



BSI Standards Publication

Masonry and masonry products — Methods for determining thermal properties

National foreword

This British Standard is the UK implementation of EN 1745:2020. It supersedes BS EN 1745:2012, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/519, Masonry and associated testing.

A list of organizations represented on this committee can be obtained on request to its committee manager.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2020

Published by BSI Standards Limited 2020

ISBN 978 0 539 03668 8

ICS 91.080.30; 91.120.10

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 July 2020.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

English Version

Masonry and masonry products - Methods for determining thermal properties

Maçonnerie et éléments de maçonnerie - Méthodes
pour la détermination des propriétés thermiques

Mauerwerk und Mauerwerksprodukte - Verfahren zur
Bestimmung von wärmeschutztechnischen
Eigenschaften

This European Standard was approved by CEN on 17 May 2020.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

Contents	Page
European foreword.....	4
Introduction	5
1 Scope.....	8
2 Normative references.....	8
3 Terms, definitions and symbols.....	9
3.1 Terms and definitions	9
3.2 Symbols.....	10
4 Determination of $\lambda_{10,dry,unit}$ –values for solid masonry units and $\lambda_{10,dry,mor}$ –values for mortars	11
4.1 General.....	11
4.2 $\lambda_{10,dry,mat}$ –values for solid masonry units and mortars.....	12
4.2.1 Method S1. Determination of $\lambda_{10,dry,unit}$ –values from tabulated $\lambda_{10,dry,mat}$ /net dry density relationship	12
4.2.2 Method S2. Determination of $\lambda_{10,dry,unit}$ –values based on $\lambda_{10,dry,mat}$ /net dry density curve	12
4.2.3 Method S3. Determination of $\lambda_{10,dry,unit}$ –values from determining the thermal transmittance (U_{mas}) of masonry built from solid masonry units and mortar	14
4.3 Test methods and numbers of samples to be taken	16
5 Determination of equivalent $\lambda_{10,dry,unit}$ -values for masonry units with formed voids and composite masonry units	16
5.1 General.....	16
5.2 Calculation methods.....	17
5.3 $\lambda_{10,dry,unit}$ -values of masonry units with formed voids and composite units	17
5.3.1 Determination of $\lambda_{10,dry,unit}$ -values from tabulated $\lambda_{unit} / \lambda_{mat}$ relationship	17
5.3.2 Determination of $\lambda_{10,dry,unit}$ -values based on calculation.....	18
5.3.3 Method P5. Determination of $\lambda_{10,dry,unit}$ –values from determining the thermal transmittance (U_{mas}) of masonry built from masonry units with formed voids or composite masonry units and mortar	18
5.4 Test methods and numbers of samples to be taken	21
6 Moisture conversion	22
6.1 General.....	22
6.2 Procedure A (for materials, mortar, solid masonry units and masonry):.....	22
6.3 Procedure B (for masonry units with formed voids):.....	23
6.4 Procedure C (for composite masonry units):.....	23
7 Determination of design thermal values ($R_{design,mas}$ or $\lambda_{design,mas}$) for masonry built from masonry units and mortar	23
7.1 General.....	23
7.2 $R_{design,mas}$ – or $\lambda_{design,mas}$ –values based on calculation.....	24
7.2.1 $R_{design,mas}$ – or $\lambda_{design,mas}$ –values based on λ_{design} –values for the masonry units and the mortar.....	24
7.2.2 $R_{design,mas}$ –or $\lambda_{design,mas}$ –values using a numerical calculation method based on the design thermal conductivity of the materials used –	24
7.3 $R_{design,mas}$ – or $\lambda_{design,mas}$ –values of masonry built from masonry units with formed voids and mortar based on tabulated values.....	24
7.3.1 Tabulated values	24
7.3.2 Application of Annex B.....	25
7.3.3 Alternative application of Annex B.....	25

7.4	Method S4/P6 $R_{design,mas}$ – or $\lambda_{design,mas}$ –values of masonry based on masonry testing	26
8	Determination of the thermal transmittance of masonry	26
9	Specific heat capacity	27
10	Rounding rules for λ-values for masonry units and masonry	27
Annex A	(normative) Tabulated $\lambda_{10,dry,mat}$ -values of materials used for masonry products	28
Annex B	(informative) $R_{dry,mas}$ - or $\lambda_{10,dry,mas}$ -values of masonry built from a range of masonry units containing formed voids.....	38
Annex C	(informative) Example of how to use the tables in Annex B	78
Annex D	(normative) Requirements for appropriate calculation procedures	80
D.1	Capabilities of the program	80
D.2	Input data and results.....	80
D.3	Testing of the program accuracy.....	81
D.4	Reference cases	81
D.4.1	Case 1: Calculation of thermal resistance R and thermal conductivity $\lambda_{10,dry,unit}$ of a masonry unit (vertically perforated unit)	81
D.4.2	Case 2: Calculation of thermal resistance $R_{dry,mas}$ of masonry consisting of vertically perforated masonry units, bed joints with mortar layers and internal/external plaster layers.....	83
D.4.3	CASE 3: Calculation of thermal resistance R_t of masonry consisting of masonry units, horizontal mortar layers, vertical mortar pockets and additional external insulation layer	85
Annex E	(informative) Assessment and verification of constancy of performance	89
Annex F	(informative) Alternative procedure for the moisture correction of units with formed voids.....	91
Annex G	(informative) Simplified methodology for determining design moisture content of composite masonry units.....	92

European foreword

This document (EN 1745:2020) has been prepared by Technical Committee CEN/TC 125 “Masonry”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2021, and conflicting national standards shall be withdrawn at the latest by January 2021.

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

This document supersedes EN 1745:2012.

The following is a list of significant technical changes since the last edition EN 1745:2012:

- replacement of Figure 1 by Tables 1 a and 1 b;
- editorial improvement;
- changes in the definitions 3.1.5 and 3.1.10;
- correction of term in Annex A;
- amendment heading of column in Annex A;
- addition of Annex G.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

This document provides methods for the determination of dry and design thermal conductivity and thermal resistance values of masonry products and masonry.

The following types of masonry unit are covered by this document:

- solid masonry units;
- masonry units with formed voids;
- composite masonry units.

Methods are described for the determination of the dry thermal conductivity of solid masonry units ($\lambda_{10,dry,unit}$) and of mortar ($\lambda_{10,dry,mor}$) and for the determination of equivalent dry thermal conductivity of masonry units with formed voids and composite masonry units ($\lambda_{10,dry,unit}$). Procedures are also described for the determination of the design thermal values of masonry units and masonry. The different methods are illustrated in Table 1.

The value in dry state is a characteristic of a masonry material, masonry unit or of masonry.

The determination of thermal values can be based on tabulated data, measurements, calculations or a combination of these.

Design thermal values may be determined according to procedures given in this European standard according to the intended application, environmental and climatic conditions, bearing in mind the purpose of this determination, such as:

- energy consumption;
- design of heating and cooling equipment;
- surface temperature determination;
- compliance with national building regulations;
- consideration of non-steady-state thermal conditions in buildings.

Table 1 a — Determination of thermal properties of masonry units and masonry

Overview of methods to determine $\lambda_{10,dry,unit}$			
Method (Clause)	Masonry units	Determination of $\lambda_{10,dry,unit}$ ^{a b}	Required parameters
S1 (4.2.1)	solid	using tabulated value from Annex A for the $\lambda_{10,dry,mat}$ / net dry density relationship	Net dry density of unit/material ^a
S2 (4.2.2)	solid	based on determination of dry thermal conductivity by measurement and of the masonry unit material / dry density curve	Net dry density and thermal conductivity of unit/material ^a
S3 (4.2.3)	solid	based on determination of the thermal transmittance (U_{mas}) of masonry, then adjusting for the influence of the mortar	Net dry density and percentage area of units; thermal conductivity and percentage area of mortar
P1 (5.3.1.3)	with formed voids	based on determination of dry thermal conductivity of the masonry unit material, then using Annex B	Net dry density and thermal conductivity of unit/material and configuration of the units
P2 (5.3.1.4)	with formed voids	using tabulated values from Annex A, then using Annex B	Net dry density of unit/material and configuration of the units
P3 (5.3.2.2)	with formed voids and composite	by calculation according to 5.2, using dry thermal conductivity by measurement of the masonry unit material and any infill	Net dry density and thermal conductivity of unit/infill material and configuration of the units
P4 (5.3.2.3)	with formed voids and composite	by calculation according to 5.2 using tabulated thermal conductivity of the masonry unit material from Annex A and thermal conductivity of any infill material	Net dry density and thermal conductivity of unit/infill material and configuration of the units
P5 (5.3.3)	with formed voids and composite	based on determination of the thermal transmittance (U_{mas}) of masonry, then adjusting for the influence of the mortar	Gross dry density and percentage area of units, thermal conductivity and percentage area of mortar
^a Methods S1 and S2 are also applicable for the determination of $\lambda_{10,dry,mor}$. ^b If necessary, moisture correction according to Clause 6.			

Table 1 b — Determination of thermal properties of masonry units and masonry

Overview of methods to determine $\lambda_{design,unit}^a$ and $\lambda_{design,mas}^b$			
$\lambda_{design}^{a,b}$ (Clause)	Masonry units	Determination of $\lambda_{design,unit}^a$ / $\lambda_{design,mas}^b$	Required parameters
$\lambda_{design,unit}$ (6)	solid, with formed voids and composite	by applying moisture correction according to Clause 6 upon $\lambda_{10,dry,unit}$	Thermal conductivity in dry state and moisture conversion factor of unit
$\lambda_{design,mas}$ (7.2.1)	solid, with formed voids and composite	by using a simplified calculation based on $\lambda_{design,unit}$ and $\lambda_{design,mor}$	Design thermal conductivity of unit and mortar and percentage area of mortar joints
$\lambda_{design,mas}$ (7.2.2)	solid, with formed voids and composite	by numerical calculation based on $\lambda_{design,mat}$	Design thermal conductivity of materials and configuration
$\lambda_{design,mas}$ (7.3)	with formed voids	using of Annex B and application of the correction according to 6.3	Net dry density and thermal conductivity of unit/material and respective moisture conversion factors
S4/P6 $\lambda_{design,mas}$ (7.4)	solid, with formed voids and composite	by applying moisture correction according to Clause 6 onto the thermal transmittance (U_{mas}) of masonry	Thermal transmission of masonry and moisture conversion factor
^a Or alternatively the design thermal resistance of the unit $R_{design,unit}$. ^b Or alternatively the design thermal resistance of the masonry $R_{design,mas}$.			

1 Scope

This document specifies methods for the determination of thermal properties of masonry and masonry products.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 772-3, *Methods of test for masonry units — Part 3: Determination of net volume and percentage of voids of clay masonry units by hydrostatic weighing*

EN 772-4, *Methods of test for masonry units — Part 4: Determination of real and bulk density and of total and open porosity for natural stone masonry units*

EN 772-13, *Methods of test for masonry units — Part 13: Determination of net and gross dry density of masonry units (except for natural stone)*

EN 772-16, *Methods of test for masonry units — Part 16: Determination of dimensions*

EN 1015-10, *Methods of test for mortar for masonry — Part 10: Determination of dry bulk density of hardened mortar*

EN 1934, *Thermal performance of buildings — Determination of thermal resistance by hot box method using heat flow meter — Masonry*

EN 1936, *Natural stone test methods — Determination of real density and apparent density, and of total and open porosity*

EN 12664, *Thermal performances of building materials and products — Determination of thermal resistance by means of guarded hot plate and heat flow meter methods — Dry and moist products of medium and low thermal resistance*

EN 12667, *Thermal performance of building materials and products- Determination of thermal resistance by means of guarded hot plate and heat flow meter methods – Products of high and medium thermal resistance*

EN ISO 6946, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation methods (ISO 6946)*

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

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

EN ISO 10456:2007,¹ *Building materials and products — Hygrothermal properties — Tabulated design values and procedures for determining declared and design thermal values (ISO 10456:2007)*

3 Terms, definitions and symbols

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

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

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

3.1 Terms and definitions

3.1.1

masonry

assemblage of masonry units laid in a specified pattern and joined together with masonry mortar

3.1.2

masonry product

masonry units, masonry mortars, rendering and plastering mortars

3.1.3

solid masonry unit

masonry unit containing no perforations except external indentations such as grip holes, grooves, etc.

3.1.4

masonry unit with formed voids

masonry unit with a system of intentionally formed voids

3.1.5

composite masonry unit

masonry unit incorporating additional material

3.1.6

thermal value

common term for either the thermal conductivity ($W/(m\ K)$) or the thermal resistance ($m^2\cdot K/W$)

3.1.7

dry state

state after drying under conditions stated in the relevant standards

3.1.8

thermal value in dry state

value of a thermal property of a building material or product in a dry state determined according to this European Standard as a basis for the calculation of design thermal values

Note 1 to entry: The dry thermal value can be expressed as thermal conductivity or thermal resistance.

¹ As impacted by EN ISO 10456:2007/AC:2009.

3.1.9**design thermal value**

value of a thermal property 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 or building

3.1.10**equivalent thermal conductivity of masonry unit**

value derived by dividing the width of a masonry unit with formed voids or a composite masonry unit by its thermal resistance excluding surface resistance

3.1.11**equivalent masonry thermal conductivity**

value derived by dividing the thickness of a given masonry by its thermal resistance excluding surface resistance

3.1.12**reference conditions**

set of conditions identifying a state of equilibrium selected as the base to which the thermal values of building materials and products are referred

3.2 Symbols

The order of the indices for thermal values is temperature, condition and subject.

Symbol	Quantity	Unit
$\lambda_{10,dry,mat}$	thermal conductivity at an average temperature of 10 °C in dry state for a masonry unit material and/or infill material	W/(m·K)
$\lambda_{10,dry,mas}$	thermal conductivity at an average temperature of 10 °C in dry state for the masonry	W/(m·K)
$\lambda_{10,dry,mor}$	thermal conductivity at an average temperature of 10 °C in dry state for the mortar	W/(m·K)
$\lambda_{10,dry,unit}$	thermal conductivity at an average temperature of 10 °C in dry state for the unit. For solid units the $\lambda_{10,dry,unit}$ is the same as $\lambda_{10,dry,mat}$ and for units with formed voids and composite units the $\lambda_{10,dry,unit}$ is the equivalent thermal conductivity.	W/(m·K)
$\lambda_{design,mas}$	design thermal conductivity for the masonry	W/(m·K)
$\lambda_{design,mor}$	design thermal conductivity for the mortar	W/(m·K)
$\lambda_{design,unit}$	design thermal conductivity for the unit	W/(m·K)
λ_g	equivalent thermal conductivity of voids	W/(m·K)
λ_i	individually determined thermal conductivity	W/(m·K)
R_g	thermal resistance of voids	m ² ·K/W
R_i	individually determined thermal resistance	m ² ·K/W
$R_{dry,mas}$	thermal resistance of masonry	m ² ·K/W
$R_{design,mas}$	design thermal resistance of masonry	m ² ·K/W
R_{si}, R_{se}	internal and external surface resistance	m ² ·K/W

$R_{tot,mas}$	total thermal resistance of masonry	$m^2 \cdot K/W$
a_{mor}	percentage area of mortar joint in the measured masonry	%
a_{unit}	percentage area of units in the measured masonry	%
d	thickness of the masonry	m
T	Temperature	K
μ	water vapour resistance factor	
c_p	specific heat capacity	$J/(kg \cdot K)$
l	length of a masonry unit	mm
w	width of a masonry unit	mm
h_{unit}	height of a masonry unit	mm
h_{mor}	thickness of a mortar joint	mm
F_m	moisture conversion factor	
f_u	moisture conversion coefficient by mass	kg/kg
f_ψ	moisture conversion coefficient by volume	m^3/m^3
u	moisture content mass by mass	kg/kg
ψ	moisture content volume by volume	m^3/m^3
$U_{10,dry,mas}$	thermal transmittance of the masonry at an average temperature of 10 °C in dry state	$W/(m^2 \cdot K)$
U_{mas}	thermal transmittance of the masonry	$W/(m^2 \cdot K)$
U_{mor}	thermal transmittance of the mortar	$W/(m^2 \cdot K)$
U_{unit}	thermal transmittance of the units	$W/(m^2 \cdot K)$
P	fractile of population	%
$\rho_{g,dry}$	gross dry density	kg/m^3
$\rho_{n,dry}$	net dry density	kg/m^3
v	percentage of voids	%

4 Determination of $\lambda_{10,dry,unit}$ –values for solid masonry units and $\lambda_{10,dry,mor}$ –values for mortars

4.1 General

$\lambda_{10,dry,unit}$ –values for solid masonry units and $\lambda_{10,dry,mor}$ –values for mortars are identical to the $\lambda_{10,dry,mat}$ –values. The $\lambda_{10,dry,mat}$ –values of solid masonry units and of mortars can be determined from tests carried out on samples of the material or from tables or graphs which relate $\lambda_{10,dry,mat}$ to density or from determining the thermal transmittance (U_{mas}) of masonry built from masonry units and mortar. In all cases the $\lambda_{10,dry,mat}$ –value is to be representative of the material.

NOTE For the determination of the $\lambda_{10,dry,unit}$ -value, $\lambda_{10,dry,mor}$ -value and $\lambda_{10,dry,mat}$ -value, with fractile X and confidence level Y, the basis is the corresponding gross dry density or net dry density and configuration.

4.2 $\lambda_{10,dry,mat}$ –values for solid masonry units and mortars

4.2.1 Method S1. Determination of $\lambda_{10,dry,unit}$ –values from tabulated $\lambda_{10,dry,mat}$ /net dry density relationship

Tabulated $\lambda_{10,dry,mat}$ –values for different materials used for masonry products are given in Annex A, differentiated by material and dry density. This annex also contains values for the water vapour resistance factor, the specific heat capacity and the moisture conversion coefficient.

These tabulated values are valid for materials where there is factory production control of the net dry density but no directly determined λ –values. $\lambda_{10,dry,mat}$ –values are given as 50 % and 90 % fractiles (P).

4.2.2 Method S2. Determination of $\lambda_{10,dry,unit}$ –values based on $\lambda_{10,dry,mat}$ /net dry density curve

4.2.2.1 General

To determine the $\lambda_{10,dry,mat}$ –value from a $\lambda_{10,dry,mat}$ /net dry density relationship the following procedure shall be used:

4.2.2.2 Test specimens

Test specimens shall be in accordance with the requirements of EN 12664. Care should be taken that the test specimens are representative of the masonry product itself.

NOTE An appropriate way to ensure this, is to cut specimens from masonry units.

4.2.2.3 Conditioning of specimens

Normally masonry materials are tested in a dry condition. It is also possible to carry out tests in a moist condition (e.g. conditioned to constant mass in an environment of $(23 \pm 2)^\circ\text{C}$ and $50\% \pm 5\%$ relative humidity), in which case the measured value has to be converted to the dry state following one of the procedures given in 6.2.

4.2.2.4 Test measurement

The reference test method is given in EN 12664. The test shall be carried out at a mean temperature of 10°C .

Alternative test methods, which may require different test specimens and different conditioning methods, may be used, if the correlation between the reference test method and the alternative method can be given.

4.2.2.5 Establishing a product related $\lambda_{10,dry,mat}$ /net dry density-curve

Three items of information are necessary for this determination procedure:

- 1) the tabulated $\lambda_{10,dry,mat}$ /net dry density-correlation for the given material (see Annex A);
- 2) the product net dry density range, which can be derived either from the production history or from the net dry density tolerances which are given in the relevant product standards;
- 3) at least three individual test measurements of the net dry density and λ_i , on material which is representative for the current material produced. The measurements of net dry density and λ shall be carried out on the same specimens. The three tests have to be carried out on specimens from different production batches to represent the manufactured product net dry density range. These three measurements are used to determine the distance of the individual $\lambda_{10,dry,mat}$ /net dry density-curve, for a defined production, from the tabulated $\lambda_{10,dry,mat}$ /net dry density curve.

Determine the λ_i -value as described in 4.2.2.1 to 4.2.2.3 and calculate the arithmetic mean value of the 3 λ_i -results.

Measure the net dry density of each of the three samples following the procedure described in EN 772-4, EN 1936 or EN 772-13 or EN 1015-10 and calculate the arithmetic mean value of the 3 results.

Then use the following procedure.

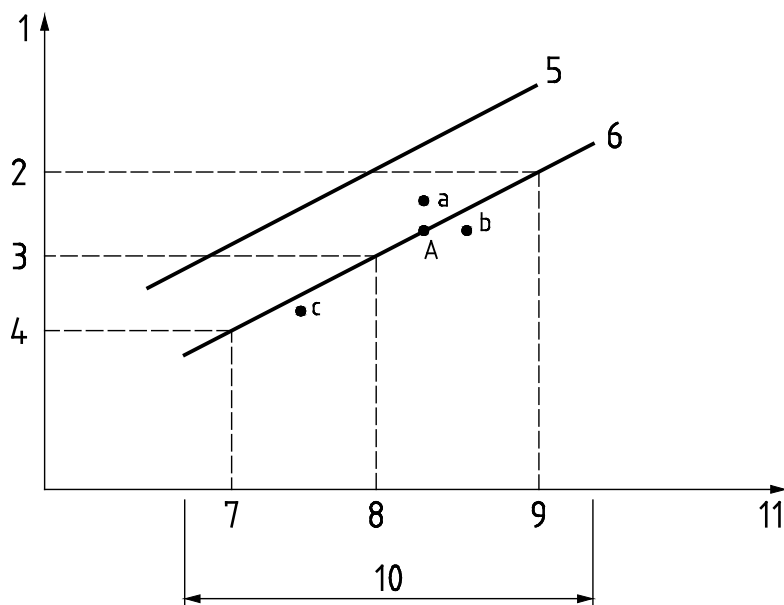
Through the point A representing mean thermal conductivity and mean net dry density draw a λ /net dry density-curve parallel to the general $\lambda_{10,dry,mat}$ /net dry density-curve obtained from plotting the tabulated λ -value and net dry density-values for the product (material) given in Annex A.

Derive the mean λ -value of the product from the average net dry density. Derive the upper and lower limit values as the values that represent 90 % and 10 % of the manufactured product under consideration density range with a confidence level of 90 % according to EN ISO 10456.

Use the product related $\lambda_{10,dry,mat}$ /net dry density-curve to determine the $\lambda_{10,dry,mat}$ -value related to the mean net dry density the manufacturer is confident to achieve.

Express the $\lambda_{10,dry,unit}$ -values for solid masonry units or the $\lambda_{10,dry,mor}$ -values for mortars as the mean $\lambda_{10,dry,mat}$ -value together with the difference between the limit and the mean value.

Figure 1 shows this process in the form of a graph.



Key

- | | |
|----|--|
| 1 | $\lambda_{10, dry, mat}$ (W/m·K) |
| 2 | upper limit λ -value |
| 3 | mean λ -value |
| 4 | lower limit λ -value |
| 5 | curve resulting from tabulated values (Annex A) |
| 6 | parallel curve drawn through point A (mean of the single values a, b, c) |
| 7 | 10 % of production of the product under consideration |
| 8 | mean net dry density |
| 9 | 90 % of production of the product under consideration |
| 10 | product density range |
| 11 | net dry density (kg/m ³) |

Figure 1 — Derivation of the material $\lambda_{10, dry, mat}$ -value

For factory production control purposes, thermal conductivity may be controlled from the net dry density of the material, see Annex E.

4.2.3 Method S3. Determination of $\lambda_{10, dry, unit}$ -values from determining the thermal transmittance (U_{mas}) of masonry built from solid masonry units and mortar

4.2.3.1 General

To determine the $\lambda_{10, dry, unit}$ -value based on test measurements of the thermal transmittance of masonry built from solid masonry units and mortars, the following procedure shall be used.

4.2.3.2 Testing procedure

- Select test samples from 3 different production batches for the product under consideration. Determine their mean net dry density.
- From each of these batches erect one wall.

- Measure the thermal transmittance on each of those walls following EN 1934. If the measured wall is not in a dry state, the measured value has to be converted to the dry state following the procedure given in 6.2.

4.2.3.3 The determination of the $\lambda_{10,dry,unit}$ -value

Calculate the $\lambda_{10,dry,mas}$ -value using the formula:

$$\lambda_{10,dry,mas} = \frac{d}{\frac{1}{U_{10,dry,mas}} - R_{si} - R_{se}}$$

where

- $U_{10,dry,mas}$ is the thermal transmittance of the masonry in dry state, in W/m^2K ;
- R_{si}, R_{se} are the internal and external surface resistance in $m^2 \cdot K/W$ according to EN ISO 6946;
- d is the thickness of the masonry in m;
- $\lambda_{10,dry,mas}$ is the thermal conductivity of the masonry in dry state in $W/(m \cdot K)$.

Calculate the $\lambda_{10,dry,unit}$ -value using the formula:

$$\lambda_{10,dry,unit} = \frac{100 \times \lambda_{10,dry,mas} - a_{mor} \times \lambda_{10,dry,mor}}{a_{unit}}$$

where

- a_{mor} is the percentage area of mortar joint in the measured masonry, in %;
- a_{unit} is the percentage area of units in the measured masonry, in %;
- $\lambda_{10,dry,mor}$ is the thermal conductivity of the actual mortar joint in $W/(m \cdot K)$;
- $\lambda_{10,dry,unit}$ is the thermal conductivity of the units in $W/(m \cdot K)$.

The thermal conductivity of the mortar joints shall take into account mortar pockets and strip bedding and the use of insulating material between the strips.

The thermal conductivity of the mortar may be taken from tabulated values as described in Clause 4 method S1, from measured values as described in method S2 or taken from a declaration of performance.

If the units are intended to be used with unfilled vertical mortar joints the masonry tested shall also be with unfilled joints and the $\lambda_{10,dry,unit}$ -values for the units will take into account the effect of the unfilled joints calculated according to EN ISO 6946.

Take the 3 individual calculated $\lambda_{10,dry,unit}$ -values and calculate the arithmetic mean value.

Measure the net dry density of each of the three samples taken from each batch of masonry units and mortar following the procedure prescribed in EN 772-4, EN 1936 or EN 772-13 or EN 1015-10 and calculate the arithmetic mean value of the 3 results.

NOTE The density of the mortar can be used to establish a tabulated $\lambda_{10,dry,mat}$ -value.

Having determined a mean $\lambda_{10,dry,unit}$ -value and the mean net dry density from solid unit masonry use procedure in 4.2.2.5 to establish a product related $\lambda_{10,dry,unit}$ /net dry density-curve.

Use 4.2.2.5 procedure assuming the mean $\lambda_{10,dry,unit}$ -value derived from the aforementioned tests in 4.2.3.2 and subsequent calculation is equivalent to the mean value derived from the arithmetic mean value of the 3 λ_i -results. The corresponding net dry density values to be used to obtain the curve are obtained from three samples taken from each batch of masonry units as described above. The curve 5 in Figure 1 is still the $\lambda_{10,dry,mat}$ /net dry density-correlation for the masonry unit material (see Annex A).

4.3 Test methods and numbers of samples to be taken

The minimum number of test specimens to be used for each test method shall be as specified in Table 2.

Table 2 — Test methods and minimum numbers of test specimens

Test methods	Minimum numbers of specimens
<i>Method S1:</i> Material density, EN 772-13, EN 772-4 or EN 1936 (natural stone units)	6
<i>Method S2:</i> Material density, EN 772-13, EN 1015-10, EN 772-4 or EN 1936 (natural stone units)	3
Thermal conductivity, EN 12664	3
<i>Method S3:</i> Net dry density, EN 772-13, EN 1015-10, EN 772-4 or EN 1936 (natural stone units)	3 × 6
Thermal transmittance, EN 1934	3

5 Determination of equivalent $\lambda_{10,dry,unit}$ -values for masonry units with formed voids and composite masonry units

5.1 General

The thermal properties of such masonry units are influenced by shape and geometry of the voids and any material in the voids.

The $\lambda_{10,dry,unit}$ -values of masonry units with formed voids can be determined (Table 1):

- from tables;
- from calculations;
- from test measurements carried out on masonry samples.

The $\lambda_{10,dry,unit}$ -values of composite masonry units can be determined (Table 1):

- from calculations;
- from test measurements carried out on masonry samples.

The $\lambda_{10,dry,mat}$ -value of any material shall be determined according to EN ISO 10456, EN 12664, EN 12667 or taken from the declaration of performance of any infill material or mortar or from Annex A.

NOTE For the determination of the $\lambda_{10,dry,unit}$ -value, $\lambda_{10,dry,mor}$ -value or $\lambda_{10,dry,mat}$ -value, with fractile X and confidence level Y, the basis is the corresponding gross dry density or net dry density and configuration.

5.2 Calculation methods

There are several different numerical methods in use (e.g. Finite Difference, Finite Element) for the calculation of the thermal properties of masonry units with formed voids or composite masonry units. The thermal conductivities of the materials and the configuration of the units are necessary input parameters for such calculations.

The requirements for appropriate calculation programs (accuracy, boundary conditions, etc.) are given in Annex D.

The simplified method described in EN ISO 6946 may also be used.

5.3 $\lambda_{10,dry,unit}$ -values of masonry units with formed voids and composite units

5.3.1 Determination of $\lambda_{10,dry,unit}$ -values from tabulated $\lambda_{unit} / \lambda_{mat}$ relationship

5.3.1.1 General

The $\lambda_{10,dry,unit}$ -values used for masonry units with different void patterns are given in Annex B. Annex C provides an example of how to use Annex B.

No tabulated values for composite masonry units are given in Annex B.

5.3.1.2 Application of Annex B

Examples for $\lambda_{10,dry,unit}$ -values of masonry units with formed voids given in Annex B, are differentiated by:

- material;
- geometry of the units and geometry of formed voids;
- λ -value of the material of the masonry units;

Linear interpolation may be used for material conductivities between the values given in the tables in Annex B.

5.3.1.3 Method P1. Determination of $\lambda_{10,dry,unit}$ -values using Annex B using measured thermal conductivity of the masonry unit material

To determine the $\lambda_{10,dry,unit}$ -value using Annex B using measured thermal conductivity of the masonry unit material, the following procedure shall be used:

Select the table relevant for the actual units. Express the $\lambda_{10,dry,unit}$ -value as the value given in the relevant table for the $\lambda_{10,dry,mat}$ -value the manufacturer is confident to achieve. The $\lambda_{10,dry,mat}$ -value is based on a thermal conductivity of the masonry unit material as specified in 4.2.2.

5.3.1.4 Method P2. Determination of $\lambda_{10,dry,unit}$ -values using Annex B using tabulated value from Annex A

To determine the $\lambda_{10,dry,unit}$ -value from using Annex B using tabulated value from Annex A, the following procedure shall be used:

Select the table relevant for the actual units. Express the $\lambda_{10,dry, unit}$ -value as the value given in the relevant table for the $\lambda_{10,dry,mat}$ -value the manufacturer is confident to achieve. The $\lambda_{10,dry,mat}$ -value is a tabulated value from Annex A.

5.3.2 Determination of $\lambda_{10,dry,unit}$ -values based on calculation

5.3.2.1 General

To determine the $\lambda_{10,dry,unit}$ -value for a masonry unit by calculation methods following 5.2, the following procedure shall be used:

Based on:

- the geometry of the units;
- the geometry of formed voids;
- the $\lambda_{10,dry,mat}$ -values;
- the orientation of the unit in use

a numerical simulation of the unit can be established and the thermal transmittance can be approximated. Any calculation method shall be in accordance with Annex D.

5.3.2.2 Method P3. Determination of $\lambda_{10,dry,unit}$ -values using measured thermal conductivity of the masonry unit materials

Express the $\lambda_{10,dry,unit}$ -value as the result of the calculation using the $\lambda_{10,dry,mat}$ -value the manufacturer is confident to achieve for unit and infill material. The $\lambda_{10,dry,mat}$ -value is determined as specified in 4.2.2.2, 4.2.2.3 and 4.2.2.4.

5.3.2.3 Method P4. Determination of $\lambda_{10,dry,unit}$ -values using tabulated value from Annex A

Express the $\lambda_{10,dry,unit}$ -value as the result of the calculation using the $\lambda_{10,dry,mat}$ -value the manufacturer is confident to achieve for the unit body in Annex A and the infill material.

5.3.3 Method P5. Determination of $\lambda_{10,dry,unit}$ -values from determining the thermal transmittance (U_{mas}) of masonry built from masonry units with formed voids or composite masonry units and mortar

5.3.3.1 General

To determine the $\lambda_{10,dry,unit}$ -value based on test measurements of thermal transmittance of masonry built from masonry units and mortar, the following procedure shall be used.

5.3.3.2 Testing procedure

- Select test samples from 3 different production batches for the product under consideration. Determine their mean gross dry density.
- From each of these batches erect one wall.
- Measure the thermal transmittance on each of those walls following EN 1934. If the measured wall is not in a dry state, the measured value has to be converted to the dry state following the procedure given in 6.4.

5.3.3.3 The determination of the $\lambda_{10,dry,unit}$ -value

- Calculate the $\lambda_{10,dry,mas}$ -value using the formula:

$$\lambda_{10,dry,mas} = \frac{d}{\frac{1}{U_{10,dry,mas}} - R_{si} - R_{se}}$$

where

$U_{10,dry,mas}$	is the thermal transmittance of the masonry in dry state, in W/m ² K;
R_{si}, R_{se}	are the internal and external surface resistance in m ² ·K/W according to EN ISO 6946;
d	is the thickness of the masonry in m;
$\lambda_{10,dry,mas}$	is the thermal conductivity of the masonry in dry state in W/(m·K).

- Calculate the $\lambda_{10,dry,unit}$ -value using the formula:

$$\lambda_{10,dry,unit} = \frac{100 \times \lambda_{10,dry,mas} - a_{mor} \times \lambda_{10,dry,mor}}{a_{unit}}$$

where

a_{mor}	is the percentage area of mortar joint in the measured masonry, in %;
a_{unit}	is the percentage area of units in the measured masonry, in %;
$\lambda_{10,dry,mor}$	is the thermal conductivity of the actual mortar joint in W/(m·K);
$\lambda_{10,dry,unit}$	is the thermal conductivity of the units in W/(m·K).

The thermal conductivity of the mortar joints shall take into account mortar pockets and strip bedding and the use of insulating material between the strips.

If the units are intended to be used with unfilled vertical mortar joints the masonry tested shall also be with unfilled joints and the $\lambda_{10,dry,unit}$ -values for the units will take into account the effect of the unfilled joints calculated according to EN ISO 6946.

Take the 3 individual calculated $\lambda_{10,dry,unit}$ -values and calculate the arithmetic mean value.

Measure the gross dry density of each of the three samples taken from each batch of masonry units and mortar following the procedure prescribed in EN 772-4 or EN 772-13 or EN 1015-10 and calculate the arithmetic mean value of the 3 results.

To the given $\lambda_{10,dry,mat}$ -values in the relevant table in Annex B find the corresponding net dry densities values in Annex A. From the corresponding net dry density values calculate the related gross dry density values using the following formula:

$$\rho_{g,dry} = \frac{100 - v}{100} \rho_{n,dry}$$

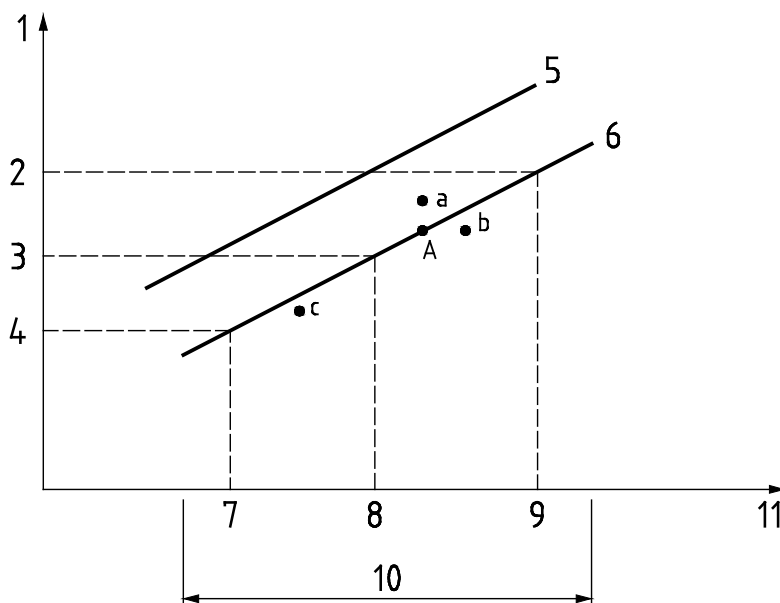
where

- $\rho_{g,dry}$ is the gross dry density in kg/m³;
- $\rho_{n,dry}$ is the net dry density in kg/m³;
- v is the percentage of voids taken from the relevant table in Annex B.

In cases where using Annex B: Through the point A representing mean thermal conductivity and mean density draw a λ /gross dry density-curve parallel to the general $\lambda_{10,dry,unit}$ /gross dry density-curve obtained from plotting the tabulated $\lambda_{10,dry,unit}$ -values in Annex B and the corresponding calculated gross dry density-values for the product.

Use the product related $\lambda_{10,dry,unit}$ /gross dry density-curve to determine the $\lambda_{10,dry,unit}$ -value related to the mean gross dry density the manufacturer is confident to achieve.

Figure 2 shows this process in the form of a graph.

**Key**

- 1 $\lambda_{10, dry, unit}$ (W/m·K)
- 2 upper limit λ -value
- 3 mean λ -value
- 4 lower limit λ -value
- 5 curve resulting from tabulated values (combination of Annexes A and B)
- 6 parallel curve drawn through point A (mean of the single values a, b, c)
- 7 10 % of production of the product under consideration
- 8 mean gross dry density
- 9 90 % of production of the product under consideration
- 10 product density range
- 11 gross dry density (kg/m³)

Figure 2 — Derivation of the $\lambda_{10, dry, unit}$ -value

For factory production control purposes, thermal conductivity may be controlled from the gross dry density of the product, see Annex E.

If there are no applicable tabulated values for the voided product in Annex B then alternatively a functional relationship between density and thermal conductivity of the units is allowed.

5.4 Test methods and numbers of samples to be taken

The minimum number of test specimens to be used for each test method shall be as specified in Table 3.

Table 3 — Test methods and minimum numbers of specimens within the test

Test methods	Minimum numbers of specimens
<i>Method P1:</i>	
Material density, EN 772-13	3 × 6
Thermal conductivity, EN 12664	3
<i>Method P2:</i>	
Material density, EN 772-13	6
<i>Method P3:</i>	
Material density, EN 772-13	3 × 6
Thermal conductivity, EN 12664	3
Thermal conductivity, EN 12667	3
<i>Method P4:</i>	
Material density, EN 772-13	6
Thermal conductivity for infill	3 or acc. relevant product standard
<i>Method P5:</i>	
Gross dry density, EN 772-13 and EN 1015-10	3 × 6
Thermal transmittance, EN 1934	3
NOTE For P1, P3 and P5, additional samples are tested to meet the requirements of each method to accurately determine the relationship between dry density and the thermal properties.	

6 Moisture conversion

6.1 General

Design thermal conductivity values/resistance values for masonry units or mortars may be determined using one of the following 3 procedures:

From the $\lambda_{10,dry}$ -value calculate the corresponding λ_{design} -value using the moisture conversion coefficient given in Annex A for each material and the design moisture content from the tables in EN ISO 10456 or the nationally given design moisture content for a specific material and application.

Alternatively, moisture conversion coefficients and moisture conversion factors can be derived from tests, carried out at several practical moisture contents.

NOTE Examples of practical conditions are the dry state, 23 °C/80 %, 23 °C/50 %.

6.2 Procedure A (for materials, mortar, solid masonry units and masonry):

$$\lambda_{design} = \lambda_{10,dry} \times F_m$$

or alternatively

$$R_{design} = \frac{R_{10,dry}}{F_m}$$

with

$$F_m = e^{f_u \times u_{design}}$$

or alternatively

$$F_m = e^{f_\psi \times \psi_{design}}$$

where

F_m	is the moisture conversion factor	;
f_u	is the moisture coefficient by mass	kg/kg;
u_{design}	is the design moisture content mass by mass	kg/kg;
f_ψ	is the moisture coefficient by volume	m ³ /m ³ ;
ψ_{design}	is the design moisture content volume by volume	m ³ /m ³ .

6.3 Procedure B (for masonry units with formed voids):

Moisture conversion has to be carried out for the thermal conductivity according to procedure A, followed by a calculation of the thermal conductivity of the unit according to 5.2.

Alternatively, an approximate method taking into account the percentage of voids can be used. Details of this procedure can be found in informative Annex F.

6.4 Procedure C (for composite masonry units):

Moisture conversion has to be carried out for the thermal conductivity of each constituent material according to procedure A, followed by a calculation of the thermal conductivity of the unit according to 5.2.

For composite masonry units the moisture conversion factors of each material have to be taken into account.

For masonry specimens consisting of composite masonry units and tested in the dry state according to EN 1934 by the hot box method, the simplified calculation method given in Annex G may be applied.

7 Determination of design thermal values ($R_{design,mas}$ or $\lambda_{design,mas}$) for masonry built from masonry units and mortar

7.1 General

Design thermal resistance or design thermal conductivity for masonry should be determined using one of following methods.

The $R_{design,mas}$ -values or $\lambda_{design,mas}$ -values of masonry built from masonry units can be determined from calculations, tables or tests.

7.2 $R_{design,mas}$ – or $\lambda_{design,mas}$ –values based on calculation

7.2.1 $R_{design,mas}$ – or $\lambda_{design,mas}$ –values based on λ_{design} –values for the masonry units and the mortar

Determine the $R_{design,mas}$ –or $\lambda_{design,mas}$ –values according to the following procedure:

Calculate the $\lambda_{design,mas}$ –values using the formula:

$$\lambda_{design,mas} = a_{mor} \lambda_{design,mor} + a_{unit} \lambda_{design,unit}$$

where

a_{mor}	is the percentage area of mortar joint, in %;
a_{unit}	is the percentage area of units, in %;
$\lambda_{design,mor}$	is the design equivalent thermal conductivity of the mortar joint, in W/(m·K);
$\lambda_{design,unit}$	is the design thermal conductivity of the units, in W/(m·K).

Calculate the design thermal resistance $R_{design,mas}$ using the formula:

$$R_{design,mas} = \frac{d}{\lambda_{design,mas}}$$

where

$R_{design,mas}$	is the design thermal resistance of masonry, in m ² ·K/W
d	is the thickness of the masonry in m.

7.2.2 $R_{design,mas}$ –or $\lambda_{design,mas}$ –values using a numerical calculation method based on the design thermal conductivity of the materials used

There are several numerical methods in use (e.g. Finite Difference, Finite Element) for the calculation of the thermal properties of masonry units. The thermal conductivities of the materials as necessary input parameters for such calculations shall be the λ_{design} -value for the masonry product used.

The requirements for appropriate calculation programs (accuracy, boundary conditions, etc.) are given in Annex D.

The method described in EN ISO 6946 may also be used.

7.3 $R_{design,mas}$ – or $\lambda_{design,mas}$ –values of masonry built from masonry units with formed voids and mortar based on tabulated values

7.3.1 Tabulated values

Equivalent $\lambda_{10,dry,mas}$ –values for masonry built with units having different void patterns are given in Annex B.

No tabulated values for composite masonry units are given in Annex B.

NOTE The types of units shown and the pattern of voids are intended as examples of units typically found on the market. They are not intended to cover every size and type of unit or void pattern produced.

7.3.2 Application of Annex B

Examples for material $\lambda_{10,dry,mat}$ –values for the determination of $R_{dry,mas}$ – or $\lambda_{10,dry,mas}$ –values of masonry built from masonry units with formed voids are given in Annex B, differentiated by:

- material;
- geometry of the units and geometry of formed voids;
- $\lambda_{10,dry,mat}$ –value of the material of the masonry units;
- $\lambda_{10,dry,mor}$ –value of the mortar.

The tabulated $R_{dry,mas}$ — or $\lambda_{10,dry,mas}$ –values should be taken as the basis for the calculation of any national design values, which are dependent on the climatic conditions and corrections for the application using 6.3.

Linear interpolation may be used for material conductivities between the values given in the tables in Annex B.

7.3.3 Alternative application of Annex B

The tabulated values have been calculated assuming a specific height and length of the masonry units, a specific thickness of the horizontal mortar joints and no mortar in the vertical joints (the “basic dimensions” are given for each geometry class). For masonry built from units with a different height, a correction for the mortar joints may be taken into account as follows. The same procedure may be used to determine values for masonry with vertical mortar joints in those cases where no separate values are given. These methods are suitable for all available masonry units.

Calculate the U_{mas} –value of the masonry from the λ_{mas} –value of the masonry in the table using the formula:

$$U_{mas} = \frac{1}{R_{si} + \frac{d}{\lambda_{mas}} + R_{se}}$$

where

- | | |
|------------------|---|
| U_{mas} | is the thermal transmittance of the masonry, in $W/(m^2 \cdot K)$; |
| R_{si}, R_{se} | are the internal and external surface resistance in $m^2 \cdot K/W$ according to EN ISO 6946; |
| d | is the thickness of the masonry in m; |
| λ_{mas} | is the tabulated value of the thermal conductivity of the masonry in $W/(m \cdot K)$. |

Calculate the thermal transmittance of the masonry units without mortar as follows:

$$U_{unit} = \frac{U_{mas} \times h - U_{mor} \times h_{mor}}{h_{unit}}$$

where

h_{unit} is the unit height which was the basis for the calculation of the tabulated value in mm;

h_{mor} is the height of the mortar joint which was basis for the calculation of the tabulated value in mm;

$h = h_{unit} + h_{mor}$ in mm;

U_{unit} is the thermal transmittance of the units without mortar influence in $W/(m^2K)$;

U_{mor} is the thermal transmittance of the mortar joint in $W/(m^2K)$ given by:

$$U_{mor} = \frac{1}{R_{si} + \frac{d}{\lambda_{mor}} + R_{se}}$$

λ_{mor} is the thermal conductivity of the mortar in $W/(m \cdot K)$.

Calculate the thermal transmittance of masonry built from units with another height, as follows:

$$U_{mas,act} = \frac{U_{unit} \times h_{unit,act} + U_{mor} \times h_{mor,act}}{h_{act}}$$

where

$U_{mas,act}$ is the thermal transmittance of masonry made from units with the height h_{unit} in $W/m^2 \cdot K$;

$h_{unit,act}$ is the actual height of the unit in mm;

$h_{mor,act}$ is the actual height of the mortar joint in mm;

$h_{act} = h_{unit,act} + h_{mor,act}$ in mm.

A similar calculation may be applied for different length of masonry units and thickness of vertical mortar joints.

If there are no vertical mortar joints the differing lengths of the units may be ignored.

NOTE 1 The thermal transmittance of masonry made from masonry units with a length > 250 mm which have a tongue and groove system instead of vertical mortar joints will be lower than the tabulated value, which means that the tabulated value is on the safe side. For masonry units with shapes as shown in Figures B.23 to B.28, where the voids run continuously over the vertical joint, the length of the unit has no influence on the thermal transmittance.

NOTE 2 The heat flow direction is indicated in the drawings in Annex B by means of an arrow.

7.4 Method S4/P6 $R_{design,mas}$ – or $\lambda_{design,mas}$ – values of masonry based on masonry testing

$\lambda_{10,dry,mas}$ – values are determined by masonry testing according to EN 1934 (Table 1).

Moisture correction according to Clause 6 is used to calculate $R_{design,mas}$ – or $\lambda_{design,mas}$ – values.

8 Determination of the thermal transmittance of masonry

Calculation of the thermal transmittance U shall be made according to EN ISO 6946.

9 Specific heat capacity

The thermal mass of the construction has a significant influence on the heating and cooling requirements of buildings. Values for the specific heat capacity c_p are therefore given in Annex A.

10 Rounding rules for λ -values for masonry units and masonry

The value should be rounded according to EN ISO 10456.

Annex A **(normative)**

Tabulated $\lambda_{10,dry,mat}$ -values of materials used for masonry products

The water vapour resistance factor μ describes how many times higher the diffusion resistance of a material layer is, than the resistance of an air layer with the same thickness under the same conditions. To compare the diffusion resistance of two building elements, it is necessary to multiply the μ -factor by the thickness of the respective layer, which leads to a figure with the dimension m. The diffusion behaviour is different, whether it is diffusion into a building component (lower values) or out of the building component (drying period, higher value). Linear interpolation may be used between the values given in the tables, with rounding according to EN ISO 10456:2007¹, Clause 5, a).