
**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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Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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

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

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 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).

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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 $+60\text{ °C}$.

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_v | moisture conversion coefficient volume by volume ^a | m ³ /m ³ |
| R | thermal resistance | m ² ·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 | kg/m ³ |
| v | moisture content volume by volume | m ³ /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 | $u_{\text{dry}}^{\text{a}}$ | $u_{23,50}^{\text{b}}$ | $u_{\text{dry}}^{\text{a}}$ | $u_{23,50}^{\text{b}}$ |
| 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 $\lambda \leq 0,08$: rounding to nearest higher 0,001 W/(m·K);
 - if $0,08 < \lambda \leq 0,20$: rounding to nearest higher 0,005 W/(m·K);
 - if $0,20 < \lambda \leq 2,00$: 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 m²·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 m²·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:

$$\lambda_2 = \lambda_1 F_T F_m F_a \quad (1)$$

$$R_2 = \frac{R_1}{F_T F_m F_a} \quad (2)$$

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

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

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:

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

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:

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

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

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

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 $\text{W}/(\text{m}\cdot\text{K})$.

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

$$Ra_m = \frac{g\beta\rho c_p}{\nu} \times \frac{dk\Delta T}{\lambda} \quad (7)$$

where

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

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 $10 \text{ }^\circ\text{C}$ given in ISO 10292.

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

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

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

$$k = \frac{\eta}{r} \quad (9)$$

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 $\cos \theta$, 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 ρ kg/m ³ | Design thermal conductivity λ W/(m·K) | Specific heat capacity c_p J/(kg·K) | Water vapour resistance factor | |
|--|---|--|---|---|--------------------------------|---------|
| | | | | | 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 | 50 000 |
| | 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 | |
|--------------------------------|--|--|---|---|--------------------------------|----------|
| | | | | | 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 – | 3,5 | 1 000 | 10 000 | 10 000 |
| | | 3 000 | | | | |
| | Gneiss | 2 400 – | 3,5 | 1 000 | 10 000 | 10 000 |
| | | 2 700 | | | | |
| | Granite | 2 500 – | 2,8 | 1 000 | 10 000 | 10 000 |
| | | 2 700 | | | | |
| | Marble | 2 800 | 3,5 | 1 000 | 10 000 | 10 000 |
| | Slate | 2 000 – | 2,2 | 1 000 | 1000 | 800 |
| | | 2 800 | | | | |
| | 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 c_p J/(kg·K) | |
|---------------------------------------|-----------------------------|---------------|---|---------------------------------------|---|---------------------------------------|--|-------|--|--------------------------------------|----------|--|-------|
| | ρ kg/m ³ | | u kg/kg | v m ³ /m ³ | u kg/kg | v m ³ /m ³ | Moisture content u kg/kg | f_u | Moisture content v m ³ /m ³ | f_v | dry | | wet |
| 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 | | | 0,7 | | | 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 ρ kg/m ³ | 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 c_p J/(kg·K) | |
|--|--|---|--|---|--|--|-------|---|--------------------------------------|-----|---|-------|
| | | 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 |
| 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 |
| <p>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.</p> | |
| <p>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.</p> | |

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 | Conversion coefficient |
|--------------|----------------------|------------------------|
| | λ W/(m·K) | f_T 1/K |
| All products | all | 0,003 3 |

Table A.8 — Wood wool boards

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

Table A.9 — Expanded cork

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

Table A.10 — Loose-fill cellulose fibre

| Product type | Conductivity | Conversion coefficient |
|--------------------------------|----------------------|------------------------|
| | λ W/(m·K) | f_T 1/K |
| Density < 40 kg/m ³ | all | 0,004 0 |
| Density ≥ 40 kg/m ³ | all | 0,003 5 |

Table A.11 — Concrete, fired clay and mortar

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

Table A.12 — Calcium silicate

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

Table A.13 — Loose-fill expanded perlite

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

Table A.14 — Loose-fill expanded clay

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

Table A.15 — Loose-fill exfoliated vermiculite

| Product type | Conductivity | Conversion coefficient |
|--------------|----------------------|------------------------|
| | λ W/(m·K) | 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>i</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):

$$L_s = \bar{\lambda} + k_2(m; p; 1 - \alpha) s \quad (\text{B.1})$$

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.