Expanded polystyrene	< 0,10	4
Extruded polystyrene	< 0,10	2,5
Flexible elastomeric foam	< 0,15	3,5
Polyurethane foam	< 0,15	6
Phenolic foam	< 0,15	5
PVC foam	< 0,1	8
Cork	< 0,1	6,0
Cellular glass	0,0	0,00
Rigid boards of perlite, fibres and binders	0 to 0,04	0,8

Some of the conversion coefficients given in Table A.2 are taken from ISO 10456:2007. They are valid in the temperature range 0 °C to 30 °C. They shall be rechecked when used for other temperatures, taking into consideration that water turns to ice below 0 °C. No moisture conversion factor shall be used when the insulation reference temperature exceeds 100 °C.

A.3 Conversion factor for compression

For flat products, the compression ratio is given for flat applications by:

$$C = \frac{d_1}{d_2} \tag{A.1}$$

where

d_1 is the nominal thickness;

d_2 is the compressed thickness.

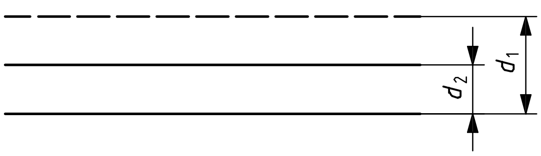


Figure A.1 — Compression of flat products

For compressible flat products used as pipe insulation, the compression ratio is given by:

$$C = \frac{D + 2d}{D + d} \tag{A.2}$$

where

d is the layer thickness;

D is the internal diameter of the layer.

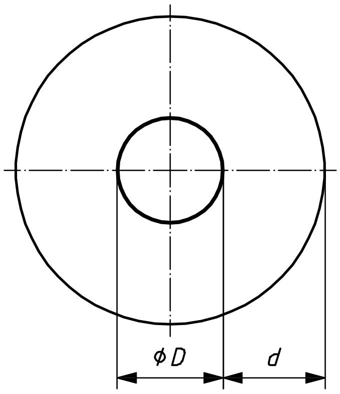


Figure A.2 — Compression of pipe insulation

The factor F_C (e.g. mineral wool) shall be determined by:

$$F_C = 1 - 10^{-6}\left[a_C\ \theta_m - 5(\rho - 50)\right]\rho(C - 1) \tag{A.3}$$

where

a_C is given in Table A.3 as a function of density;

ρ is the apparent density of the insulation product;

θ_m is the mean temperature;

C is the compression ratio given by Equation (A.1) or (A.2).

Table A.3 — Coefficient a_C for mineral wool in the temperature range 50 °C **to** 600 °C

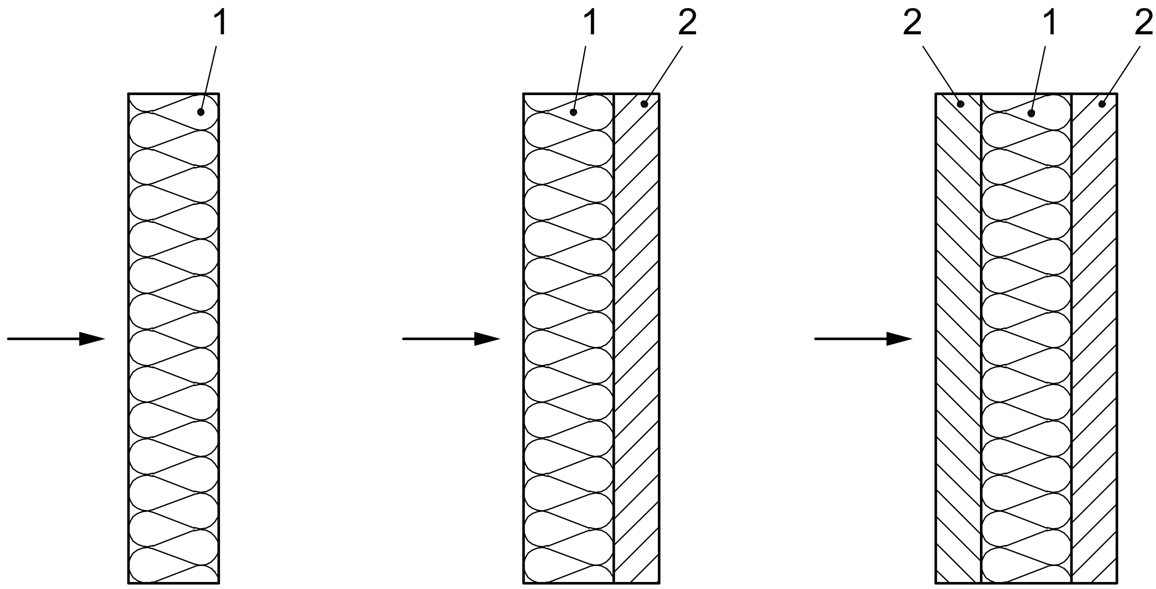
Apparent density ρ kg/m³	**Coefficient** a_C m³/(kg·K)
30	55
45	35
60	20
80	11
100	9
150	5

A.4 Conversion factor for convection in the material

A.4.1 Introduction

For vertical layers made of air permeable materials, for instance mineral wool, the convection shall be evaluated by the following method. If the airflow resistivity measured according to ISO 9053 is greater than 50 kPa·s/m^2, the influence of convection is negligible in most applications.

Depending on the installation procedure, three different cases can be identified (see Figure A.3).



a) Insulation filling the whole space

b) Air space on one side of the insulation

c) Air space on both sides of the insulation

Key

1 insulation

2 air gap

Figure A.3 — Different types of insulation systems (build-ups)

Based on computer calculations and experimental work, equations and charts have been developed to calculate the value of F_c.

The inputs are:

— the insulation thickness, d, in metres;

— the total thickness, including the possible inside air gap, the insulation and the possible outside air gap, d_g, in metres;

— the average temperature of the insulation, in °C;

— the temperature difference between the limiting surfaces of the system, in K;

— the thermal conductivity of the insulation at the average temperature (which is assumed to have the value given in Table A.4);

— the height of the insulation system, H, in metres.

The following parameters are defined:

B_A parameter taking into account the type of insulation system;

B_V parameter taking into account the possible addition of a foil used as convection barrier;

W airflow resistance of the thermal insulation layer, in Pa·s/m, measured according to ISO 9053;

r airflow resistivity of the thermal insulation material, in Pa·s/m^2.

Table A.4 — Parameters in the diagrams used to determine the influence of convection as a function of the flow resistance of the insulation

Curve designation in diagrams	Warm-side temperature °C	Mean temperature °C	Thermal conductivity W/(m·K)
1	180	100	0,050
2	440	230	0,075
3	580	300	0,100

The airflow resistance is given by Equation (A.4):

$$W = r\, d \tag{A.4}$$

and the conversion factor for convection is given by Equation (A.5):

$$F_c = 1 + \frac{(Nu^* - 1)\; 2d}{(1 + B_A + B_V)\; d_g} \tag{A.5}$$

where

Nu^* is the modified Nusselt number given in Figures A.4 to A.6;

B_A is given by Table A.5;

B_V is given by Table A.6.

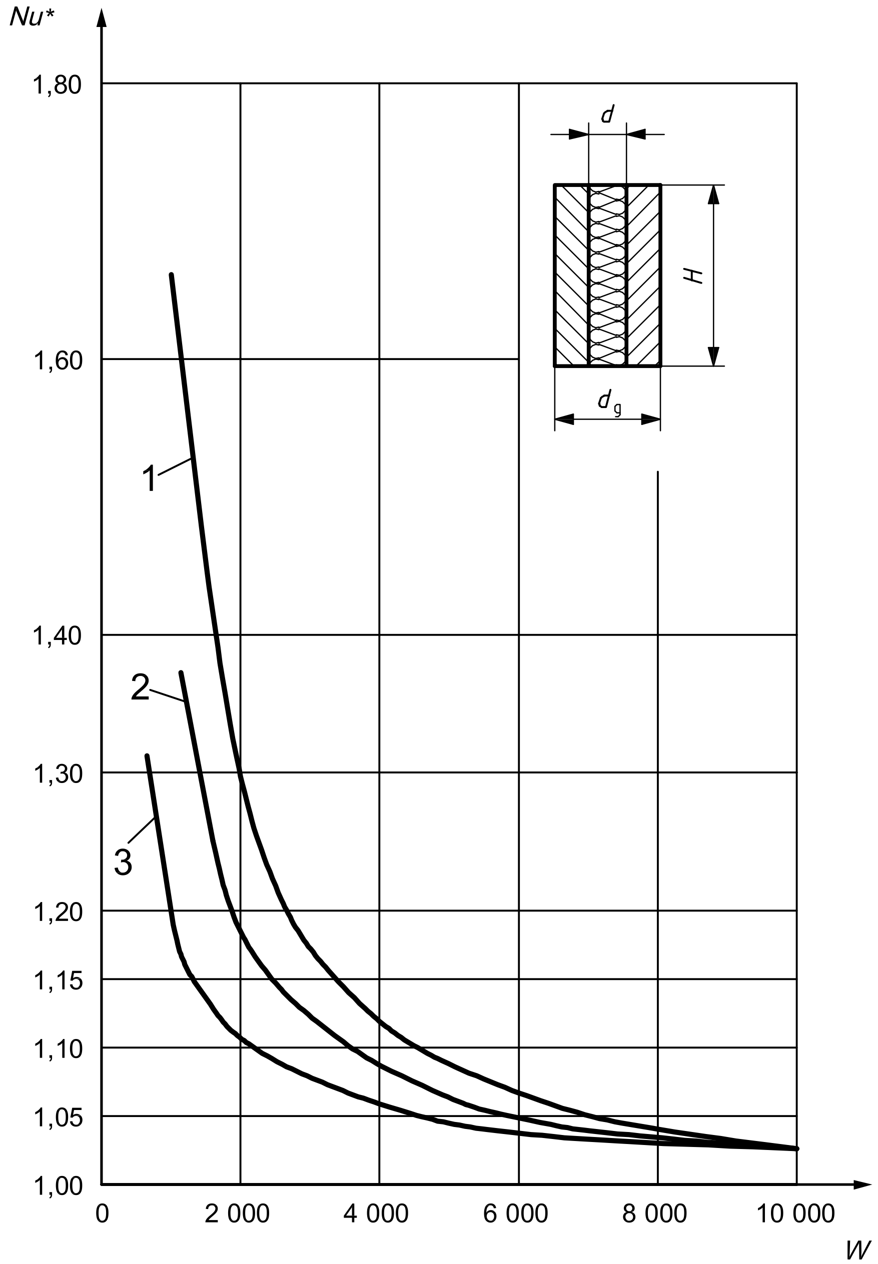


Figure A.4 — Modified Nusselt number for total thickness d_g = 0,20 m of the insulation system

Calculation parameters:

$H/d_g = 10$

d_g = 0,20 m

$d = 0{,}5\ d_g$

$x = W$ in Pa·s/m

$y = Nu^*$

Use curve 1, 2 or 3 according to the temperature conditions as given in Table A.4.

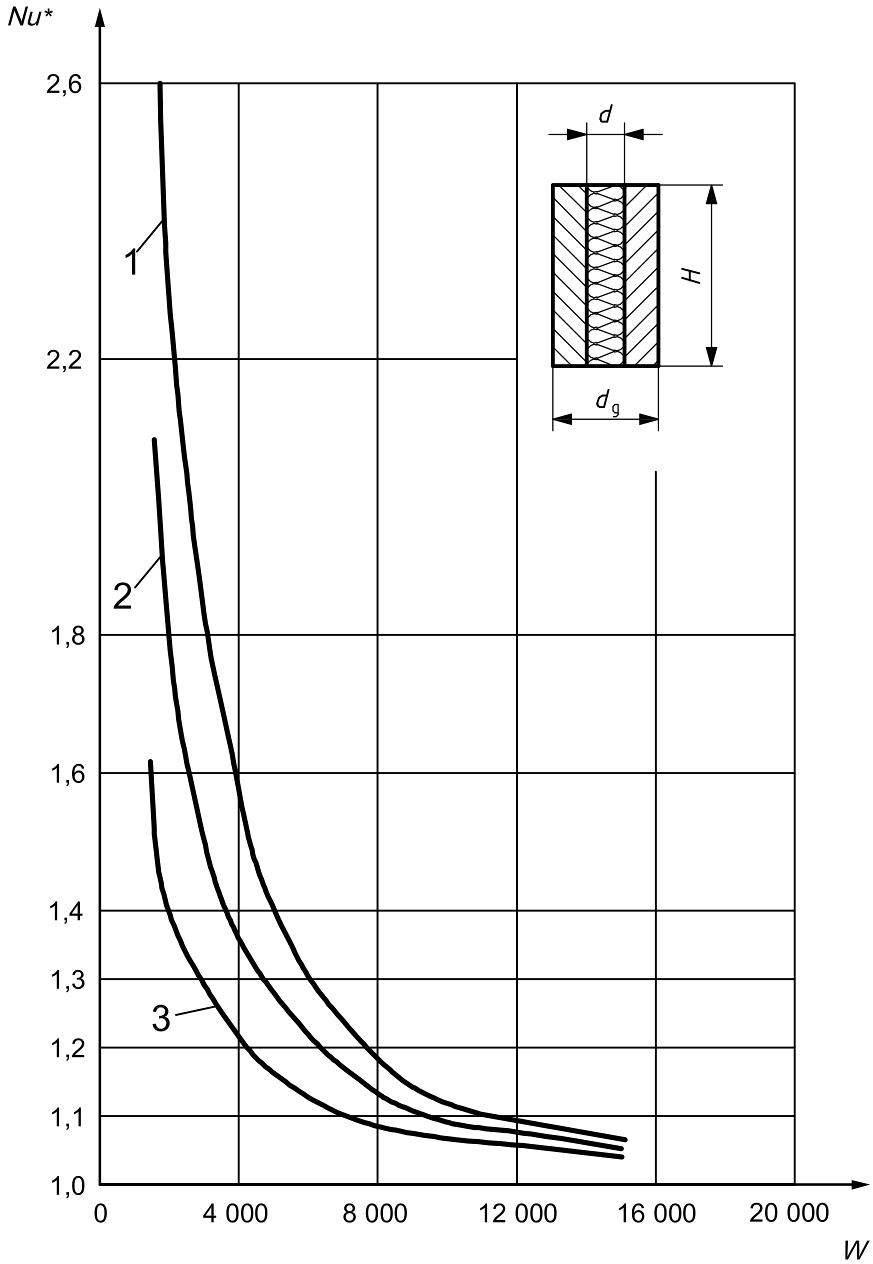


Figure A.5 — Modified Nusselt number for total thickness d_g = 0,30 m **of the insulation system**

Calculation parameters:

$H/d_g = 10$

$d_g =$ 0,30 m

$d =$ 0,5 d_g

$x = W$ in Pa·s/m

$y = Nu^*$

Use curve 1, 2 or 3 according to the temperature conditions as given in Table A.4.

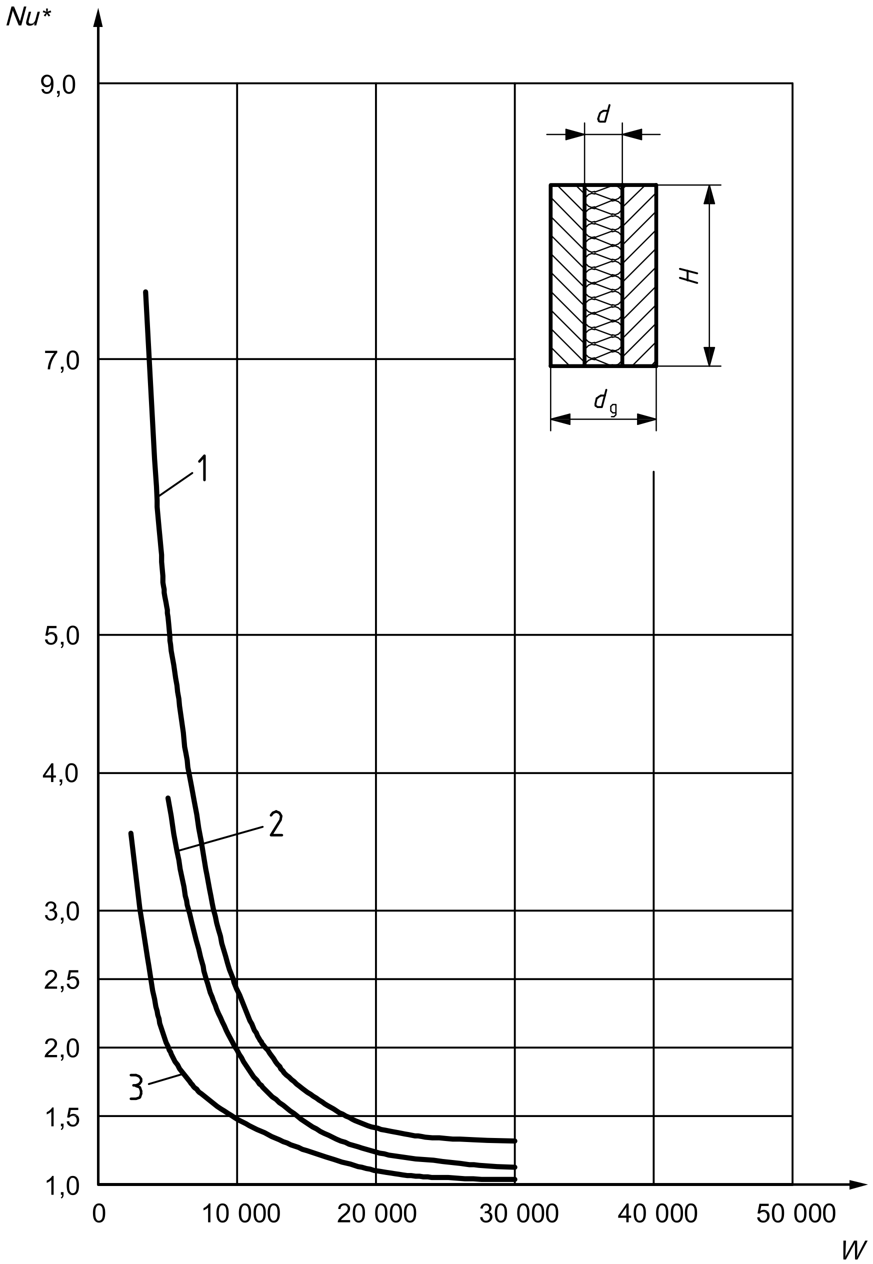


Figure A.6 — Modified Nusselt number for total thickness d_g = 0,60 m of the insulation system

Parameters:

$H/d_g = 10$

d_g = 0,60 m

d = 0,5 d_g

$x = W$, in Pa·s/m

$y = Nu^*$

Use curve 1, 2 or 3 according to the temperature conditions as given in Table A.4.

Table A.5 — Values of parameter B_A for the evaluation of the influence of convection on practical insulation applications

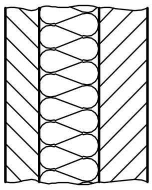
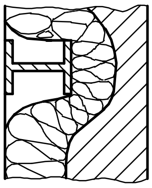
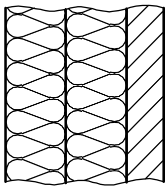
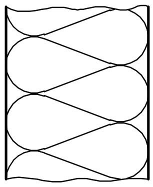
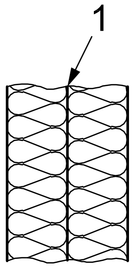
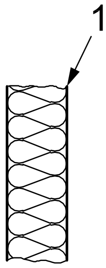
Build-up	Description	Figure	Evaluation coefficient B_A
1	*Dead space* Insulation without covering; both insulation surfaces are adjacent to a hollow space		0
2	*Following contour* Insulation following the contour of the object wall surface with locally limited hollow spaces		1
3	*Air gap* Insulation on the hot or on the cold side close-fitting		2 to 3
4	*Filling the hollow space* Insulation on the hot and cold sides close-fitting		4 to 6

Table A.6 — Values of parameter B_V for the evaluation of possible applications with additional foils

Variant No.	Description	Figure	Evaluation coefficient B_V
1	Foil as convection barrier between the layers		5 to 7
2	Foil on faced insulation or absolutely close-fitting insulation (fully adhered)		9 to 10
3	No foil		0
Key: 1 Foil			

A.4.2 Calculation of the conversion factor for convection

A.4.2.1 General

The airflow resistance of the insulation layer W shall be calculated on the basis of its airflow resistivity and thickness, using Equation (A.4).

One of the Figures A.4, A.5 or A.6 shall be chosen on the basis of the total system insulation thickness, d_g.

Based on the airflow resistance value W (horizontal axis) and the reference mean temperature curve corresponding to the warm-side and reference mean temperatures, the modified Nusselt number Nu^* shall be read from the relevant figure. If the input data are between two diagrams, interpolation shall be used.

Knowing the insulation system and the possible existence of a barrier to air movement, e.g. foil, the values of B_A shall be taken from Table A.5 and the value of B_V from Table A.6.

Using these input data, the value of F_c shall be calculated using Equation (A.5).

A.4.2.2 Example of calculation without air barrier

A vertical layer of mineral wool having the thermal conductivity given in Table A.4 has a thickness of 0,1 m. It is included in a system with an inside and an outside air gap having a total thickness of 0,2 m. The height of the system is 2 m.

The air resistivity of the mineral wool r is 20 000 Pa·s/m^2.

The reference mean temperature in the insulation layer is 300 °C, the warm side being at 580 °C and the cold side at 20 °C.

There is no air barrier.

The symbols and choice of table and chart read as follows:

$d = 0{,}10$ m

$d_g = 0{,}20$ m

$H = 2$ m

$r = 20\,000$ Pa·s/m^2

Equation (A.4) gives:

$$W = r\,d = 20\,000 \times 0{,}10 = 2\,000 \text{ Pa·s/m}$$

In Figure A.4, using $W = 2\,000$ Pa·s/m and curve 3, the resulting modified Nusselt number is 1,11.

Table A.5 gives $B_A = 0$ and Table A.6 gives $B_V = 0$.

Equation (A.5) gives:

$$F_c = 1 + \frac{(1{,}11 - 1) \times 2 \times 0{,}10}{(1 + 0 + 0) \times 0{,}20} = 1 + 0{,}11 = 1{,}11$$

A.4.2.3 Example of calculation with air barrier

Using the same inputs but applying a foil as air barrier directly on the insulation layer, a similar calculation can be carried out with $B_V = 9$ according to Table A.6.

Equation (A.5) gives:

$$F_c = 1 + \frac{(1{,}11 - 1) \times 2 \times 0{,}10}{(1 + 0 + 9) \times 0{,}20} = 1 + 0{,}011 = 1{,}01$$

A.4.2.4 Another example of calculation without air barrier

The following example illustrates the influence of thickness and height of the insulation.

Inputs:

$d = 0{,}20$ m

$d_g = 0{,}30$ m

$H = 3$ m

$r = 20\ 000$ Pa·s/m^2

Equation (A.4) gives:

$W = r\, d = 20\ 000 \times 0{,}2 = 4\ 000$ Pa·s/m

Figure A.5, using $W = 4\ 000$ Pa·s/m and curve 3, the resulting modified Nusselt number is 1,2.

Table A.5 gives $B_A = 0$ and Table A.6 gives $B_V = 0$.

Equation (A.5) gives:

$$F_c = 1 + \frac{(1{,}2 - 1) \times 2 \times 0{,}20}{(1 + 0 + 0) \times 0{,}30} = 1 + 0{,}267 = 1{,}267$$

A.4.2.5 Another example of calculation with air barrier

To illustrate the strong influence of applying a foil as air barrier, the same calculation gives with $B_V = 10$, according to Table A.6:

$$F_c = 1 + \frac{(1{,}2 - 1) \times 2 \times 0{,}20}{(1 + 0 + 10) \times 0{,}30} = 1 + 0{,}024 = 1{,}024$$

A.5 Thickness conversion factor

$$F_d = \frac{d_2}{d_1 + f_d (d_2 - d_1)} \quad \text{(A.6)}$$

where

d_1 is the thickness for which the thermal conductivity has been determined;

d_2 is the thickness of the insulating layer in design conditions;

f_d is the coefficient according to Table A.7.

Table A.7 — Thickness conversion coefficients f_d for insulation materials permeable to infrared radiation (temperature range from 20 °C to 60 °C)

Density[a] ρ kg/m³	**Thickness** d_1 mm				
	20	40	60	80	100
20	0,92	0,93	0,94	0,96	0,98
40	0,93	0,94	0,96	0,98	0,99
60	0,94	0,96	0,98	0,99	0,99
80	0,96	0,98	0,99	0,99	1,0
100	0,98	0,99	0,99	1,0	1,0
120	0,99	0,99	1,0	1,0	1,0

[a] These thickness conversion coefficients apply to the indicated density range of mineral wool and insulating materials with fine pores or cells only. Materials with rough pores e.g. perlite or other poring are still permeable to infrared radiation even at higher densities.

A.6 Conversion factor for regular joint opening

The influence of regular joint openings due to the effect of different thermal expansions of the insulation and the support (steel) shall be taken into account by the following factors:

for single layer of insulation: $F_j = 1{,}10$

for double layers of insulation: $F_j = 1{,}05$

for three or more layers of insulation: $F_j = 1{,}00$

Applying these conversion factors is on the safe side.

Annex B
(informative)

Examples of determination of the design thermal conductivity

EXAMPLE Three insulation materials with different thermal conductivities for the same application.

Insulation product No. 1: Mineral wool wired mat

Density ρ: 80 kg/m^3

Table B.1 — Declared thermal conductivity based on measurements with guarded hot plate apparatus according to EN 12667 or ISO 8302 for a thickness of 50 mm

Temperature, in °C	50	100	150	200	250	300	400	500
Thermal conductivity, in W/(m·K)	0,038	0,045	0,053	0,062	0,075	0,090	0,125	0,16

Insulation product No. 2: Mineral wool lamella mat

Density ρ: 60 kg/m^3

Table B.2 — Declared thermal conductivity based on measurementswith guarded hot plate apparatus according to EN 12667 or ISO 8302 for a thickness of 60 mm

Temperature, in °C	50	100	150	200	250	300	400	500
Thermal conductivity, in W/(m·K)	0,043	0,053	0,064	0,079	0,098	0,116	0,168	0,238

Insulation product No. 3: Mineral wool pipe section

Density ρ: 90 kg/m^3

Table B.3 — Declared thermal conductivity based on measurementswith test-pipe method according to ISO 8497 for a thickness of 100 mm

Temperature, in °C	50	100	150	200	250	300
Thermal conductivity, in W/(m·K)	0,036	0,044	0,054	0,066	0,080	0,097

Application: Insulation of a pipe with a diameter D_I of 108 mm

Operating temperature θ_I: 260 °C

Ambient temperature θ_a: 20 °C

Construction of the insulation:

Number of layers: one

Thickness: 100 mm

Table B.4 — Insulation with or without spacer

Spacer for insulation material		
Metal mesh blanket	Lamella mats	Pipe section
Yes	No	No

Cladding: galvanized sheet metal

Determination of the conversion factors and $\Delta\lambda$

a) Determination of the reference mean temperature of the insulation:

Estimated surface temperature $\theta_s = 40$ °C

Mean temperature $\theta_m = \frac{\theta_i + \theta_s}{2} = \frac{260 + 40}{2} = 150$ °C

b) Determination of parameters for calculating conversion factors:

$F_{\Delta\theta}$: temperature difference $\Delta\theta = 260 - 40 = 220$ K

F_m: no moisture conversion required $u_2 = u_1$

F_a: no aging conversion required

F_C: compression ratio $C_p = \frac{D + 2d}{D + d} = \frac{108 + 200}{108 + 100} = 1{,}48$

F_c: no convection conversion required

F_d: coefficient f_d for thickness conversion factor according to Table A.7:

metal wired mesh: $f_d = 0{,}985$

lamella mat: $f_d = 0{,}98$

pipe section: $f_d = 1{,}0$

F_j: according to Table B.5 for one layer insulation material

Table B.5 — Conversion factors for the application

Insulation material	Conversion factors						
	$F_{\Delta\theta}$	F_m	F_a	F_C	F_c	F_d	F_j	F
Wired mat	1,05	1,0	1,0	0,94	1,0	1,01	1,1	1,10
Lamella mat	1,08	1,0	1,0	0,90	1,0	1,01	1,1	1,08
Pipe section	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0

c) $\Delta\lambda$ = 0,010 W/(m·K) for increase in the thermal conductivity due to spacers according to 7.9 for wired mat.

Declared thermal conductivity λ_d at 150 °C mean temperature according to Tables B.1, B.2 and B.3:

wired mat: 0,053 W/(m·K)

lamella mat: 0,064 W/(m·K)

pipe section: 0,054 W/(m·K)

Table B.6 shows the results of the examples given above.

Table B.6 — Design thermal conductivity for the insulation

Insulation product	Design thermal conductivity λ
Wired mat	$\lambda = 0{,}053 \times 1{,}10 + 0{,}010 = 0{,}0683$ W/(m·K)
Lamella mat	$\lambda = 0{,}064 \times 1{,}08 + 0 = 0{,}0691$ W/(m·K)
Pipe section	$\lambda = 0{,}054 \times 1{,}0 + 0 = 0{,}054$ W/(m·K)

Annex C
(informative)

Approximate values of conversion factors

Table C.1 gives values of the overall conversion factor F for a number of common situations. These values can be used when it is not necessary to have detailed design data for building equipment or industrial installations. The application of these values can be agreed upon between the parties involved or they can be recommended at national level.

Table C.1 — Approximate values of the overall conversion factor F

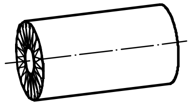
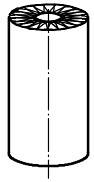
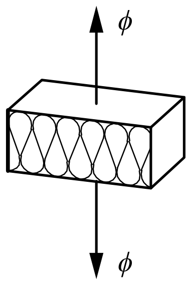
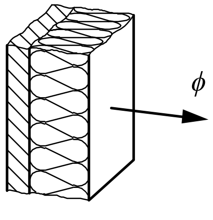
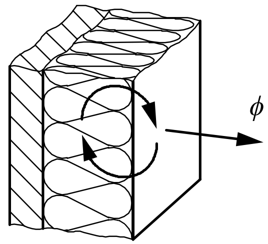
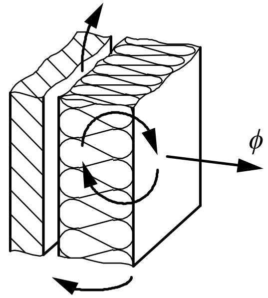
	Pipe horizontal/vertical			Wall horizontal/vertical, cavity filling without air gap or with vertical convection barrier [i]			Wall vertical; air gap in one side, no convection barrier [i]			Wall vertical without convection barrier [i]; unavoidable air gap on the warm side		
Application **Insulant** **Form of supply**												
mineral wool	Insulation											
	ratio $d/D_N = 1$						airflow resistance 30 kPa·s/m²					
	layers	mean temperature		layer	mean temperature		layer	mean temperature		layer	mean temperature	
		50 °C	300 °C		50 °C	300 °C		50 °C	300 °C		50 °C	300 °C
	one [a]	1,10	1,05	one [a]	1,10	1,20	one [a]	1,20	1,25	one [a]	1,80	1,40
	two [b]	—	1,05	two [b]	—	1,15	two [b]	—	1,25	two [b]	—	1,60
	several [c]	—	1,00	several [c]	—	1,10	several [c]	—	1,30	several [c]	—	1,60
	ratio $d/D_N = 0{,}5$						airflow resistance 50 kPa·s/m²					
wired mesh mat	layers	mean temperature					layer	mean temperature		layer	mean temperature	
		50 °C	300 °C					50 °C	300 °C		50 °C	300 °C
board (only plane application)	one [a]	1,10	1,10				one [a]	1,15	1,20	one [a]	1,40	1,30
	two [b]	—	1,10				two [b]	—	1,20	two [b]	—	1,40
	several [c]	—	1,05				several [c]	—	1,20	several [c]	—	1,35
							airflow resistance 70 kPa·s/m²					
							layer	mean temperature		layer	mean temperature	
								50 °C	300 °C		50 °C	300 °C
							one [a]	1,15	1,20	one [a]	1,30	1,30
							two [b]	—	1,20	two [b]	—	1,30
							several [c]	—	1,15	several [c]	—	1,25

Table C.1 (*continued*)

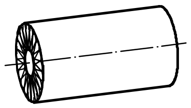
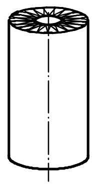
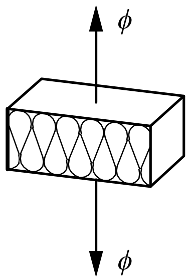
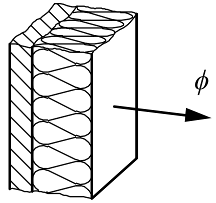
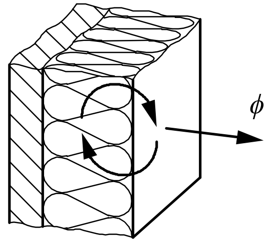
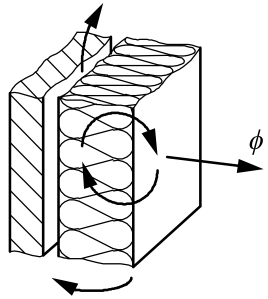
	Pipe horizontal/vertical			**Wall horizontal/vertical, cavity filling without air gap or with vertical convection barrier [i]**			**Wall vertical; air gap in one side, no convection barrier [i]**			**Wall vertical without convection barrier [i]; unavoidable air gap on the warm side**		
Application **Insulant** **Form of supply**												
pipe section	1,00											
lamella mat	ratio $d/D_N = 1$											
	layers	mean temperature			mean temperature							
		50 °C	150 °C		50 °C	150 °C						
	one	1,10	1,10	one [d]	1,10	1,15						
	two	1,05	1,05	two [a]	1,05	1,10						
	ratio $d/D_N = 0,5$											
	layers	mean temperature										
		50 °C	150 °C									
	one	1,10	1,10									
	two	1,05	1,10									
calcium-magnesium-silicate fibre		Insulation										
pipe section and board (only plane application)	1,00						airflow resistance 70 kPa·s/m²					
				layers	mean temperature		layers	mean temperature		layers	mean temperature	
					250 °C	500 °C		50 °C	300 °C		50 °C	300 °C
				one [a]	1,10	1,20	one [a]	1,15	1,20	one [a]	1,30	1,30
				two [b]	1,05	1,15	two [b]	—	1,20	two [b]	—	1,30
				several [c]	1,00	1,10	several [c]	—	1,15	several [c]	—	1,25

Table C.1 (*continued*)

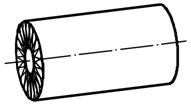
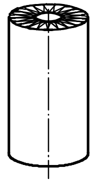
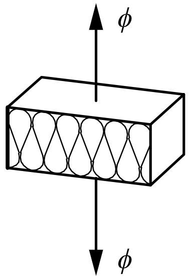
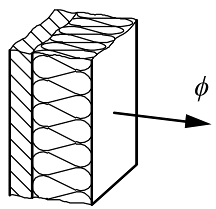
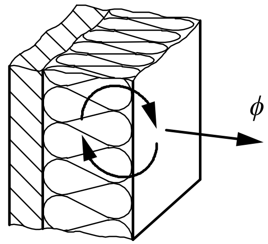
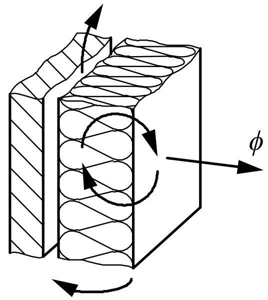
	Pipe horizontal/vertical		Wall horizontal/vertical, cavity filling without air gap or with vertical convection barrier [i]			Wall vertical; air gap in one side, no convection barrier [i]			Wall vertical without convection barrier [i]; unavoidable air gap on the warm side
Application **Insulant** **Form of supply**									
calcium silicate	Insulation								
pipe section and board (only plane application)	1,00		layers	mean temperature		layers	mean temperature		
				250 °C	500 °C		250 °C	500 °C	
			one	1,15	1,20	one [a]	1,10	1,20	
			two	1,05	1,15	two [b]	1,05	1,15	
			several	1,00	1,10	several [c]	1,00	1,10	
microporous insulants	Insulation								
pipe section and board (only plane application) flexible board [h]	1,00		layers	mean temperature		layers	mean temperature		
				250 °C	500 °C		250 °C	500 °C	
			one	1,10	1,15	one	1,10	1,15	
			two	1,05	1,10	two	1,05	1,10	
			several	1,00	1,05	several	1,00	1,05	

Table C.1 (*continued*)

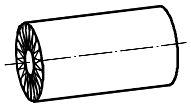
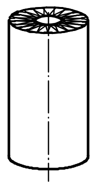
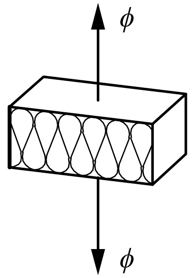
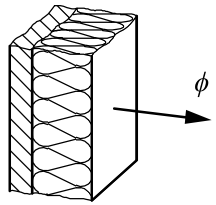
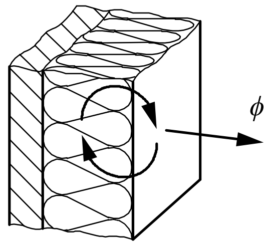
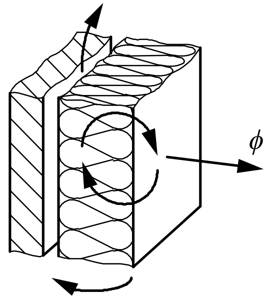
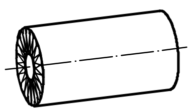
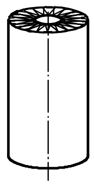
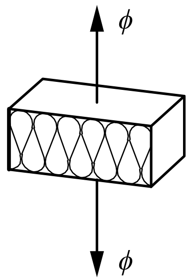
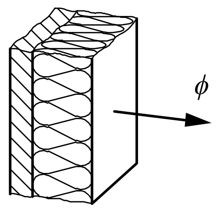
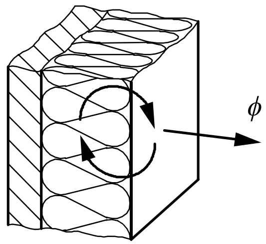
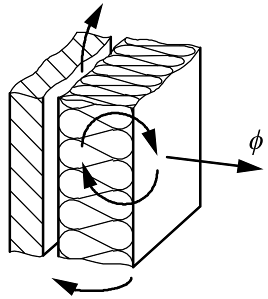
	Pipe horizontal/vertical		Wall horizontal/vertical, cavity filling without air gap or with vertical convection barrier [i]			Wall vertical; air gap in one side, no convection barrier [i]			Wall vertical without convection barrier [i]; unavoidable air gap on the warm side
Application **Insulant** **Form of supply**									
PUR, EPS, XPS	Insulation								
pipe section board	1,00		layers	mean temperature					
				50 °C					
			one	1,10					
			two	1,05					
	cold isolation with vapour retarder [e]								
	1,10								
cellular glass	Warm insulation								
pipe section board	1,00		layers	mean temperature		layers	mean temperature		
				50 °C	250 °C		50 °C	250 °C	
			one	1,10	1,20	one	1,10	1,20	
			two	1,05	1,10	two	1,05	1,10	
	Cold insulation								
	1,00		layers	mean temperature					
				– 100 °C	0 °C				
			one	1,10	1,10				
			two	1,05	1,05				

Table C.1 (*continued*)

Application / Insulant / Form of supply	Pipe horizontal/vertical		Wall horizontal/vertical, cavity filling without air gap or with vertical convection barrier [i]		Wall vertical; air gap in one side, no convection barrier [i]	Wall vertical without convection barrier [i]; unavoidable air gap on the warm side
Application **Insulant** **Form of supply**			 	 	 	

polyethylene — Warm insulation

pipe section, flexible board	Pipe horizontal/vertical	isolation layer thickness/layers [k]	mean temperature 10 °C	mean temperature 40 °C	isolation layer thickness/layers [k]	mean temperature 10 °C	mean temperature 40 °C	
	1,00	10/1	1,10	1,10	10/1	1,10	1,10	
		20/2	1,15	1,15	20/2	1,15	1,15	
		30/3	1,15	1,20	30/3	1,15	1,20	

Cold insulation

g

	d	*μ* 3 000	*μ* 5 000	*μ* 7 000		*d*	*μ* 3 000	*μ* 5 000	*μ* 7 000
life cycle 5 years	13	1,07	1,04	1,03	life cycle 5 years	13	1,03	1,02	1,01
	19	1,04	1,02	1,01		19	1,01	1,01	1,00
	32	1,02	1,00	1,00		32	1,00	1,00	1,00
life cycle 10 years	13	1,17	1,09	1,06	life cycle 10 years	13	1,07	1,04	1,03
	19	1,09	1,05	1,03		19	1,03	1,02	1,01
	32	1,04	1,02	1,02		32	1,01	1,00	1,00

Table C.1 (*continued*)

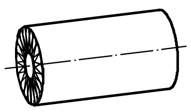
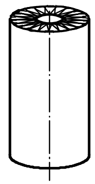
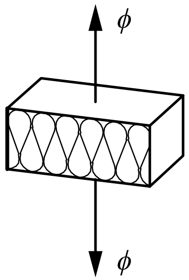
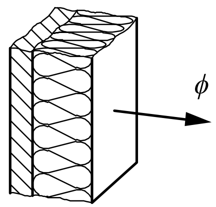
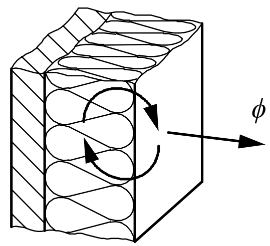
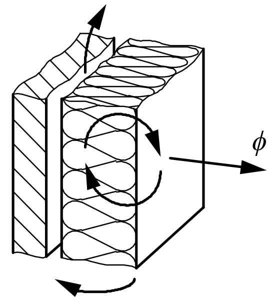
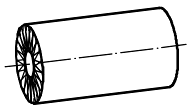
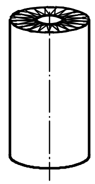
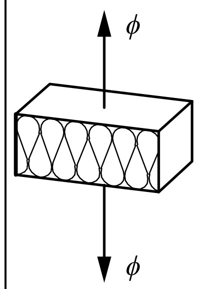
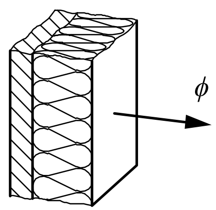
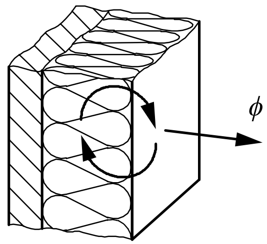
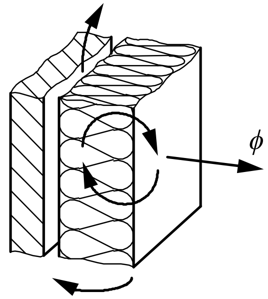
	Pipe horizontal/vertical					**Wall horizontal/vertical, cavity filling without air gap or with vertical convection barrier** [i]					**Wall vertical; air gap in one side, no convection barrier** [i]	**Wall vertical without convection barrier** [i]**; unavoidable air gap on the warm side**
Application **Insulant** **Form of supply**												
flexible elastomeric foam	Warm insulation											
	1,00					1,00						
	Cold insulation											
	g											
		d	*μ*				*d*	*μ*				
			3 000	5 000	7 000			3 000	5 000	7 000		
pipe section flexible board [i]	life cycle 5 year	13	1,07	1,04	1,03	life cycle 5 year	13	1,03	1,02	1,01		
		19	1,04	1,02	1,01		19	1,01	1,01	1,00		
		32	1,02	1,00	1,00		32	1,00	1,00	1,00		
	life cycle 10 yea	13	1,17	1,09	1,06	life cycle 10 yea	13	1,07	1,04	1,03		
		19	1,09	1,05	1,03		19	1,03	1,02	1,01		
		32	1,04	1,02	1,02		32	1,01	1,00	1,00		
PUR in-situ foam	Warm insulation											
	mean temperature 50 °C											
	1,05											
	cold isolation with vapour retarder [e]											
	1,10 [f]											

Table C.1 (*continued*)

	Pipe horizontal/vertical		**Wall horizontal/vertical, cavity filling without air gap or with vertical convection barrier** [i]		**Wall vertical; air gap in one side, no convection barrier** [i]	**Wall vertical without convection barrier** [i]**; unavoidable air gap on the warm side**
Application **Insulant** **Form of supply**						
perlite	Warm insulation					
	layers	mean temperature				
		50 °C		250 °C		
		1,10		1,15		
	Cold insulation with double-skin casing					
	layers	mean temperature				
		− 50 °C		0 °C		
		1,10		1,10		

Symbols: d thickness of the wall of the pipe D_N nominal diameter of pipes → direction of heat flux ϕ heat flux deviation

[a] Equivalent of an insulation layer thickness of 100 mm.
[b] Equivalent of an insulation layer thickness of 200 mm.
[c] Equivalent of an insulation layer thickness of 300 mm.
[d] Equivalent of an insulation layer thickness of 50 mm.
[e] Vapour retarder made of vapour tight materials.
[f] Equals 1,5 to 4 Vol. % moisture in the insulant.
[g] D_N 20 mm, medium temperature 0 °C, ambient conditions 23 °C/50 % RH.
[h] For the application of flexible boards on pipes, the factors for plane applications apply.
[i] With application of air-tight insulation.
[k] Taking account of the “thickness-effect” starting with 10 mm thick polyethylene boards.

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