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Building materials and products — Hygrothermal properties — Tabulated design values and procedures for determining declared and design thermal values

Matériaux et produits pour le bâtiment — Propriétés hygrothermiques — Valeurs utiles tabulées et procédures pour la détermination des valeurs thermiques déclarées et utiles

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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 10456 was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*.

This third edition cancels and replaces the second edition (ISO 10456:1999), which has been technically revised.

The following changes have been made to the second edition:

- the Scope has been extended to include tabulated design values of thermal and moisture properties of materials, and the title has been modified accordingly;
- an Introduction has been added;
- the Scope specifies that moisture coefficients are valid only between 0 °C and 30 °C;
- 4.2 has been added as a new subclause on tests for moisture properties;
- 7.2 has been extended to contain general information about climates;
- 7.4 contains clarification that ageing factors are not applied if taken into account in declared values;
- 7.5 has been added as a new subclause dealing with convection in insulating materials;
- Clause 8 has been added, giving tabulated design values (in Tables 3, 4 and 5); the data, taken from EN 12524, have been reviewed and updated.
- Annex A contains data reviewed for extruded polystyrene (XPS) and polyurethane (PU).

Introduction

This International Standard provides the means (in part) to assess the contribution that building products and services make to energy conservation and to the overall energy performance of buildings.

Heat and moisture transfer calculations require design values of thermal and moisture properties for materials used in building applications.

Design values can be derived from declared values that are based on measured data on the product concerned, which is usually the case for thermal insulation materials. Where the design conditions differ from those of the declared value, the data needs to be converted to the applicable conditions. This International Standard provides the methods and data for making this conversion.

For materials for which measured values are not available, design values can be obtained from tables. This International Standard provides such tabulated information based on the compilation of existing data (see reference documents listed in the Bibliography).

Building materials and products — Hygrothermal properties — Tabulated design values and procedures for determining declared and design thermal values

1 Scope

This International Standard specifies methods for the determination of declared and design thermal values for thermally homogeneous building materials and products, together with procedures to convert values obtained under one set of conditions to those valid for another set of conditions. These procedures are valid for design ambient temperatures between −30 °C and +60 °C.

This International Standard provides conversion coefficients for temperature and for moisture. These coefficients are valid for mean temperatures between 0 °C and 30 °C.

This International Standard also provides design data in tabular form for use in heat and moisture transfer calculations, for thermally homogeneous materials and products commonly used in building construction.

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 8990, *Thermal insulation — Determination of steady-state thermal transmission properties — Calibrated and guarded hot box*

ISO 12572, *Hygrothermal performance of building materials and products — Determination of water vapour transmission properties*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

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

3.1.1
declared thermal value
expected value of a thermal property of a building material or product assessed from measured data at reference conditions of temperature and humidity, given for a stated fraction and confidence level, and corresponding to a reasonable expected service lifetime under normal conditions

3.1.2
design thermal value
design thermal conductivity or design thermal resistance

NOTE A given product can have more than one design value, for different applications or environmental conditions.

3.1.3
design thermal conductivity
value of thermal conductivity of a building 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 component

3.1.4
design thermal resistance
value of thermal resistance of a building product under specific external and internal conditions, which can be considered as typical of the performance of that product when incorporated in a building component

3.1.5
material
piece of a product irrespective of its delivery form, shape and dimensions, without any facing or coating

3.1.6
product
final form of a material ready for use, of given shape and dimensions and including any facings or coatings

3.2 Symbols and units

Symbol	Quantity	Unit
c_p	specific heat capacity at constant pressure	J/(kg·K)
F_a	ageing conversion factor	—
F_m	moisture conversion factor	—
F_T	temperature conversion factor	—
f_T	temperature conversion coefficient	K^{-1}
f_u	moisture conversion coefficient mass by mass [a]	kg/kg
f_ψ	moisture conversion coefficient volume by volume [a]	$\mathrm{m}^3/\mathrm{m}^3$
R	thermal resistance	$\mathrm{m}^2\cdot\mathrm{K/W}$
s_d	water vapour diffusion-equivalent air layer thickness	m
T	thermodynamic temperature	K
u	moisture content mass by mass	kg/kg
λ	thermal conductivity	W/(m·K)
μ	water vapour resistance factor	—
ρ	density	$\mathrm{kg/m}^3$
ψ	moisture content volume by volume	$\mathrm{m}^3/\mathrm{m}^3$

[a] For conversion of thermal properties.

4 Test methods and test conditions

4.1 Tests for thermal properties

4.1.1 Test methods

Measured values of thermal conductivity or thermal resistance shall be obtained using the following methods:

- guarded hot plate, in accordance with ISO 8302 or equivalent national method;
- heat flow meter, in accordance with ISO 8301 or equivalent national method;
- calibrated and guarded hot box, in accordance with ISO 8990.

4.1.2 Test conditions

To avoid conversions, it is recommended that measurements be conducted under conditions corresponding to the selected set of conditions given in Table 1.

The mean test temperature should be chosen so that the application of the temperature coefficients does not introduce a change of more than 2 % from the measured value.

The following testing conditions are required:

- measured thickness and density for identification;
- mean test temperature;
- moisture content of the specimen during test;
- (for aged materials) age of the specimen and conditioning procedures before testing.

4.2 Tests for moisture properties

Measured values of water vapour resistance factor or water vapour diffusion-equivalent air layer thickness shall be obtained using ISO 12572.

5 Determination of declared thermal values

A declared thermal value shall be given under one of the sets of conditions a) or b) in Table 1, with reference temperature **I** (10 °C) or **II** (23 °C).

Table 1 — Declared value conditions

Property	**Sets of conditions**			
	I (10 °C)		**II (23 °C)**	
	a)	**b)**	**a)**	**b)**
Reference temperature	10 °C	10 °C	23 °C	23 °C
Moisture	u_{dry} [a]	$u_{23,50}$ [b]	u_{dry} [a]	$u_{23,50}$ [b]
Ageing	aged	aged	aged	aged

[a] u_{dry} is a low moisture content reached by drying according to specifications or standards for the material concerned.

[b] $u_{23,50}$ is the moisture content when in equilibrium with air at 23 °C and relative humidity of 50 %.

Either the declared value shall be determined at a thickness large enough to neglect the thickness effect, or the declared values for smaller thicknesses shall be based on measurements at those thicknesses.

The data used shall be either

- directly measured values according to the test methods given in Clause 4, or
- obtained indirectly by making use of an established correlation with a related property such as density.

When all data have not been measured under the same set of conditions, they shall first be brought to one set of conditions (see Clause 7). A statistical single value estimate shall then be calculated. Annex C refers to International Standards on statistics that may be used.

During calculations, no value shall be rounded to less than three significant figures.

The declared value is the estimated value of the statistical single value, rounded according to either or both of the following rules:

a) for thermal conductivity, λ, expressed in W/(m·K):
   - if $\lambda \leqslant 0{,}08$: rounding to nearest higher 0,001 W/(m·K);
   - if $0{,}08 < \lambda \leqslant 0{,}20$: rounding to nearest higher 0,005 W/(m·K);
   - if $0{,}20 < \lambda \leqslant 2{,}00$: rounding to nearest higher 0,01 W/(m·K);
   - if $2{,}00 < \lambda$: rounding to nearest higher 0,1 W/(m·K);

b) for thermal resistance, R, expressed in m^2·K/W, as the nearest lower value rounded to not more than two decimals or three significant figures.

Rules for determining declared values for specific products may be specified in applicable product standards.

6 Determination of design thermal values

6.1 General

Design values can be obtained from declared values, measured values or tabulated values (see Clause 8).

Measured data shall be either

- directly measured values in accordance with the test methods given in Clause 4, or
- obtained indirectly by making use of an established correlation with a related property, such as density.

If the set of conditions for declared, measured or tabulated values can be considered relevant for the actual application, those values can be used directly as design values. Otherwise, conversion of data shall be undertaken according to the procedure given in Clause 7.

6.2 Rounding of design values

The design value shall be rounded in accordance with the rules given in Clause 5:

- for thermal conductivity, as the nearest higher value, in W/(m·K);
- for thermal resistance, as the nearest lower value, in m^2·K/W.

6.3 Design values derived from declared values

When the design value is calculated from the declared value and is based on the same statistical evaluation, the declared value shall be converted to the design conditions.

Information is given in Annex C on how to derive design values based on another statistical evaluation different from the one applicable to the declared value.

6.4 Design values derived from measured values

When necessary, all data shall first be converted to the design conditions. A statistical single value estimate shall then be calculated. Annex C refers to International Standards on statistics that can be used.

7 Conversion of thermal values

7.1 General

Conversions of thermal values from one set of conditions (λ_1, R_1) to another set of conditions (λ_2, R_2) are carried out according to the following equations:

$$\lambda_2 = \lambda_1 F_T F_\mathrm{m} F_\mathrm{a} \tag{1}$$

$$R_2 = \frac{R_1}{F_T F_\mathrm{m} F_\mathrm{a}} \tag{2}$$

Conversion coefficients may be taken from the applicable tables in this International Standard. Alternatively, they may be derived from measured data obtained in accordance with the test methods referred to in 4.1, provided that the procedure for determining conversion coefficients other than those in Table 4 are validated by independent test institutes.

7.2 Conversion for temperature

The factor F_T for temperature is determined by

$$F_T = \mathrm{e}^{f_T (T_2 - T_1)} \tag{3}$$

where

f_T is the temperature conversion coefficient;

T_1 is the temperature of the first set of conditions;

T_2 is the temperature of the second set of conditions.

Values of the temperature conversion coefficient for insulation materials and masonry materials are given in Annex A.

NOTE The effect of temperature on the thermal properties of other materials is generally not significant for heat transfer calculations, and can usually be neglected.

Design thermal values should be obtained for the expected mean temperature of the material as installed in the component in the applicable climate.

7.3 Conversion for moisture

The factor F_m for moisture content is determined as follows:

a) conversion of moisture content given as mass by mass:

$$F_m = e^{f_u(u_2 - u_1)} \qquad (4)$$

where

f_u is the moisture conversion coefficient mass by mass;

u_1 is the moisture content mass by mass of the first set of conditions;

u_2 is the moisture content mass by mass of the second set of conditions;

b) conversion of moisture content given as volume by volume:

$$F_m = e^{f_\psi(\psi_2 - \psi_1)} \qquad (5)$$

where

f_ψ is the moisture conversion coefficient volume by volume;

ψ_1 is the moisture content volume by volume of the first set of conditions;

ψ_2 is the moisture content volume by volume of the second set of conditions.

Values of the moisture conversion coefficient for insulation and masonry materials are given in Table 4.

7.4 Age conversion

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. There are no simple rules to correlate ageing over time for a given material.

If the declared thermal value takes account of ageing, no further ageing conversions shall be applied for design thermal values.

If a conversion factor F_a is used, it shall allow 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 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. Procedures for establishing aged values or ageing factors are given in some product standards.

7.5 Natural convection

The onset of natural convection in an insulating material with an open structure depends on permeability, thickness and temperature difference. The driving force for natural convection is described by the modified Rayleigh number, Ra_m, which is a dimensionless number defined for the purposes of this International Standard by

$$Ra_m = 3 \times 10^6 \frac{dk\Delta T}{\lambda} \qquad (6)$$

where

ΔT is the temperature difference across the insulation, in K;

d is the thickness of the insulation, in m;

k is the permeability of the insulation, in m^2;

λ is the thermal conductivity of the insulation without convection, in W/(m·K).

If Ra_m does not exceed the critical value in Table 2, no correction for natural convection shall be made.

NOTE 1 The formal definition of Ra_m is

$$Ra_\mathrm{m} = \frac{g\beta\rho c_p}{\nu} \times \frac{dk\Delta T}{\lambda} \tag{7}$$

where

g is the acceleration due to gravity (9,81 $\mathrm{m/s}^2$);

β is the thermal expansion coefficient for air;

ρ is the density for air;

c_p is the specific heat capacity for air at constant pressure;

ν is the kinematic viscosity for air (equal to dynamic viscosity divided by density).

Equation (6) is obtained by substituting the properties for air at 10 °C given in ISO 10292.

NOTE 2 Permeability is defined for one-dimensional steady-state conditions by the equation:

$$\frac{\Delta P}{d} = \frac{\eta}{k} \times \frac{\dot{V}}{A} \tag{8}$$

where

ΔP is the pressure difference;

η is the dynamic viscosity of air;

$\dot{V}$ is the volumetric air flow rate;

A is the area.

It can be obtained from measurements of the airflow resistivity of the product, r, in accordance with ISO 9053 from

$$k = \frac{\eta}{r} \tag{9}$$

NOTE 3 In cold climates, the risk of convection is greater for a given material because the value of ΔT in Equation (6) is larger.

Table 2 — Critical modified Rayleigh number

Direction of heat flow [a]	Ra_m
Horizontal	2,5
Upwards, open upper surface	15
Upwards, wind-protected upper surface (not air permeable)	30

[a] Use linear interpolation of the modified Rayleigh number for intermediate angles based on cos θ, where horizontal is $\theta = 0$.

At present, there are no commonly accepted procedures to allow for convection in insulating materials. If Ra_m exceeds the critical value in Table 2, detailed analysis or measurements are needed to quantify the effect of convection.

8 Tabulated design hygrothermal values

8.1 General

Tables 3, 4 and 5 give typical design values which are suitable for use in calculations of heat and moisture transfer in the absence of specific information on the product(s) concerned. Where available, manufacturers' certified values should be used in preference to values from the tables.

Table 3 gives design values for thermal conductivity, specific heat capacity and water vapour resistance factor for materials commonly used in building applications. Where a range of values are given for one material depending on density, linear interpolation can be used.

Table 4 gives design values for specific heat capacity and information on moisture content, moisture conversion coefficients and water vapour resistance factors for insulation materials and masonry materials. The moisture content of materials and products are given in equilibrium with air at 23 °C and relative humidity of 50 % and 80 %. The ranges of density and moisture content shown in Table 4 indicate the range of applicability of the data.

Table 5 gives the water vapour diffusion-equivalent air layer thickness for thin layers.

NOTE EN 1745 gives information on the thermal conductivity of masonry units in the dry state.

8.2 Design thermal values

Design thermal values for insulation and masonry materials should be converted to the applicable design conditions using the conversion coefficients in Annex A and Table 4 respectively.

The data on moisture contents in Table 4 (at 23 °C and relative humidity of 50 % and 80 %) are indicative of the equilibrium moisture content of the materials concerned in typical building applications. They are not applicable to situations of high moisture, as can be the case below ground, for example. Data on equilibrium moisture content for specific applications may be provided in national tables.

8.3 Design moisture values

Tables 3 and 4 give values of the water vapour resistance factor for “dry cup” and “wet cup” conditions (as defined in ISO 12572).

At low ambient relative humidities, water vapour is transported through porous materials predominantly by vapour diffusion. As the relative humidity rises, the pores start to fill with liquid water and liquid flow becomes an increasingly important transport mechanism. The apparent vapour resistance therefore falls with increasing relative humidity. This effect is summarized by the dry cup values, which apply when the mean relative humidity across a material is less than 70 %, and the wet cup values that apply when the mean relative humidity is greater than or equal to 70 %. For heated buildings, the dry cup values are generally applicable to materials on the inside of an insulation layer, and wet cup values to those on the outside of an insulation layer. If a specific insulation layer (e.g. monolithic masonry walls) is not present, dry cup values apply when the component is wetting from a dry state, and wet cup values apply when it is drying from a wet state.

Table 3 — Design thermal values for materials in general building applications

Material group or application		Density ρ kg/m^3	Design thermal conductivity λ W/(m·K)	Specific heat capacity c_p J/(kg·K)	Water vapour resistance factor μ	
					dry	wet
Asphalt		2 100	0,70	1 000	50 000	50 000
Bitumen	Pure	1 050	0,17	1 000	50 000	50 000
	Felt/sheet	1 100	0,23	1 000	50 000	50 000
Concrete [a]	Medium density	1 800	1,15	1 000	100	60
		2 000	1,35	1 000	100	60
		2 200	1,65	1 000	120	70
	High density	2 400	2,00	1 000	130	80
	Reinforced (with 1 % of steel)	2 300	2,3	1 000	130	80
	Reinforced (with 2 % of steel)	2 400	2,5	1 000	130	80
Floor coverings	Rubber	1 200	0,17	1 400	10 000	10 000
	Plastic	1 700	0,25	1 400	10 000	10 000
	Underlay, cellular rubber or plastic	270	0,10	1 400	10 000	10 000
	Underlay, felt	120	0,05	1 300	20	15
	Underlay, wool	200	0,06	1 300	20	15
	Underlay, cork	< 200	0,05	1 500	20	10
	Tiles, cork	> 400	0,065	1 500	40	20
	Carpet / textile flooring	200	0,06	1 300	5	5
	Linoleum	1 200	0,17	1 400	1 000	800
Gases	Air	1,23	0,025	1 008	1	1
	Carbon dioxide	1,95	0,014	820	1	1
	Argon	1,70	0,017	519	1	1
	Sulphur hexafluoride	6,36	0,013	614	1	1
	Krypton	3,56	0,009 0	245	1	1
	Xenon	5,68	0,005 4	160	1	1
Glass	Soda lime glass (including “float glass”)	2 500	1,00	750	∞	∞
	Quartz glass	2 200	1,40	750	∞	∞
	Glass mosaic	2 000	1,20	750	∞	∞
Water	Ice at −10 °C	920	2,30	2 000	—	—
	Ice at 0 °C	900	2,20	2 000	—	—
	Snow, freshly fallen (< 30 mm)	100	0,05	2 000	—	—
	Snow, soft (30 to 70 mm)	200	0,12	2 000	—	—
	Snow, slightly compacted (70 to 100 mm)	300	0,23	2 000	—	—
	Snow, compacted (< 200 mm)	500	0,60	2 000	—	—
	Water at 10 °C	1 000	0,60	4 190	—	—
	Water at 40 °C	990	0,63	4 190	—	—
	Water at 80 °C	970	0,67	4 190	—	—
Metals	Aluminium alloys	2 800	160	880	∞	∞
	Bronze	8 700	65	380	∞	∞
	Brass	8 400	120	380	∞	∞
	Copper	8 900	380	380	∞	∞
	Iron, cast	7 500	50	450	∞	∞
	Lead	11 300	35	130	∞	∞
	Steel	7 800	50	450	∞	∞
	Stainless steel [b], austenitic or austenitic-ferritic	7 900	17	500	∞	∞
	Stainless steel [b], ferritic or martensitic	7 900	30	460	∞	∞
	Zinc	7 200	110	380	∞	∞

Table 3 (*continued*)

Material group or application		Density	Design thermal conduct-ivity	Specific heat capacity	Water vapour resistance factor	
		ρ kg/m^3	λ W/(m·K)	c_p J/(kg·K)	μ	
					dry	wet
Plastics, solid	Acrylic	1 050	0,20	1 500	10 000	10 000
	Polycarbonates	1 200	0,20	1 200	5 000	5 000
	Polytetrafluoroethylene (PTFE)	2 200	0,25	1 000	10 000	10 000
	Polyvinylchloride (PVC)	1 390	0,17	900	50 000	50 000
	Polymethylmethacrylate (PMMA)	1 180	0,18	1 500	50 000	50 000
	Polyacetate	1 410	0,30	1 400	100 000	100 000
	Polyamide (nylon)	1 150	0,25	1 600	50 000	50 00
	Polyamide 6.6 with 25 % glass fibre	1 450	0,30	1 600	50 000	50 000
	Polyethylene/polythene, high density	980	0,50	1 800	100 000	100 000
	Polyethylene/polythene, low density	920	0,33	2 200	100 000	100 000
	Polystyrene	1 050	0,16	1 300	100 000	100 000
	Polypropylene	910	0,22	1 800	10 000	10 000
	Polypropylene with 25 % glass fibre	1 200	0,25	1 800	10 000	10 000
	Polyurethane (PU)	1 200	0,25	1 800	6 000	6 000
	Epoxy resin	1 200	0,20	1 400	10 000	10 000
	Phenolic resin	1 300	0,30	1 700	100 000	100 000
	Polyester resin	1 400	0,19	1 200	10 000	10 000
Rubber	Natural	910	0,13	1 100	10 000	10 000
	Neoprene (polychloroprene)	1 240	0,23	2 140	10 000	10 000
	Butyl, (isobutene), solid/hot melt	1200	0,24	1 400	200 000	200 000
	Foam rubber	60 – 80	0,06	1 500	7 000	7 000
	Hard rubber (ebonite), solid	1 200	0,17	1 400	∞	∞
	Ethylene propylene diene monomer (EPDM)	1 150	0,25	1 000	6 000	6 000
	Polyisobutylene	930	0,20	1 100	10 000	10 000
	Polysulfide	1 700	0,40	1 000	10 000	10 000
	Butadiene	980	0,25	1 000	100 000	100 000
Sealant materials, weather stripping and thermal breaks	Silica gel (desiccant)	720	0,13	1 000	∞	∞
	Silicone, pure	1 200	0,35	1 000	5 000	5 000
	Silicone, filled	1 450	0,50	1 000	5 000	5 000
	Silicone foam	750	0,12	1 000	10 000	10 000
	Urethane/polyurethane (thermal break)	1 300	0,21	1 800	60	60
	Polyvinylchloride (PVC), flexible, with 40 % softener	1 200	0,14	1 000	100 000	100 000
	Elastomeric foam, flexible	60 – 80	0,05	1 500	10 000	10 000
	Polyurethane (PU) foam	70	0,05	1 500	60	60
	Polyethylene foam	70	0,05	2 300	100	100
Gypsum	Gypsum	600	0,18	1 000	10	4
	”	900	0,30	1 000	10	4
	”	1 200	0,43	1 000	10	4
	”	1 500	0,56	1 000	10	4
	Gypsum plasterboard [c]	700	0,21	1 000	10	4
	”	900	0,25	1 000	10	4
Plasters and renders	Gypsum insulating plaster	600	0,18	1 000	10	6
	Gypsum plastering	1 000	0,40	1 000	10	6
	”	1 300	0,57	1 000	10	6
	Gypsum, sand	1 600	0,80	1 000	10	6
	Lime, sand	1 600	0,80	1 000	10	6
	Cement, sand	1 800	1,00	1 000	10	6
Soils	Clay or silt	1 200 – 1 800	1,5	1 670 – 2 500	50	50
	Sand and gravel	1 700 – 2 200	2,0	910 – 1 180	50	50

Table 3 (*continued*)

Material group or application		Density ρ kg/m^3	Design thermal conductivity λ W/(m·K)	Specific heat capacity c_p J/(kg·K)	Water vapour resistance factor μ	
					dry	wet
Stone	Natural, crystalline rock	2 800	3,5	1 000	10 000	10 000
	Natural, sedimentary rock	2 600	2,3	1 000	250	200
	Natural, sedimentary rock, light	1 500	0,85	1 000	30	20
	Natural, porous, e.g. lava	1 600	0,55	1 000	20	15
	Basalt	2 700 – 3 000	3,5	1 000	10 000	10 000
	Gneiss	2 400 – 2 700	3,5	1 000	10 000	10 000
	Granite	2 500 – 2 700	2,8	1 000	10 000	10 000
	Marble	2 800	3,5	1 000	10 000	10 000
	Slate	2 000 – 2 800	2,2	1 000	1000	800
	Limestone, extra soft	1 600	0,85	1 000	30	20
	Limestone, soft	1 800	1,1	1 000	40	25
	Limestone, semi-hard	2 000	1,4	1 000	50	40
	Limestone, hard	2 200	1,7	1 000	200	150
	Limestone, extra hard	2 600	2,3	1 000	250	200
	Sandstone (silica)	2 600	2,3	1 000	40	30
	Natural pumice	400	0,12	1 000	8	6
	Artificial stone	1 750	1,3	1 000	50	40
Tiles (roofing)	Clay	2 000	1,0	800	40	30
	Concrete	2 100	1,5	1 000	100	60
Tiles (other)	Ceramic/porcelain	2 300	1,3	840		∞
	Plastic	1 000	0,20	1 000	10 000	10 000
Timber [d]		450	0,12	1 600	50	20
		500	0,13	1 600	50	20
		700	0,18	1 600	200	50
Wood-based panels [d]	Plywood [e]	300	0,09	1 600	150	50
		500	0,13	1 600	200	70
		700	0,17	1 600	220	90
		1 000	0,24	1 600	250	110
	Cement-bonded particleboard	1 200	0,23	1 500	50	30
	Particleboard	300	0,10	1 700	50	10
		600	0,14	1 700	50	15
		900	0,18	1 700	50	20
	Oriented strand board (OSB)	650	0,13	1 700	50	30
	Fibreboard, including MDF [f]	250	0,07	1 700	5	3
	”	400	0,10	1 700	10	5
	”	600	0,14	1 700	20	12
	”	800	0,18	1 700	30	20

NOTE 1 For computational purposes the ∞ value may have to be replaced with an arbitrarily large value, e.g. 106.

NOTE 2 Water vapour resistance factors are given as dry cup and wet cup values, see 8.3.

[a] The density for concrete is the dry density.

[b] EN 10088-1 contains extensive lists of properties of stainless steels which may be used when the precise composition of the stainless steel is known.

[c] The thermal conductivity includes the effect of the paper liners.

[d] The density for timber and wood-based products is the density in equilibrium with 20 °C and 65 % relative humidity, including the mass of hygroscopic water.

[e] As an interim measure and until sufficient significant data for solid wood panels (SWP) and laminated veneer lumber (LVL) are available, the values given for plywood may be used.

[f] MDF: Medium density fibreboard, dry process.

Table 4 — Moisture properties and specific heat capacity of thermal insulation materials and masonry materials

Material	Density	Moisture content at 23 °C, 50 % RH [a]		Moisture content at 23 °C, 80 % RH [a]		Moisture conversion coefficient [b]				Water vapour resistance factor μ		Specific heat capacity
	ρ kg/m^3	u kg/kg	ψ m^3/m^3	u kg/kg	ψ m^3/m^3	Moisture content u kg/kg	f_u	Moisture content ψ m^3/m^3	f_ψ	dry	wet	c_p J/(kg·K)
Expanded polystyrene	10 – 50		0		0			< 0,10	4	60	60	1 450
Extruded polystyrene foam	20 – 65		0		0			< 0,10	2,5	150	150	1 450
Polyurethane foam, rigid	28 – 55		0		0			< 0,15	6	60	60	1 400
Mineral wool	10 – 200		0		0			< 0,15	4 [c]	1	1	1 030
Phenolic foam	20 – 50		0		0			< 0,15	5	50	50	1 400
Cellular glass	100 – 150	0		0		0	0			∞	∞	1 000
Perlite board	140 – 240	0,02		0,03		0 to 0,03	0,8			5	5	900
Expanded cork	90 – 140		0,008		0,011			< 0,10	6	10	5	1 560
Wood wool board	250 – 450		0,03		0,05			< 0,10	1,8	5	3	1 470
Wood fibreboard	40 – 250	0,1		0,16				< 0,05	1,4	5	3	2 000
Urea-formaldehyde foam	10 – 30	0,1		0,15		< 0,15	0,7			2	2	1 400
Spray applied polyurethane foam	30 – 50		0		0			< 0,15	6	60	60	1 400
Loose-fill mineral wool	15 – 60		0		0			< 0,15	4	1	1	1 030
Loose-fill cellulose fibre	20 – 60	0,11		0,18		< 0,20	0,5			2	2	1 600
Loose-fill expanded perlite	30 – 150	0,01		0,02		0 to 0,02	3			2	2	900
Loose-fill exfoliated vermiculite	30 – 150	0,01		0,02		0 to 0,02	2			3	2	1 080
Loose-fill expanded clay	200 – 400	0		0,001		0 to 0,02	4			2	2	1 000
Loose-fill expanded polystyrene beads	10 – 30		0		0	< 0,10		4	4	2	2	1 400
Fired clay	1 000 – 2 400		0,007		0,012			0 to 0,25	10	16	10	1 000

Table 4 (*continued*)

Material	Density	Moisture content at 23 °C, 50 % RH [a]		Moisture content at 23 °C, 80 % RH [a]		Moisture conversion coefficient [b]				Water vapour resistance factor μ		Specific heat capacity
	ρ kg/m^3	u kg/kg	ψ m^3/m^3	u kg/kg	ψ m^3/m^3	Moisture content u kg/kg	f_u	Moisture content ψ m^3/m^3	f_ψ	dry	wet	c_p J/(kg·K)
Calcium silicate	900 – 2 200		0,012		0,024			0 to 0,25	10	20	15	1 000
Concrete with no other aggregate than pumice	500 – 1 300		0,02		0,035			0 to 0,25	4	50	40	1 000
Dense aggregate concrete and manufactured stone	1 600 – 2 400		0,025		0,04			0 to 0,25	4	150	120	1 000
Concrete with polystyrene aggregates	500 – 800		0,015		0,025			0 to 0,25	5	120	60	1 000
Concrete with no other aggregate than expanded clay	400 – 700	0,02		0,03		0 to 0,25	2,6			6	4	1 000
Concrete with expanded clay as predominant aggregate	800 – 1 700	0,02		0,03		0 to 0,25	4			8	6	1 000
Concrete with more than 70 % expanded blast-furnace slag aggregate	1 100 – 1 700	0,02		0,04		0 to 0,25	4			30	20	1 000
Concrete with the predominant aggregate derived from pyroprocessed colliery material	1 100 – 1 500	0,02		0,04		0 to 0,25	4		15		10	1 000
Autoclaved aerated concrete	300 – 1 000	0,026		0,045		0 to 0,25	4			10	6	1 000
Concrete with other lightweight aggregates	500 – 2 000		0,03		0,05			0 to 0,25	4	15	10	1 000
Mortar (masonry mortar and rendering mortar)	250 – 2 000		0,04		0,06			0 to 0,25	4	20	10	1 000

General values are given in this table. Other values dependent on material and application may be provided in national tables.

[a] See 8.2.

[b] The effect of mass transfer by liquid water and water vapour, and the effects of water phase changes, are not covered by these data. The moisture content is the range for which the coefficients are valid.

[c] Data are not valid when there could be a continuous supply of moisture to the warm side of the insulation.

Table 5 — Water vapour diffusion-equivalent air layer thickness

Product/material	Water vapour diffusion-equivalent air layer thickness s_d m
Polyethylene 0,15 mm	50
Polyethylene 0,25 mm	100
Polyester film 0,2 mm	50
PVC foil	30
Aluminium foil 0,05 mm	1 500
PE foil (stapled) 0,15 mm	8
Bituminous paper 0,1 mm	2
Aluminium paper 0,4 mm	10
Breather membrane	0,2
Paint – emulsion	0,1
Paint – gloss	3
Vinyl wallpaper	2

NOTE 1 The water vapour diffusion-equivalent air layer thickness of a product is the thickness of a motionless air layer with the same water vapour resistance as the product. It is an expression of resistance to diffusion of water vapour.

NOTE 2 The thickness of the products in this table is not normally measured and they can be regarded as very thin products with a water vapour resistance. The table quotes nominal thickness values as an aid to the identification of the product.

Annex A
(normative)

Conversion coefficients for temperature

For conductivities between those given in Tables A.1 to A.15, use linear interpolation.

Unless otherwise specified, the conversion coefficients apply to both factory-made products and loose-fill materials.

Values of thermal conductivity are given as identification parameters only and are not intended for any other purpose. The values in Tables A.1 to A.15 are valid for mean temperatures between 0 °C and 30 °C.

The data for extruded polystyrene (XPS) and polyurethane (PU) are valid for all blowing agents.

Table A.1 — Mineral wool

Product type	**Conductivity** λ W/(m·K)	**Conversion coefficient** f_T 1/K
Batts, mats and loose fill	0,035	0,004 6
	0,040	0,005 6
	0,045	0,006 2
	0,050	0,006 9
Boards	0,032	0,003 8
	0,034	0,004 3
	0,036	0,004 8
	0,038	0,005 3
Rigid boards	0,030	0,003 5
	0,033	0,003 5
	0,035	0,003 5

Table A.2 — Expanded polystyrene

Thickness d mm	**Conductivity** λ W/(m·K)	**Conversion coefficient** f_T 1/K
$d < 20$	0,032	0,003 1
	0,035	0,003 6
	0,040	0,004 1
	0,043	0,004 4
$20 < d < 40$	0,032	0,003 0
	0,035	0,003 4
	0,040	0,003 6
$40 < d < 100$	0,032	0,003 0
	0,035	0,003 3
	0,040	0,003 6
	0,045	0,003 8
	0,050	0,004 1
$d > 100$	0,032	0,003 0
	0,035	0,003 2
	0,040	0,003 4
	0,053	0,003 7

Table A.3 — Extruded polystyrene

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
Without skin	0,025 0,030 0,040	0,004 6 0,004 5 0,004 5
With skin, fine cell products without skin	0,025 0,030 0,035	0,004 0 0,003 6 0,003 5
With impermeable cover	0,025 0,030 0,035 0,040	0,003 0 0,002 8 0,002 7 0,002 6

Table A.4 — Polyurethane foam

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
Products without facings	0,025 0,030	0,005 5 0,005 0
Products with impermeable facings	0,022 0,025	0,005 5 0,005 5

Table A.5 — Phenolic foam

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
Closed cell foam (> 90 %) 0 °C to 20 °C 20 °C to 30 °C [a, b]	up to 0,025	0,002 0 0,005 0
Open cell foam 0 °C to 30 °C	0,032	0,002 9

[a] Conversions shall be applied separately between 0 °C and 20 °C and between 20 °C and 30 °C. To convert from 10 °C to 25 °C, first convert from 10 °C to 20 °C, then from 20 °C to 25 °C.

[b] Conversion coefficients apply for blowing agents of pentane or hydro-fluoro-carbon (HFC). They may differ for other blowing agents.

Table A.6 — Cellular glass

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
All products	0,035 0,040 0,045 0,050 0,055	0,004 3 0,003 7 0,003 3 0,003 0 0,002 7

Table A.7 — Rigid boards of perlite, fibres and binders

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
All products	all	0,003 3

Table A.8 — Wood wool boards

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
All products	0,070	0,004 0
	0,080	0,004 1
	0,090	0,004 6

Table A.9 — Expanded cork

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
All products	all	0,002 7

Table A.10 — Loose-fill cellulose fibre

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
Density < 40 kg/m^3	all	0,004 0
Density $\geqslant 40$ kg/m^3	all	0,003 5

Table A.11 — Concrete, fired clay and mortar

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
Lightweight concrete	0,100	0,003
	0,150	0,002
	0,400	0,001
Dense concrete, fired clay and mortar	all	0,001

Table A.12 — Calcium silicate

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
All products	all	0,003

Table A.13 — Loose-fill expanded perlite

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
All products	0,040	0,004 1
	0,050	0,003 3

Table A.14 — Loose-fill expanded clay

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
All products	0,070 to 0,150	0,004

Table A.15 — Loose-fill exfoliated vermiculite

Product type	Conductivity λ W/(m·K)	Conversion coefficient f_T 1/K
All products	all	0,003

Annex B
(informative)

Examples of calculations

B.1 Introduction

This annex gives three examples illustrating the procedure for deriving declared or design values from available data. Numerical inputs that are not taken from this International Standard are purely indicative.

B.2 Declared value determined from 10 measured samples

A mineral wool manufacturer has conductivity measurements of 10 samples from mineral wool boards. The measurements were conducted at a mean temperature of 11 °C. The samples were conditioned at a temperature of 23 °C and relative humidity of 50 %.

The declared value is to be given for a temperature of 10 °C and a moisture content equal to the one the material has when in equilibrium with air at 23 °C and relative humidity of 50 %.

The measurements are as shown in Table B.1.

Table B.1 — Measured conductivities

Sample number i	1	2	3	4	5	6	7	8	9	10
Measured conductivity λ W/(m·K)	0,033 1	0,034 3	0,034 6	0,033 8	0,033 6	0,034 1	0,033 4	0,034 2	0,033 5	0,033 9

The declared value is to be a 90 % fractile with 90 % confidence. The statistical formula used to find the limit for this one sided statistical tolerance interval, L_s, is as follows (see ISO 16269-6:2005, Annex A):

$$L_\text{s} = \bar{\lambda} + k_2 \left(n;\, p;\, 1 - \alpha\right) s \qquad \text{(B.1)}$$

where

$\bar{\lambda}$ is the mean value;

k_2 is the coefficient used to determine L_s when the standard deviation is estimated for one-sided tolerance interval;

n is the number of samples;

p is the fractile giving the minimum proportion of the population claimed to be lying in the statistical tolerance interval;

$1 - \alpha$ is the confidence level for the claim that the proportion of the population lying within the tolerance interval is greater than or equal to the specified level p;

s is the sample standard deviation.

The mean value, λ, is calculated as

$$\bar{\lambda} = \frac{\sum \lambda_i}{10} = 0{,}033\,85 \tag{B.2}$$

where

λ_i is the ith measured value.

In Annex C, the coefficient k_2 is 2,07 for $n = 10$.

The standard deviation, s, is calculated as

$$s = \sqrt{\frac{\sum (\lambda_i - \bar{\lambda})^2}{n-1}} = 0{,}000\,460 \tag{B.3}$$

The limit value for the tolerance interval is then

$$L_\text{s} = 0{,}033\,85 + 2{,}07 \times 0{,}000\,460 = 0{,}034\,80 \tag{B.4}$$

This value is then converted to 10 °C using Equation (1):

$$\lambda_2 = \lambda_1 F_T \tag{B.5}$$

The conversion factor is calculated from Equation (3):

$$F_T = \mathrm{e}^{f_T (T_2 - T_1)} \tag{B.6}$$

The conversion coefficient for mineral wool boards with a conductivity of 0,034 8 W/(m·K) is given in Table A.1 (using linear interpolation):

$$f_T = 0{,}004\,5 \tag{B.7}$$

The conversion factor then becomes

$$F_T = \mathrm{e}^{0{,}004\,5(10-11)} = 0{,}995\,51 \tag{B.8}$$

The converted value then becomes

$$\lambda_2 = 0{,}034\,80 \times 0{,}995\,51 = 0{,}034\,64 \tag{B.9}$$

The declared value is rounded to the nearest higher 0,001 W/(m·K), which means that

$$\lambda = 0{,}035\ \text{W/(m} \cdot \text{K)} \tag{B.10}$$

can be used as the declared value for this product.

B.3 Determination of design value from declared value

B.3.1 General

An expanded polystyrene board will be used in an application where the moisture content is assumed to be 0,02 m^3/m^3. The declared value for this product, being a 90/90 value, is 0,036 W/(m·K).

Two different design values are required, one representing the same fractile as the declared one and another representing a mean value.

B.3.2 90 % fractile

The only conversion necessary is for the moisture content. This is calculated by Equation (5):

$$F_\text{m} = \text{e}^{f_\psi(\psi_2 - \psi_1)} \tag{B.11}$$

The moisture conversion coefficient is given in Table 4:

$$f_\psi = 4{,}0 \tag{B.12}$$

The moisture conversion factor, F_m, and the converted thermal conductivity, λ_2, then become

$$F_\text{m} = \text{e}^{\left[4{,}0(0{,}02-0)\right]} = 1{,}083\ 3 \tag{B.13}$$

$$\lambda_2 = 0{,}036 \times 1{,}083\ 3 = 0{,}038\ 998\ 8 \tag{B.14}$$

The design value is the nearest value rounded to 0,001 W/(m·K):

$$\lambda = 0{,}039 \text{ W/(m·K)} \tag{B.15}$$

B.3.3 Mean value

A mean value can be found by using Equation (C.1), as shown in Equation (B.16):

$$\overline{\lambda} = \lambda_{90} - \Delta\lambda \tag{B.16}$$

The value of $\overline{\lambda}$ could be calculated if at least the number of measurements and the estimated standard deviation were known.

If this is not the case, the value of $\Delta\lambda$ may be found in standards or literature giving values for $\overline{\lambda}$ and λ_{90}.

In this example, the value 0,002 for $\Delta\lambda$ is used, so that

$$\overline{\lambda} = 0{,}036 - 0{,}002 = 0{,}034 \tag{B.17}$$

This value is then corrected using the same conversion factor as calculated in B.3.2:

$$\lambda_2 = 0{,}034 \times 1{,}083\ 3 = 0{,}036\ 832\ 2 \tag{B.18}$$

The design value is the nearest value rounded to 0,001 W/(m·K):

$$\lambda = 0{,}037 \text{ W/(m·K)} \tag{B.19}$$

Annex C
(informative)

Statistical calculations

C.1 Generation of fractile values

The distribution is normally not known, but it is assumed to be Gaussian. The calculation of statistical tolerance intervals (confidence fractiles) is carried out in accordance with ISO 16269-6. Estimation of means is carried out in accordance with ISO 2602[1]. Comparison of two means is carried out in accordance with ISO 2854.

Table C.1 gives the coefficients k_1 and k_2 for a 90 % ($1 - \alpha$, in percent) confident statistical tolerance interval (fractile, p) of 50 % and 90 %. k_1 is the coefficient to be used when the standard deviation is known; k_2 is the coefficient to be used when the standard deviation is estimated.

C.2 Conversion between mean and fractile values

If the design value is to be determined as another statistical estimate (90 % or a mean), Equations (C.1) and (C.2) are used:

$$\lambda_\mathrm{f} = \bar{\lambda} \pm \Delta\lambda_\mathrm{f} \tag{C.1}$$

$$R_\mathrm{f} = \bar{R} \pm \Delta R_\mathrm{f} \tag{C.2}$$

where

λ_f, R_f are the high or low fractiles;

$\Delta\lambda_\mathrm{f}$ or ΔR_f is the difference between the mean value and the chosen fractile.

$\Delta\lambda_\mathrm{f}$ and ΔR_f can be found from a statistical evaluation of measured values, or they can be found in standards or literature giving values for means and 90 % fractiles.

Table C.1 — Coefficients for one-sided tolerance intervals

n	k_1 $1 - \alpha = 0{,}90$		k_2 $1 - \alpha = 0{,}90$	
	$p = 50$ %	$p = 90$ %	$p = 50$ %	$p = 90$ %
3	0,74	2,02	1,09	4,26
4	0,64	1,92	0,82	3,19
5	0,57	1,86	0,69	2,74
6	0,52	1,81	0,60	2,49
7	0,48	1,77	0,54	2,33
8	0,45	1,74	0,50	2,22
9	0,43	1,71	0,47	2,13
10	0,41	1,69	0,44	2,07
11	0,39	1,67	0,41	2,01
12	0,37	1,65	0,39	1,97
13	0,36	1,64	0,38	1,93
14	0,34	1,63	0,36	1,90
15	0,33	1,61	0,35	1,87
16	0,32	1,60	0,34	1,84
17	0,31	1,59	0,33	1,82
18	0,30	1,58	0,32	1,80
19	0,30	1,58	0,31	1,78
20	0,29	1,57	0,30	1,77
22	0,27	1,56	0,28	1,74
25	0,25	1,54	0,26	1,70
30	0,23	1,52	0,24	1,66
35	0,22	1,50	0,22	1,62
40	0,20	1,49	0,21	1,60
45	0,19	1,47	0,19	1,58
50	0,18	1,46	0,18	1,56
75	0,15	1,43	0,15	1,50
100	0,13	1,41	0,13	1,47
200	0,09	1,37	0,08	1,40
500	0,06	1,34	0,06	1,36
1 000	0,04	1,32	0,04	1,34
∞	0,00	1,28	0,00	1,28

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