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Masonry units test methods — Determination of thermal properties

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Rwanda Standards Board

P.O Box 7099 Kigali-Rwanda

KK 15 Rd, 49

Tel. +250 788303492

Toll Free: 3250

E-mail: info@rsb.gov.rw

Website: www.rsb.gov.rw

ePortal: www.portal.rsb.gov.rw

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Foreword

Rwanda Standardsarepreparedby Technical Committees and approved by Rwanda Standards Board (RSB) Board of Directors in accordance with the procedures of RSB, in compliance with Annex 3 of the WTO/TBT agreement on the preparation, adoption and application of standards.

The main task of technical committees is to prepare national standards. Final Draft Rwanda Standards adopted by Technical committees are ratified by members of RSB Board of Directors for publication and gazettment as Rwanda Standards.

DRS524 was prepared by Technical Committee RSB/TC 9, *Civil engineering and Building materials.*

In the preparation of this standard, reference was made to the following standard:

BS EN 1745:2012 : Masonry and masonry products — Methods for determining thermal properties :

The assistance derived from the above source is hereby acknowledged with thanks.

Committee membership

The following organizations were represented on the Technical Committee on *Civil engineering and Building materials*(RSB/TC 9) in the preparation of this standard.

A+Construction Group Ltd

Africeramics Ltd

Consultants Engineers Group (CEG) Ltd

D&D Resources Ltd

Dutureheza Ltd

Enabel Rwanda

Greenpack Africa Ltd

Integrated Polytechnic Regional Centre (IPRC) - Musanze

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Stonecraft Industries Ltd

University of Rwanda - College of Science and Technology (UR - CST)

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Introduction

This Draft Rwanda Standard provides rules for the determination of dry and design thermal conductivity and thermal resistance values of masonry products and masonry.

It describes how dry thermal values are determined. It also describes the correction methods to derive design values from a dry value. The dry value is a characteristic of a masonry material, masonry unit or of masonry. On the basis of dry thermal conductivity values determination methods of design thermal values are given.

Three procedures (model S1 – S3) for the determination of dry thermal conductivity ($\lambda_{10,dry,unit}$) of solid masonry units are described and five procedures (model P1 – P5) for the determination of equivalent dry thermal conductivity ($\lambda_{10,dry,unit}$) of masonry units with formed voids and composite masonry units are described, see Figure 1.

For mortars according to EN 998-1 and EN 998-2, the models S1 – S2 can be used.

Additionally, three procedures for the determination of thermal resistance are described. These procedures are:

— the use of tabulated R-values;

— the measurement of R-value;

— the numerical calculation of R-value.

The following major types of masonry units are covered by this European Standard:

— solid masonry units;

— masonry units with formed voids;

— composite masonry units.

In Figure 1, the different models and procedures are illustrated.

The design value of a product characteristic is the value determined for a specific application and for use in calculations.

Design thermal values are determined, according to the procedure 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.

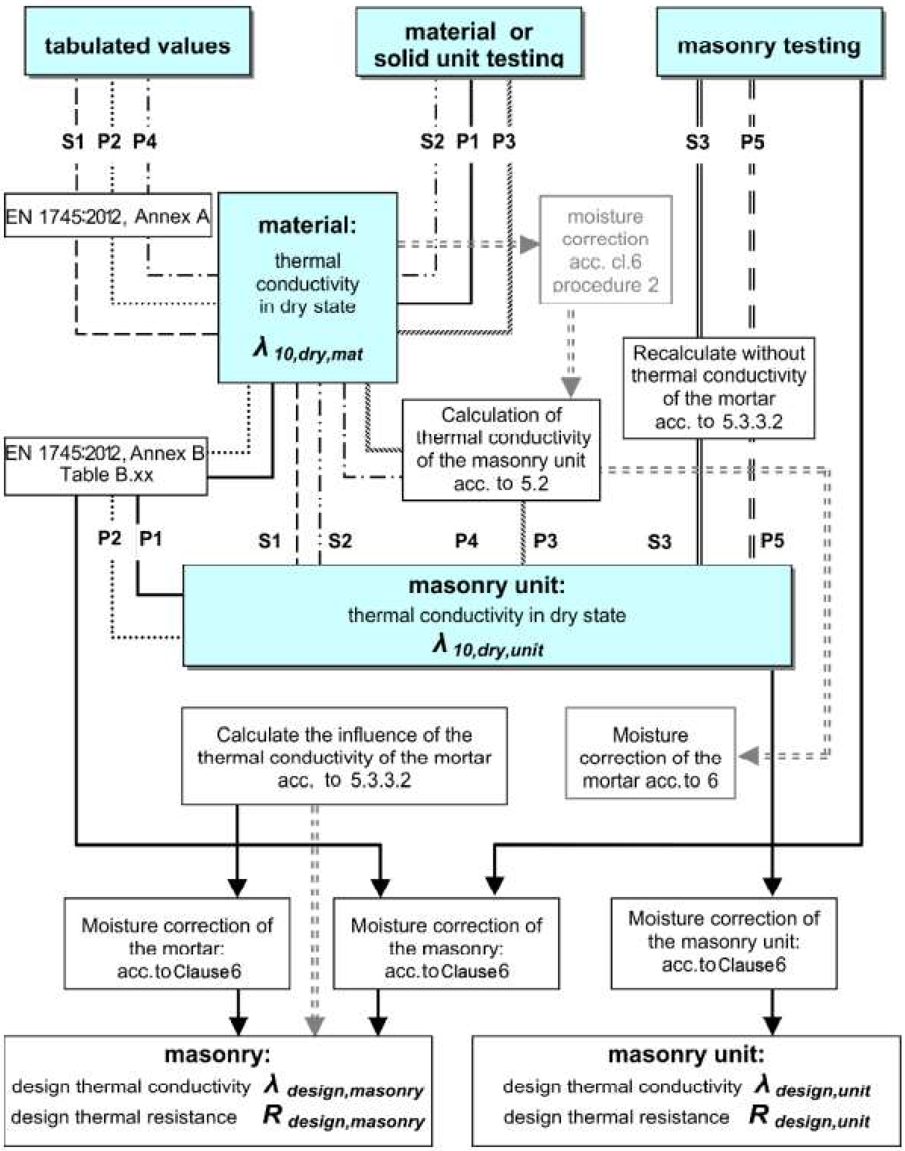


Figure 1 — Determination of thermal properties of masonry units and masonry

Masonry and masonry products — Methods for determining thermal properties

1 Scope

This Draft Rwanda standards specifies procedures 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.

DRS 526, Natural stone test methods : Determination of real and bulk density and of total and open porosity

DRS 526, Natural stone test methods — Determination of real and apparent density and total porosity

Comment [SN1]: Replaced by Annex B

ISO 6946, Building components and building elements — Thermal resistance and thermal transmittance — Calculation method

ISO 7345, Thermal insulation — Physical quantities and definitions

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

ISO 10456, Building materials and products — Hydrothermal properties — Tabulated design values and procedures for determining declared and design thermal values

3 Terms and definitions

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

3.1

masonry

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

3.2

masonry product

masonry units, masonry mortars, rendering and plastering mortars

3.3

solid masonry unit

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

3.4

masonry unit with formed voids

masonry unit with a system of intentionally formed voids

3.5

composite masonry unit

masonry unit incorporating one or more layers of additional material to enhance performance

3.6

thermal value

common term for either the thermal conductivity [W/(m·K)] or the thermal resistance [m2·K/W]

3.7

dry state

state after drying under conditions stated in the relevant standards

3.8

dry thermal value

value of a thermal property of a building material or product in a dry state determined according to this Rwanda standards 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.

3.9

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

3.10

masonry thermal conductivity

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

3.11

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

3.12

equivalent thermal conductivity

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

4 Symbols (and abbreviated terms)

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 the material	W/(mK)
$\lambda_{10,dry,mas}$	thermal conductivity at an average temperature of 10 °C in dry state for the masonry	W/(mK)
$\lambda_{10,dry,mor}$	thermal conductivity at an average temperature of 10 °C in dry state for the mortar	W/(mK)
$\lambda_{10,dry,unit}$	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/(mK)
$\lambda_{design,mas}$	design thermal conductivity for the masonry	W/(mK)
$\lambda_{design,mor}$	design thermal conductivity for the mortar	W/(m¢K)
$\lambda_{design,unit}$	design thermal conductivity for the unit	W/(mK)
λ_i	individual measured or calculated thermal conductivity	W/(mK)
R_i	individual measured thermal resistance	m^2¢K/W

$R_{dry,mas}$	thermal resistance of masonry	m^2K/W
$R_{design,mas}$	design thermal resistance of masonry	m^2K/W
R_{si}, R_{se}	internal and external surface resistance	m^2K/W
$R_{t,mas}$	the true thermal resistance of the masonry	m^2K/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 diffusion coefficient	
c_p	specific heat capacity	J/(kg·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 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	%

3.3 Subscripts

$_{10}$ average test temperature of 10 °C

$_{dry}$ state after drying under conventional conditions as stated in the relevant standards

$_{mas}$ masonry

$_{mat}$ material

$_{mor}$ mortar

$_{unit}$ masonry unit

5 Procedures to determine $\lambda_{10,dry,\ unit}$-values for solid masonry units and $\lambda_{10,dry,mor}$-values for mortars

5.1 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.

5.2 $\lambda_{10,dry,\ mat}$-values for solid masonry units and mortars

5.2.1 Model S1. Determination of $\lambda_{10,dry,unit}$-values from tabulated $\lambda_{10,dry,mat}$/net dry density relation

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 diffusion coefficient, 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 measured λ-values. $\lambda_{10,dry,mat}$ - values are given as 50 % and 90 % fractiles (P).

5.2.2 Model S2. Determination of λ10,dry,unit-values based on λ10,dry,mat /net dry density curve

5.2.2.1 General

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

5.2.2.2 Test specimens

Test specimens shall be in accordance with the requirements of Annex C . 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.

5.2.2.3 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 ± 2) °C and 50 % ± 5 % relative humidity), in which case the measured value has to be converted to the dry state following one of the procedures given in Clause 6.

5.2.2.4 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 measured λ_i-value as prescribed in 5.2.2.1 to 5.2.2.3 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 prescribed in DRS 526 and calculate the arithmetic mean value of the 3 results.

Comment [SN2]: I think, since they propose more options, we can remain other one option and omit others.

Then use the following procedure.

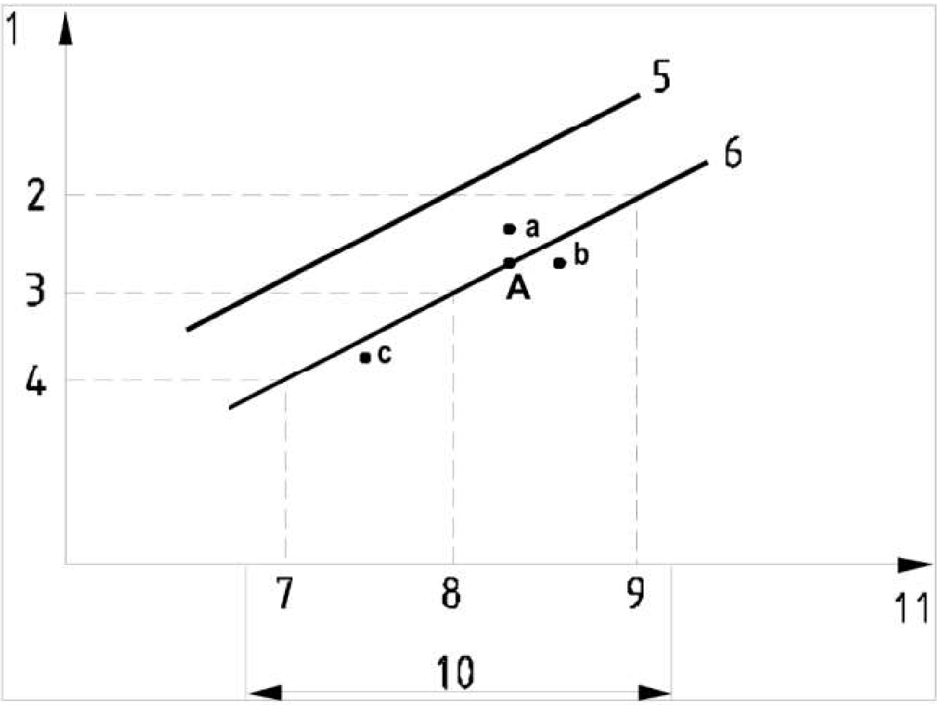
Through the point A representing mean thermal conductivity and mean net dry density draw a λ/net dry density-curve parallel to the general $\lambda_{10,dry,mat}$/net dry density-curve obtained from plotting the tabulated λ- and net dry density-values for the product (material) given in Annex A.

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 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 2 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 2 — Derivation of the material $\lambda_{10,dry,mat}$-value

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

5.2.3 Model S3. Procedures to determine $\lambda_{10,dry,unit}$-values from determining the thermal transmittance (U_{mas}) of masonry built from solid masonry units and mortar

To determine a $\lambda_{10,dry\ unit}$-values from test measurements of the thermal transmittance of masonry built from masonry units and mortars, the procedure in 6.3.3 shall be used.

5.3 Test methods and numbers of samples to be taken for the different models

In the following table test methods and numbers of samples to be taken for the different models is given.

Table 1 — Test methods and minimum numbers of specimens within the test

Test methods	Minimum numbers of specimens
Model S1: Material density, DRS 526 (natural stone units) *Model S2:* Material density, DRS 526 (natural stone units) Thermal conductivity, Annex B Gross dry density, DRS 526 (natural stone units) Thermal transmittance, Annex B	6 3 3 3 × 6 3

6 Procedures to determine equivalent $\lambda_{10,dry,unit}$-values for masonry units with formed voids and composite masonry units

6.1 General

The thermal properties of masonry units with formed voids cannot fully be determined by the $\lambda_{10,dry,mat}$-value of the material, there is also a high influence from the shape and the geometry of the voids in the unit. The thermal conductivity of the materials can be derived from tables or measurements.

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

— 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:

— from calculations;

— from measurements carried out on masonry samples.

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

6.3 $\lambda_{10,dry,unit}$-values of masonry units

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

6.3.1.1 General

$\lambda_{10,dry,unit}$-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.

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.

6.3.1.2 Application of Annex B

Examples for λ10,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.

6.3.1.3 Model P1. The determination of the $\lambda_{10,dry,unit}$-value using Annex B using measured thermal conductivity of the masonry unit material

To determine a $\lambda_{10,dry,unit}$-value from 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 a measured thermal conductivity of the masonry unit material as specified in 4.2.2.

6.3.1.4 Model P2. The determination of the $\lambda_{10,dry,unit}$-value using Annex B using tabulated value from Annex A

To determine a $\lambda_{10,dry,unit}$-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.

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

6.3.2.1 General

To determine a $\lambda_{10,dry,unit}$-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 $\lambda_{10,dry,mat}$-value;
- the orientation of the unit in use a numerical model of the unit can be established and the thermal transmittance can be approximated.

This method is also suitable for composite masonry units, where the calculation is dealt with separately for each layer.

6.3.2.2 Model P 3. Determination of $\lambda_{10,dry,unit}$–values using measured thermal conductivity of the masonry unit material

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. The $\lambda_{10,dry,mat}$-value is a measured thermal conductivity of the masonry unit material as specified in 4.2.2.

6.3.2.3 Model P 4. 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. The $\lambda_{10,dry,mat}$-value is tabulated values from Annex A.

6.3.3 Model 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

6.3.3.1 General

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

6.3.3.2 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 Annex B . 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 Clause 6.

6.3.3.3 The determination of the $\lambda_{10,dry,unit}$–value

Calculate the $\lambda_{10,\ dry,\ mas}$ - value using the equation: $\lambda_{10,dry,mas}$ = $\lambda_{10,dry,mas} = \frac{d}{\frac{1}{U_{10,dry,mas}} - R_{si} - R_{se}}$

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}єK/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).

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

a_{mor} is the percentage area of mortar joint in the measured masonry;

a_{unit} is the percentage area of units in the measured masonry;

$\lambda_{10,dry,mor}$ is the thermal conductivity of the actual mortar joint;

$\lambda_{10,dry,unit}$ is the thermal conductivity of the units.

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 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 DRS 526 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 equation:

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

ρg,dry =100100−vρn,dry

where

$\rho_{g,dry}$ is the gross dry density in kg/m³;

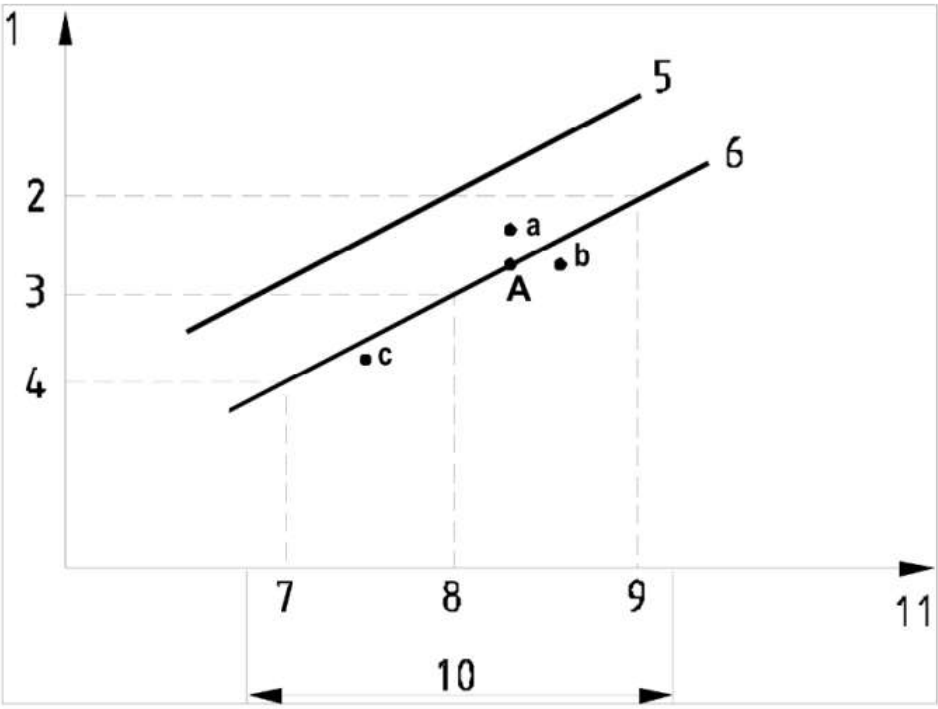
$\rho_{n,dry}$ is the net dry density in kg/m³;

v is the percentage of voids taken from the relevant table in AnnexB.

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 3 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/m^3)

Figure 3 — Derivation of the $\lambda_{10,dry,unit}$-value

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

6.4 Test methods and numbers of samples to be taken for the different models

In the following table test methods and numbers of samples to be taken for the different models is given.

6.4.1.1 Table 2 — Test methods and minimum numbers of specimens within the test

Test methods	**Minimum numbers of specimens**
Model P1:	
Material density, DRS 526 13	6
Thermal conductivity, Annex B	3
Material density, DRS 526 *:*	6
Material density, DRS 526 13	
Thermal conductivity, Annex B	3
	3
Material density, DRS 526	
Gross dry density, DRS 526	6
Thermal transmittance, ISO 1934	
	3×6
	3

7 Moisture conversion

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.

Procedure 1 (for materials, mortar and solid masonry units):

$\lambda_{design} = \lambda_{10,dry} x F_m$ Or alternatively $R_{design} = \frac{R_{10,dry}}{F_m}$

$F_m = e^{f_u \times u_{design}}$ Or alternatively $F_m = e^{f_\psi \times \psi_{design}}$

F_m is the moisture conversion factor [1];

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 m³/m³ ;

Ψ_{design} is the design moisture content volume by volume m³/m³.

Procedure 2 (for masonry units with formed voids and composite masonry units):

Moisture conversion has to be carried out for the thermal conductivity of each constituent material according to procedure 1, followed by a calculation of the thermal conductivity of the unit according to 5.2.

For composite masonry units and partially filled units with formed voids the moisture conversion factors of each material have to be taken into account.

Procedure 3 (for masonry units with formed voids):

As an alternative to procedure 2 an approximate method taking into account the percentage of voids can be used. Details of this procedure can be found in informative Annex F.

8 Procedures to determine design thermal values ($R_{design,mas}$ or $\lambda_{design, mas}$) for masonry built from masonry units and mortar

8.1 General

Design thermal resistance or design thermal conductivity for masonry may be determined using one of following procedures.

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

8.2 $R_{design,mas}$- or $\lambda_{design,mas}$-values based on calculation

8.2.1 $R_{design,mas}$- 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 equation

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

were

a_{mor} is the percentage area of mortar joint;

a_{unit} is the percentage area of units;

$\lambda_{design,mor}$ is the design equivalent thermal conductivity of the mortar joint;

$\lambda_{design,unit}$ is the design thermal conductivity of the units.

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

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

where d is the thickness of the masonry in m.

8.2.2 Rdesign,mas- or λdesign,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 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.

8.3 Rdesign,mas- or λdesign,mas-values of masonry built from masonry units with formed voids or composite masonry units and mortar based on tabulated values

8.3.1 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.

8.3.2 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 Rdry,mas- or λ10,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 Clause 6.

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

8.3.3 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 equation:

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

Where:

U_{mas} is the thermal transmittance of the masonry, in W/(m2·K);

R_{si}, R_{se} are the internal and external surface resistance in m2cK/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·K).

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

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

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/(m2 K);

U_{mor} is the thermal transmittance of the mortar joint in W/(m2K) 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·K).

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

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

where

$U_{mas,act}$ is the thermal transmittance of masonry made from units with the height hunit in W/m2·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.

9 Determination of the thermal transmittance of masonry

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

10 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 cp are therefore given in Annex A.

11 Rounding rules for λ-values for 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 diffusion coefficient μ is defined as the factor, which 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).

Table A.1 — Clay units (fired clay)

Density of the material (net dry density)	$\lambda_{10,dry,mat}$ [W/(m·K)]		Water vapour diffusion coefficient	Specific heat capacity c_p
[kg/m³]	*P* = 50 % [a]	*P* = 90 %	μ	[J/(kg·K)]
1 000	0,20	0,27	5/10	1 000
1 100	0,23	0,30	5/10	1 000
1 200	0,26	0,33	5/10	1 000
1 300	0,30	0,36	5/10	1 000
1 400	0,34	0,40	5/10	1 000
1 500	0,37	0,43	5/10	1 000
1 600	0,41	0,47	5/10	1 000
1 700	0,45	0,51	5/10	1 000
1 800	0,49	0,55	5/10 [b]	1 000
1 900	0,53	0,60	5/10 [b]	1 000
2 000	0,58	0,64	5/10 [b]	1 000
2 100	0,62	0,69	5/10 [b]	1 000
2 200	0,67	0,74	5/10 [b]	1 000
2 300	0,72	0,79	5/10 [b]	1 000
2 400	0,77	0,84	5/10 [b]	1 000

$f\psi = 10$ (m3/m3)

Calculations in support of the Energy Performance of Buildings Directive are related to buildings and not to individual products. U-values used in such calculations are based on the mean thermal resistance of masonry elements. Therefore the recommended material λ value is the 50 % fractile.

For clay materials with a density between 1 800 kg/m3 and 2 400 kg/m3 used as facing materials the μ-value is 50/100 instead of 5/10.

Table A.2 — Calcium silicate units

Density of the material (net dry density)	$\lambda_{10,dry,mat}$ [W/(m·K)]		Water vapour diffusion coefficient	Specific heat capacity c_p
[kg/m³]	P = 50 % [a]	P = 90 %	μ	[J/(kg·K)]
900	0,22	0,29	5/10	1 000
1 000	0,24	0,30	5/10	1 000
1 100	0,26	0,32	5/10	1 000
1 200	0,30	0,36	5/10	1 000
1 300	0,34	0,41	5/10	1 000
1 400	0,40	0,46	5/10	1 000
1 500	0,47	0,53	5/25	1 000
1 600	0,55	0,61	5/25	1 000
1 700	0,64	0,70	5/25	1 000
1 800	0,75	0,81	5/25	1 000
1 900	0,86	0,92	5/25	1 000
2 000	0,98	1,05	5/25	1 000
2 100	1,14	1,20	5/25	1 000
2 200	1,31	1,37	5/25	1 000
2 300	1,49	1,56	5/25	1 000
2 400	1,68	1,76	5/25	1 000

f_ψ = 10 (m3/m3)

a Calculations in support of the Energy Performance of Buildings Directive are related to buildings and not to individual products. U-values used in such calculations are based on the mean thermal resistance of masonry elements. Therefore the recommended material λ value is the 50 % fractile.

Table A.3 — Dense aggregate concrete units and manufactured stone units

Density of the material (net dry density)	$\lambda_{10,dry,mat}$ [W/(m·K)]		Water vapour diffusion coefficient	Specific heat capacity c_p
[kg/m³]	P = 50 % [a]	P = 90 %	μ	[J/(kg·K)]
1 600	0,69	0,88	5/15	1 000
1 700	0,75	0,93	5/15	1 000
1 800	0,82	1,01	5/15	1 000

1 900	0,90	1,09	5/15	1 000
2 000	1,00	1,19	5/15	1 000
2 100	1,11	1,30	5/15	1 000
2 200	1,24	1,42	30/100	1 000
2 300	1,37	1,56	50/150	1 000
2 400	1,52	1,72	50/150	1 000

fψ = 4 (m3/m3)

a Calculations in support of the Energy Performance of Buildings Directive are related to buildings and not to individual products. U-values used in such calculations are based on the mean thermal resistance of masonry elements. Therefore the recommended material λ value is the 50 % fractile.

Table A.4 — Concrete units with no other aggregate than pumice

Density of the material (net dry density)	*λ10,dry,mat* [W/(m·K)]		Water vapour diffusion coefficient	Specific heat capacity c_p
[kg/m³]	*P* = 50 % [a]	*P* = 90 %	μ	[J/(kg·K)]
500	0,11	0,14	5/15	1 000
600	0,13	0,16	5/15	1 000
700	0,16	0,18	5/15	1 000
800	0,19	0,21	5/15	1 000
900	0,22	0,24	5/15	1 000
1 000	0,26	0,28	5/15	1 000
1 100	0,30	0,32	5/15	1 000
1 200	0,34	0,36	5/15	1 000
1 300	0,38	0,41	5/15	1 000

fψ = 4 (m3/m3)

a Calculations in support of the Energy Performance of Buildings Directive are related to buildings and not to individual products. U-values used in such calculations are based on the mean thermal resistance of masonry elements. Therefore the recommended material λ value is the 50 % fractile.

Table A.5 — Concrete units with polystyrene aggregate

Density of the material (net dry density)	λ*10,dry,mat* [W/(m·K)]		Water vapour diffusion coefficient	Specific heat capacity c_p
[kg/m^3]	*P* = 50 % [a]	*P* = 90 %	μ	[J/(kg·K)]
500	0,13	0,16	5/15	1 000
600	0,14	0,19	5/15	1 000
700	0,17	0,22	5/15	1 000
800	0,18	0,25	5/15	1 000

fψ = 5 (m3/m3)

a Calculations in support of the Energy Performance of Buildings Directive are related to buildings and not to individual products. U-values used in such calculations are based on the mean thermal resistance of masonry elements. Therefore the recommended material λ value is the 50 % fractile.

Table A.6 — Concrete units with expanded clay aggregate

Density of the material (net dry density)	λ*10,dry,mat* [W/(m·K)]		Water vapour diffusion coefficient	Specific heat capacity c_p
[kg/m^3]	*P* = 50 % [a]	*P* = 90 %	μ	[J/(kg·K)]
400	0,10	0,12	5/15	1 000
500	0,12	0,15	5/15	1 000
600	0,16	0,18	5/15	1 000
700	0,19	0,21	5/15	1 000
800	0,22	0,25	5/15	1 000
900	0,26	0,28	5/15	1 000
1 000	0,30	0,32	5/15	1 000
1 100	0,34	0,36	5/15	1 000
1 200	0,39	0,41	5/15	1 000
1 300	0,43	0,46	5/15	1 000
1 400	0,48	0,51	5/15	1 000
1 500	0,53	0,56	5/15	1 000
1 600	0,60	0,63	5/15	1 000
1 700	0,67	0,70	5/15	1 000

f_u = 4 (kg/kg) if expanded clay is the predominant aggregate f_u = 2,6 (kg/kg) if expanded clay is the only aggregate

[a] Calculations in support of the Energy Performance of Buildings Directive are related to buildings and not to individual products. *U*-values used in such calculations are based on the mean thermal resistance of masonry elements. Therefore the recommended material λ value is the 50 % fractile.

Table A.7 — Concrete units with more than 70 % expanded blast-furnace slag aggregate [a]

Density of the material (net dry density)	$\lambda_{10,dry,mat}$ [W/(m·K)]		Water vapour diffusion coefficient	Specific heat capacity c_p
[kg/m³]	*P* = 50 % [b]	*P* = 90 %	μ	[J/(kg·K)]
1 100	0,19	0,21	5/15	1 000
1 200	0,23	0,24	5/15	1 000
1 300	0,28	0,29	5/15	1 000
1 400	0,33	0,34	5/15	1 000
1 500	0,39	0,40	5/15	1 000
1 600	0,45	0,47	5/15	1 000
1 700	0,52	0,54	5/15	1 000

f_u = 4 (kg/kg)

A lightweight aggregate produced by the expansion of molten blast-furnace slag with water. Blast-furnace slag is a by-product of the extraction of iron haematite ores.

Calculations in support of the Energy Performance of Buildings Directive are related to buildings and not to individual products. *U*-values used in such calculations are based on the mean thermal resistance of masonry elements. Therefore the recommended material λ value is the 50 % fractile.

Table A.8 — Concrete units with the predominant aggregate derived from pyroprocessed colliery material

Density of the material (net dry density)	$\lambda_{10,dry,mat}$ [W/(m·K)]		Water vapour diffusion coefficient	Specific heat capacity c_p
[kg/m³]	*P* = 50 % [a]	*P* = 90 %	μ	[J/(kg·K)]
1 100	0,31	0,35	5/15	1 000
1 200	0,33	0,37	5/15	1 000
1 300	0,35	0,39	5/15	1 000
1 400	0,37	0,41	5/15	1 000
1 500	0,39	0,43	5/15	1 000

$f_u = 4$ (kg/kg)

[a] Calculations in support of the Energy Performance of Buildings Directive are related to buildings and not to individual products. *U*-values used in such calculations are based on the mean thermal resistance of masonry elements. Therefore the recommended material λ value is the 50 % fractile

Table A.9 is to be used for concrete units with lightweight aggregates, where no history for λexists (e.g. for new products). Therefore, no 50 % and 90 % fractiles (*P*) can be given, the givenλ-values are to be understood as safe values for all different types of aggregates.

Table A.9 — Concrete units with other lightweight aggregates

Density of the material (net dry density) [kg/m^3]	$\lambda_{10,dry,mat}$ [a] [W/(m·K)]	Water vapour diffusion coefficient μ	Specific heat capacity c_p [J/(kg·K)]
500	0,24	5/15	1 000
600	0,27	5/15	1 000
700	0,30	5/15	1 000
800	0,33	5/15	1 000
900	0,37	5/15	1 000
1 000	0,41	5/15	1 000
1 100	0,46	5/15	1 000
1 200	0,52	5/15	1 000
1 300	0,58	5/15	1 000
1 400	0,66	5/15	1 000
1 500	0,74	5/15	1 000
1 600	0,83	5/15	1 000
1 800	1,08	5/15	1 000
2 000	1,33	5/15	1 000

$f_\psi = 4$ (m^3/m^3)

[a] Calculations in support of the Energy Performance of Buildings Directive are related to buildings and not to individual products. *U*-values used in such calculations are based on the mean thermal resistance of masonry elements. Therefore, the recommended material λ value is the 50 % fractile.

Table A.10 — Autoclaved aerated concrete units

Density of the material (net dry density)	$\lambda_{10,dry,mat}$ [W/(m·K)]	Water vapour diffusion coefficient	Specific heat capacity c_p

[kg/m³]	*P* = 50 % [a]	*P* = 90 %	μ	[J/(kg·K)]
300	0,072	0,085	5/10	1 000
400	0,096	0,11	5/10	1 000
500	0,12	0,13	5/10	1 000
600	0,15	0,16	5/10	1 000
700	0,17	0,18	5/10	1 000
800	0,19	0,21	5/10	1 000
900	0,22	0,24	5/10	1 000
1 000	0,24	0,26	5/10	1 000

f_u = 4 (kg/kg)

[a] Calculations in support of the Energy Performance of Buildings Directive are related to buildings and not to individual products. *U*-values used in such calculations are based on the mean thermal resistance of masonry elements. Therefore the recommended material λ value is the 50 % fractile.

Table A.11 — Natural stone units [a]

Type of stone	Density of the material (net dry density) [kg/m³]	$\lambda_{10,dry,mat}$ [W/(m·K)]	Water vapour diffusion coefficient μ dry	wet	**Specific heat capacity** c_p [J/(kg·K)]
1. METAMORPHIC AND PLUTONIC ROCKS					
Gneiss, porphyry	2 300 to 2 900	3,5	10 000	10 000	1 000
Marble	2 600 to 2 800	3,5	10 000	10 000	1 000
Granites	2 500 to 2 700	2,8	10 000	10 000	1 000
Shale, slates	2 000 to 2 800	2,2	1 000	800	1 000
2. VOLCANIC ROCKS					
Basalt	2 700 to 3 000	1,6	10 000	10 000	1 000
Trachytes, andesites	2 000 to 2 700	1,1	20	15	1 000
Vacuole lava					

	≤ 1 600	0,55	20	15	1 000
3. LIMESTONE					
- very hard stone	2 200 to 2 590	2,3	250	200	1 000
- hard rock	2 000 to 2 190	1,7	200	150	1 000
- compact stone	1 800 to 1 990	1,4	50	40	1 000
- soft stone	1 600 to 1 790	1,1	40	25	1 000
- very soft stone	≤ 1 590	0,85	30	20	1 000
4. SANDSTONE					
- Quartz sandstone	2 600 to 2 800	2,6	40	30	1 000
- Siliceous sandstone	2 200 to 2 590	2,3	40	30	1 000
- Calciferous sandstone	2 000 to 2 700	1,9	30	20	1 000
5. FLINT, MILLSTONE, PUMICE					
- Flint	2 600 to 2 800	2,6	10 000	10 000	1 000
- Millstone	1 900 to 2 500	1,8	50	40	1 000
- Millstone	1 300 to 1 900	0,9	30	20	1 000
- Natural pumice	≤ 400	0,12	8	6	1 000
[a] For these materials the 50 % / 90 % approach is not applicable.					

Table A.12 — Mortar (masonry mortar and rendering mortar)

Density of the material (net dry density)	$\lambda_{10,dry,mat}$ [W/(m·K)]		Water vapour diffusion coefficient	Specific heat capacity c_p
[kg/m^3]	P = 50 % [a]	P = 90 %	μ	[J/(kg·K)]
200	0,074	0,081	5/20	1 000
300	0,086	0,094	5/20	1 000
400	0,10	0,11	5/20	1 000

500	0,12	0,13	5/20	1 000
600	0,14	0,15	5/20	1 000
700	0,16	0,17	5/20	1 000
800	0,18	0,20	5/20	1 000
900	0,21	0,23	5/20	1 000
1 000	0,25	0,27	5/20	1 000
1 200	0,33	0,36	5/20	1 000
1 400	0,45	0,49	5/20	1 000
1 600	0,61	0,66	15/35	1 000
1 800	0,82	0,89	15/35	1 000
2 000	1,11	1,21	15/35	1 000

f_ψ = 4 (m3/m3)

a Calculations in support of the Energy Performance of Buildings Directive are related to buildings and not to individual products. U-values used in such calculations are based on the mean thermal resistance of masonry elements. Therefore the recommended material λ value is the 50 % fractile.

Annex B
(normative)

Determination of thermal resistance by hot box method using heat flow meter — Masonry

B.1 Test procedure

B.1.1 Applicability of the method

The applicability of the method to a particular specimen should be assessed, see also the introduction. Layered specimens with highly conducting facings and a core material of low thermal conductivity may induce a lateral heat flow larger than permitted by 6.2.1, hence measurements of the individual layer sand subsequent calculations on the whole structure may be necessary.

Simplified calculations are also a suitable means to assess measured values and related accuracy.

B.1.2 Conditioning of the specimen

Specimens shall be stored for a sufficient period of time to achieve an even moisture distribution within them. Three conditioning alternatives apply.

a) Dry specimen: as a general rule, drying shall be done at 105 8C until constant mass is reached. For specimens containing materials susceptible to property changes at this temperature, the drying should be at 70 8C (e.g. polystyrene plastic foams) or at 40 8C (e.g. materials containing gypsum). The specimen shall then be allowed to cool before starting the test. To keep the specimen dry it may be necessary to enclose the specimen in a vapour-tight envelope.

b) Conditioning under a temperature gradient: the test specimen shall be conditioned at the same boundary conditions (temperature and relative humidity) as those foreseen for the hot box test. The conditioning shall continue until moisture equilibrium is reached.

c) Conditioning to a specified moisture content: the test specimen shall be conditioned at (23 ± 2) 8C and a certain relative humidity (not exceeding 95 %, in order to stay in the hygroscopic range), until constant mass is reached. After conditioning, it may be necessary to enclose the test specimen in a vapour-tight envelope.

For measurements on masonry walls in a moist condition, according to options b) and c) of this subclause, the range of moisture content of the specimens should correspond to the practical moisture content or at least not exceed this value by more than 3 % by volume.

To keep the influence of moisture redistribution during the test within acceptable limits, the duration of the measurements shall be kept as short as possible,

i.e. testing should be finished as soon as the thermal steady-state condition is reached.

The mass of the specimen before and after the test shall be reported, or core samples shall be taken before and after the test.

The dry bulk densities of all building materials are to be determined. The size and bulk density of masonry have to be examined in accordance with the relevant product standard. For masonry mortar, the dry bulk density shall be measured; for light masonry material both the bulk density and mortar density shall be measured. The bulk density of concrete and similar materials shall be examined in accordance with the respective product standards. Aggregates and their mixing ratio and grain size distribution shall be measured. For loose fill insulation materials, the bulk density in the dry state and, if possible, grain size distribution are to be determined in accordance with respective product standards.

B.1.3 Specimen selection and mounting

The test specimen shall be selected or constructed in such a way that it is representative and according to common practice; areas likely to have different surface temperatures should be included in the metering section in a representative way. For specimens of this type, the local density of heat flow rate can be estimated by preliminary additional measurements before the installation of the heat flow meter. For this purpose small size heat flow meters can be used whose thermal resistances do not significantly alter the local density of heat flow rate (thickness: less than 1 mm) and whose areas correspond to the influence areas of the thermal bridges. Also thermographic inspections can help in evaluating inhomogeneities. Specimens not meeting the homogeneity criteria defined in 5.3.2, see also 6.2.1 and 6.3.2, shall be tested according to another method or calculations shall be undertaken.

If the specimen is modular, the metering section should be an integral multiple of the module. The edge of the metering section should either coincide with the module lines or be midway between module lines. Specimens should be tested without plaster. Air flow through the specimen shall be avoided by sealing the surfaces.

To ensure perfect contact with the heat flow meter and guard section cover sheet, specimens with coarse-pored or uneven surfaces have to be smoothed with plaster or other suitable material, having the minimum thickness necessary to achieve flatness.

The specimen shall be mounted or sealed in such a way that neither air nor moisture will gain ingress into the specimen from the edges or pass from the hot side to the cold side or vice versa.

It is necessary to control the dew-point of the air on the hot side, to ensure that in the selected testing condition no condensation will take place on the hot side of the specimen.

It should be considered whether continuous cavities in the specimen require barriers at the periphery of the metering section, and whether high conductivity facings should be cut at the perimeter of the metering section.

Surface temperature sensors shall be mounted in such a way that there is no air pocket between the sensor and the specimen surface. The sensors have to be mounted such as to avoid heat flow rates to or from the metering section.

The emissivities of sensors and specimen surfaces should be equal. Surface temperature sensors between the heat flow meter (and guard section sheet) and the specimen shall be mounted as indicated in 6.3.2.

The heat flow meter and the guard sheet shall be glued to the hot side surface of the specimen or shall be installed with a two-sided adhesive foil, avoiding the formation of any air pocket. The glue shall be a thin layer not adding a significant thermal resistance, shall not penetrate deeply into the specimen, shall avoid the presence of any air pocket between the specimen and the heat flow meter and shall allow the disassembling of the heat flow meter without causing severe stresses to it that could cause a change in the heat flow meter calibration characteristics.

In general, test specimens are in a vertical position. If results can be influenced by convection (for specimens with hollow cores), tests shall be conducted in the position that corresponds to the practical end use application.

B.2 Measurement

B.2.1 Test conditions

Test conditions shall be chosen to suit the product standard requirements or specific end use applications, having in mind the effect of testing conditions on accuracy. Both mean test temperature and temperature differences affect the test results. NOTE Mean temperatures of 10 8C to 20 8C and a difference of at least 20 K are common in building applications.

The moisture content of the specimen during the measuring period is determined by recording its mass before and after measurement and in the dry state after the test has been completed. The specimen can also be broken down into its constituents, and the individual building materials can be dried at their allowed maximum temperatures.

B.2.2 Measurement period

The required time to reach stability for steady-state tests depends upon such factors as thermal resistance and thermal capacity of the specimen, surface coefficient of heat transfer, presence of mass transfer and/or moisture redistribution within the specimen, type and the performance of automatic controllers associated with the apparatus. Due to variation of these factors, it is impossible to give a single criterion for steady-state.

To ensure that steady-state conditions have been reached, measurements of some relevant temperatures and the density of heat flow rate shall be plotted versus time to detect any monotonic variation.

B.2.3 Calculations

This test method allows the measurement of the specimen surface-to-surface thermal resistance, Rt.

Rt = (Tsi 2 Tse)/q (2)

From this measured quantity and the surface resistances according to EN ISO 6946 the heat transfer properties are calculated according to the following equations:

RT = Rsi + Rt + Rse (3)

U = 1/RT (4)

If the surface-to-surface thermal resistance Rt of a masonry test specimen is determined according to this standard for at least three levels of moisture content, a value Rt* of the surface-to-surface thermal resistance for each defined practical moisture content (moisture condition under national service conditions) and a moisture factor describing the influence of moisture content on the thermal properties of the tested material, can be derived.

Annex C
(normative)

Test specimen

C.1 General

Testing may be split into specimen handling, see below, and actual testing procedure, see clause 7. Some decisions about measurable heat transfer properties, specimen handling and testing conditions shall be taken when starting testing, see A.5. Directions on these decisions shall only be sought in this standard and/or in the relevant product standard applicable to the specimen to be tested.

C.2 Selection and size

One or two specimens shall be selected (from each sample) according to the type of apparatus (see 5.2.2 or 5.2.3 for guarded hot plate apparatus and 5.3.1 for heat flow meter apparatus). The specimen or specimens shall meet the general requirements outlined in A.3 and A.4. When two specimens are required they shall be as identical as possible with thicknesses differing by less than 2 %. The specimen or specimens shall be of such size as to cover the heating unit surfaces completely (including the guard section), without exceeding the overall linear dimension of the heating unit or heat flow meter by more than 3 %. They shall have a thickness according to the relevant product standard and additionally the relationship between the thickness of the test specimen used and the dimensions of the heating unit shall be restricted so as to limit the sum of the imbalance error (guarded hot plate apparatus only) and edge heat loss errors to 0,5 %, see thickness limits of Table A.1 in A.3. For the minimum specimen thickness see A.3.4 and Tables A.1 and A.2.

C.3 Specimen preparation and instrumentation

C.3.1 Conformity with product standards

The preparation of the specimens shall be in accordance with the appropriate product standard; unless otherwise specified in product standards, the general criteria in 6.3.2 and 6.3.3 should be fulfilled.

C.3.2 All specimens except loose-fills

C.3.2.1 Preparation

As building materials and in particular masonry materials exist in many forms, e.g. bricks, blocks and cast slabs, use the method appropriate to the particular form available, e.g. edge to edge gluing of smaller pieces of similar density, (but never with joint surfaces parallel to the faces of the specimen) machining directly from larger pieces or casting directly from a mix. In all cases, ensure that there is a high degree of flatness of the test specimen and that other dimensions are within the tolerances specified.

When edge-to-edge joining or joint gluing is necessary, make the joints between machined surfaces perpendicular to the main specimen surfaces and preferably symmetrical with respect to the line passing through the centre of the specimen and perpendicular to its main surfaces. Keep the number of pieces used to the minimum dictated by the module size of the product, especially in the metering area. Ensure that, within the metering area, the total joint cross-section does not exceed 0,1 % of the metering area. Use a cold setting adhesive, such as an epoxy or polyester resin for bonding; adhesives approaching the specimen conductivity are preferred. Apply the adhesive to the mating surfaces avoiding impregnation as far as possible. After bonding, either grind flat the faces of eachspecimen using a surface grinder or milling machine, or hand finish the faces by rubbing with abrasive paper fixed to an engineer's surface plate.

Cure cement and masonry materials from which specimens are to be prepared for 28 days prior to testing and record the date of manufacture. Specimens may initially contain a large amount of water as a consequence of manufacture and preparation. Great care shall be taken in selecting testing conditions with reference to moisture content in order to eliminate mass transfer during the test, or establish conditions for which mass transfer effects are repeatable and well understood, see 7.2.2 and 7.2.3.

The surface of the test specimens shall be made plane by appropriate means (sandpapering, face-cutting in a lathe, and grinding are often used), so that close contact between the specimens and apparatus or interposed sheets can be effected.

For rigid materials, the faces of the specimens shall be made as flat as the apparatus surfaces (see A.3.6.2) and shall be parallel over the total surface area within 2 % of the specimen thickness.

The planeness of the surfaces can be checked with, for example, a good quality engineer's straightedge (straight to 0,01 mm) held against the surface and viewing at grazing incidence with a light behind the straightedge. Departures as small as 25 m are readily visible. Large departures can be measured using feeler gauges and the straightedge as follows. The straightedge should be supported on a gauge block of known thickness, say 1 mm, at each end of the surface to be checked.

Positive and negative deviations can be measured using feeler gauges along a straight line. Eight straight lines should be investigated as follows: the four edges of the surface, the two diagonals and a central cross (two lines parallel to the edges of the surface). When this procedure, applicable to both apparatus and specimen surfaces, is applied to specimen checking, it should be repeated for each face of the specimen.

Scratches, chips or similar defects over and above the naturally occurring surface irregularities in the finished surfaces of cellular or aggregate materials are accepted provided that the total of their surface areas is an acceptable fraction of the metering area and that their maximum depth is an acceptable fraction of the specimen thickness, so as to keep the added thermal resistance due to the corresponding air pockets low. For the purpose of this standard:

— if $(A_d/A_m)(R_a/R) < 0{,}000\,5$ the effect may be ignored;

— if $0{,}000\,5 \leq (A_d/A_m)(R_a/R) \leq 0{,}005$ the test may be undertaken, but the presence of the defectshall be mentioned in the test report;

where:

$A_d$is the overall cross-sectional area of the defects;

$A_m$is the area of the metering section;

$R_a$is the thermal resistance of an air layer of thickness equal to the maximum depth of anydefect;

R is the thermal resistance of the specimen.

C.3.2.2 Selection and installation of contact sheets

Imperfect apparatus and/or specimen flatness produces contact thermal resistances, see in A.3.6.2 the maximum allowed limit when testing rigid specimens without contact sheets.

When the specimens' thermal resistance is less than 0,3 m2·K/W, or if their flatness does not meet the requirements of A.3.6.2, thin sheets of an adequately compressible material shall be inserted between the specimen surfaces and the plates of the apparatus to establish good thermal contact between them. The thin sheets shall also insulate electrically the thermocouples which are then to be placed on the specimen surfaces to determine the temperature difference across the specimen (see 6.3.2.3).

If all other requirements are met (homogeneity, compressibility, etc.), sheets of the highest thermal conductivity material available should be chosen. When using contact sheets, the thermal resistance of the sheets should be the smallest compatible with the elimination of air pockets.

NOTE 1 Foamed silicone rubber of density about 600 kg/m3 and thickness about0,5 % to 1 % of the overall apparatus size (typically 2 to 3 mm for medium size apparatus)have been found to meet the requirements satisfactorily.

Sufficient clamping pressure, in excess of 10 kPa, is required to produce uniform thermal contact between apparatus surfaces, thermocouples, thermal contact sheets and specimens.

NOTE 2 These high pressures can damage the heat flow transducer of the heat flow meter apparatus, and thus the guarded hot plate apparatus is preferred for tests on specimens having a thermal resistance less than 0,3 m2·K/W.

The use of contact sheets introduces the errors described in A.3.6.3. When the contact resistance is deemed to be too high, an alternative solution to the use of contact sheets is to improve the surface finish of the specimen and/or that of the plates of the apparatus.

NOTE 3 The lowest measurable thermal resistance according to B.5, is 0,02 m2·K/W (e.g. 0,04 m of structural concrete), but the overall accuracy of 2 % around room temperature may be achieved only when the specimen thermal resistance is equal to or greater than 0,1 m2·K/W.

C.3.2.3 Thermocouples mounted on the specimen

When contact sheets are used, thermocouples mounted on the specimen surfaces, or cemented in shallow grooves accurately machined to a known depth in the specimen surfaces, shall be used to measure the temperature difference through the specimens. The number of uniformly distributed thermocouples on each side of the specimen in the area corresponding to the metering section of the apparatus should be not less than N A , or 2, whichever is greater, where N = 10 m-1 and A is the area in square metres of one side of the metering section. For the error in the temperature difference when using contact sheets and thermocouples mounted on the specimen, see A.3.6.3.

It is recommended that at least two more thermocouples are added on each side of the specimen in the area corresponding to the metering section of the apparatus.

Thermocouples mounted directly into the surfaces shall either be:

a) flattened fine wire, or

b) thin foil types which may be bought ready-made, or

c) prepared by rolling or pressing the junctions together with about 20 mm of the adjoining wire of conventional thermocouples.

The thermocouples shall be fabricated from a stock of calibrated thermocouple wire, or from wire that has been certified by the manufacturer to comply with Table B.1 of ISO 8302:1991, or they shall be individually calibrated.

NOTE 1 It is important to establish good contact between the junctions and the specimen surfaces. In some circumstances it will be necessary to improve the mounting area locally to achieve this. This can be done effectively and with minimal loss of accuracy by smoothing the surface locally using a machinable, quick-drying filling compound using a thickness of less than 0,5 mm.

The thermocouples shall be taped in position on these prepared surface areas (approximately 15 mm to 20 mm in diameter) using narrow strips of adhesive tape about 2 mm to 4 mm wide placed some 5 mm from the junction itself.

NOTE 2 Wider strips of tape can be used in the guard area to insulate and protect the wire around the edges of the apparatus.

NOTE 3 The clamping pressure exerted on the thermal contact sheets ensures that the thermocouples are firmly in contact with the specimen surfaces during the test. However, when practicable (i.e. if the prepared surface is non-absorbent), a smear of thermoconductive compound loaded with zinc oxide can be introduced between the thermocouple junctions and the surfaces to further improve thermal contact.

C.3.3 Loose-fill materials

When testing loose-fill materials, the thickness of the specimen shall be at least 10 times the mean dimension of the beads, grains, flakes, etc. of the loose-fill material. To prepare the specimen(s) it is recommended that a representative portion, slightly greater than the amount needed for the test, be taken from the sample and weighed before and after it has been conditioned as in 7.2, where applicable. From these masses the percentage mass loss is calculated. An amount of the conditioned material is weighed out such that it will produce one (two) specimen(s) of the desired density using the procedure described in the relevant product standard. As the ultimate volume of the specimen is known, the required mass can be determined. The specimens are then quickly mounted in the apparatus or left to reach equilibrium with the standard laboratory atmosphere (23 °C, 50 % relative humidity), in accordance with the guidelines given in the relevant product standard or in 7.2.

Annex D
(informative)

$R_{dry,mas}$- or λ10,dry,mas-values of masonry built from a range of masonry units containing formed voids

NOTE The range of size and types of unit and void pattern is intended to be representative of units typically found on the market. It is not intended to be an exhaustive list covering all combinations of material, unit size, void configuration and size. The procedure according to 7.3.3 will need to be followed for configurations of units not covered by these tables.

The geometries are defined numerically by two figures:

— the number of rows of voids; and

— the number of voids in a row.

For example, 3,7/1,6 means that this type of unit has 3,7 rows of voids per 100 mm thickness and 1,6 voids in a row per 100 mm length, which means 11 rows of voids in the case of a masonry thickness of 300 mm and 4 voids in a row in the case of a unit length of 250 mm. The transverse web portion is defined as the sum of the thicknesses of the transverse webs divided by the unit length expressed as a percentage and is given for each geometry as additional information.

Further information is given for each geometry about the dimensions, which were the basis for the numerical calculation.

The following tabulated values should be used as a basis for the determination of unit equivalent $\lambda_{10,dry,unit}$-values or $R_{dry,mas}$- or λ10,dry,mas-values of the masonry if neither an individual test measurement nor a calculation are available for a specific product.

The values in this annex were calculated using a three-dimensional Finite-Difference-Program.

The equivalent thermal conductivity of the air in the voids was determined according to EN ISO 6946:2007, B.2. The program used was checked through the examples shown in Annex D and fulfils all the requirements for appropriate calculation procedures.

The theoretical background for the selection of geometries was knowledge about the principal geometrical influences on the thermal resistance:

— number of rows of voids;

— thickness of the material webs between the voids (transverse web portion);

— voids staggered or "in line";

— shape of the voids. (Experience shows that the last two factors can be neglected-for the purpose of tabulated values).

The tabulated values in the following tables are generally given for masonry with only horizontal mortar joints.

In some cases, the tabulated values are split into two, one of which is valid without vertical mortar joints and the second is valid with vertical mortar joints. For those geometry classes, where no separate values are given use the calculation procedure in 7.3.3.

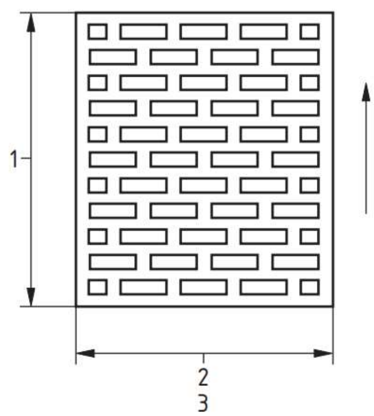
The thermal resistance of the mortar joints on which the calculation results are based can be derived in different ways. Full bed mortar joints may be provided using an insulating mortar or it is possible to reach the same resistance/equivalent conductivity by making twin strip mortar joints from a general-purpose mortar, possible with a strip of insulating material in between.

The values are grouped according to the material of the masonry units, nevertheless, the calculation results are also valid for other materials, if the geometry and the thermal conductivity of the material is the same.

The resistance-values are tabulated as resistance per 100 mm, which means for example that for a masonry of 300 mm thickness the values have to be multiplied by 3. As additional information, the calculation results are also given as $\lambda_{10,dry,mas}$ -values of the masonry, which are calculated according to the following equation:

$$\lambda_{10,dry,mas} = \frac{0.1}{\lambda_{dry,mas}}$$

The values for the percentage of voids given in the tables are related to the cross section of the units.



Key

1 width
2 length
3 horizontal cross section

Figure B.1 — Vertical perforated clay masonry units — Geometry 3,7/1,6

(transverse web portion: 26,4 %; percentage of voids : 38,4 %)

basic dimensions: l = 250 mm, w = 300 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

Table B.1 — Vertical perforated clay masonry units — Geometry 3,7/1,6

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/m·K]		
		0,16	0,32	0,80
0,34	0,175	0,57/ 0,18	0,55/ 0,18	0,49/ 0,20
0,42	0,199	0,50/ 0,20	0,49/ 0,20	0,44/ 0,23
0,51	0,224	0,46/ 0,22	0,44/ 0,23	0,40/ 0,25
0,60	0,245	0,42/ 0,24	0,40/ 0,25	0,37/ 0,27

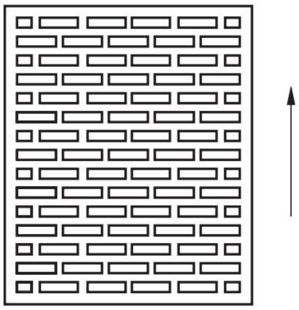


Figure B.2 — Vertically perforated clay masonry units — Geometry 5/2

Table B.2 — Vertically perforated clay masonry units — Geometry 5/2

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	*R*[m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)]		
		with a mortar with a conductivity of [W/m·K]		
		0,16	0,32	0,80
0,34	0,161	0,62/ 0,16	0,59/ 0,17	0,53/ 0,19
0,42	0,182	0,58/ 0,18	0,53/ 0,19	0,48/ 0,21
0,51	0,203	0,50/ 0,20	0,48/ 0,21	0,43/ 0,23
0,60	0,224	0,45/ 0,22	0,44/ 0,23	0,40/ 0,25

(transverse web portion: 26,4 %; percentage of voids : 38,4 %)

basic dimensions: l = 250 mm, w = 300 mm, h_{unit}= 238 mm, h_{mor} = 12 mm

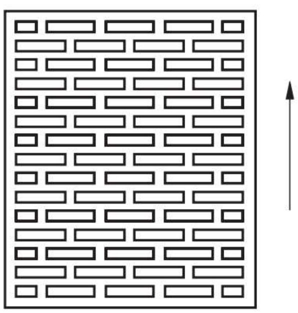


Figure B.3 — Vertically perforated clay masonry units — Geometry 5/1,6

Table B.3 — Vertically perforated clay masonry units — Geometry 5/1,6

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	*R*[m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)]		
		with a mortar with a conductivity of [W/m·K]		
		0,16	0,32	0,80
0,34	0,150	0,65/ 0,15	0,62/ 0,16	0,55/ 0,18
0,42	0,171	0,58/ 0,17	0,56/ 0,18	0,50/ 0,20
0,51	0,192	0,53/ 0,19	0,51/ 0,20	0,46/ 0,22
0,60	0,203	0,49/ 0,20	0,47/ 0,21	0,43/ 0,23

(transverse web portion: 22,2 %; percentage of voids: 39,1 %)
basic dimensions: l = 250 mm, w = 300 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

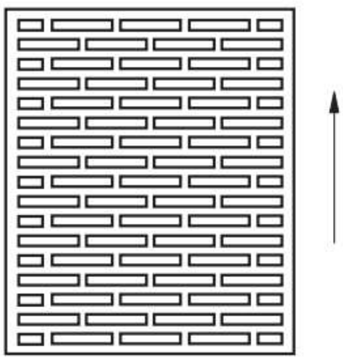


Figure B.4 — Vertically perforated clay masonry units — Geometry 5,7/1,6

Table B.4 — Vertically perforated clay masonry units — Geometry 5,7/1,6

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)]		
		with a mortar with a conductivity of [W/m·K]		
		0,16	0,32	0,80
0,34	0,140	0,70/ 0,14	0,66/ 0,15	0,59/ 0,17
0,42	0,161	0,63/ 0,16	0,60/ 0,17	0,54/ 0,19
0,51	0,175	0,57/ 0,18	0,55/ 0,18	0,49/ 0,20
0,60	0,192	0,53/ 0,19	0,51/ 0,20	0,46/ 0,22

(transverse web portion: 20,8 %; percentage of voids: 39,3 %)
basic dimensions: l = 250 mm, w = 300 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

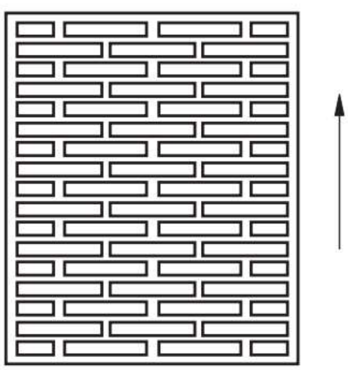


Figure B.5 — Vertically perforated clay masonry units — Geometry 5,7/1,2

Table B.5 — Vertically perforated clay masonry units — Geometry 5,7/1,2

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)]		
		with a mortar with a conductivity of [W/(m·K)]		
		0,16	0,32	0,80
0,34	0,129	0,75/ 0,13	0,71/ 0,14	0,63/ 0,16
0,42	0,140	0,69/ 0,14	0,65/ 0,15	0,58/ 0,17
0,51	0,157	0,64/ 0,16	0,61/ 0,16	0,54/ 0,19
0,60	0,171	0,59/ 0,17	0,57/ 0,18	0,51/ 0,20

(transverse web portion: 15,6 %; percentage of voids: 50,9 %)
basic dimensions: l = 250 mm, w = 300 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

Table B.6 — Vertically perforated clay masonry — Geometry 1,6/3,7

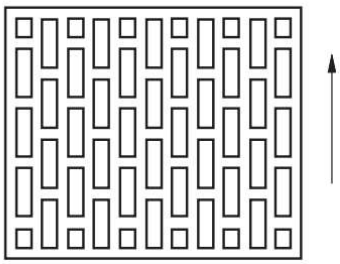


Figure B.6 — Vertically perforated clay masonry — Geometry 1,6/3,7

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)]	
		with a mortar with a conductivity of [W/(m·K)]	
		0,32	0,80
0,34	0,296	0,33 0,30	0,31 0,32
0,42	0,342	0,29 0,34	0,27 0,37
0,51	0,392	0,26 0,39	0,24 0,41
0,60	0,441	0,23 0,44	0,22 0,46

(transverse web portion: 48,0 %; percentage of voids: 38,4 %)

basic dimensions: l = 300 mm, w = 250 mm, hunit = 238 mm, hmor = 12 mm

NOTE There are no values given for a combination of such a masonry unit with a mortar with a conductivity of 0,16 W/mcK, because such a combination would not be sensible.

Table B.7 — Vertically perforated clay masonry units — Geometry 2,8/4,1

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)]			
		with a mortar with a conductivity of [W/(m·K)]			
		0,16	0,32	0,80	[a]
0,25	0,221	0,48/ 0,21	0,42/ 0,24	0.32/ 0,31	(0,30)/ (0,33)
0,34	0,265	0,40/ 0,25	0,36/ 0,28	0,29/ 0,34	(0,28)/ (0,36)/
0,42	0,324	0,33/ 0,30	0,31/ 0,33	0,25/ 0,39	(0,24)/ (0,41)/
0,51	0,387	0,28/ 0,35	0,26/ 0,38	0,22/ 0,45	(0,21)/ (0,47)/
0,60	0,446	0,25/ 0,40	0,23/ 0,43	0,20/ 0,50	(0,19)/ (0,52)/

[a] Values in brackets are where there is a vertical mortar joint.

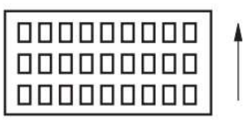


Figure B.7 — Vertically perforated clay masonry units — Geometry 2,8/4,1

(transverse web portion: 50,9 %; percentage of voids: 30 %)
basic dimensions: l = 220 mm, w = 105 mm, h_{unit} = 65 mm, h_{mor} = 12 mm

Table B.8 — Vertically perforated clay masonry units — Geometry 2,17/4,51

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)]		
		with a mortar with a conductivity of [W/(m·K)] [a]		
		0,16	0,32	0,80
0,25	0,20	0,53 0,19	0,50 0,20	0,42 0,24
0,34	0,21	0,50 0,20	0,48 0,21	0,40 0,25
0,42	0,21	0,43 0,23	0,42 0,24	0,36 0,28
0,51	0,24	0,38 0,26	0,37 0,27	0,32 0,31
0,60	0,29	0,34 0,29	0,33 0,30	0,29 0,34

[a] All values are with vertical mortar joints.

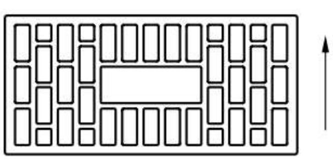


Figure B.8 — Vertically perforated clay masonry units — Geometry 2,17/4,51

(transverse web portion: 31 %; percentage of voids: 53 %)
basic dimensions: l = 288 mm, w = 138 mm, h_{unit} = 138 mm, h_{mor} = 12 mm

Table B.9 — Vertically perforated clay masonry units — Geometry 3,62/3,82

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)]		
		with a mortar with a conductivity of [W/(m·K)] [a]		
		0,16	0,32	0,80
0,25	0,20	0,50 0,20	0,48 0,21	0,42 0,24
0,34	0,22	0,45 0,22	0,43 0,23	0,38 0,26
0,42	0,27	0,37 0,27	0,36 0,28	0,32 0,31
0,51	0,30	0,34 0,29	0,33 0,30	0,29 0,34
0,60	0,37	0,28 0,36	0,27 0,37	0,24 0,41

[a] All values are with vertical mortar joints.

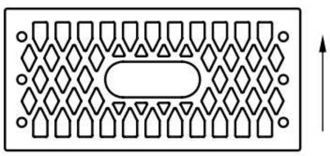


Figure B.9 — Vertically perforated clay masonry units — Geometry 3,62/3,82

(transverse web portion: 64 %; percentage of voids: 39 %)
basic dimensions: l = 288 mm, w = 138 mm, h_{unit} = 138 mm, h_{mor} = 12 mm

Table B.10 — Vertically perforated clay masonry units — Geometry 1,9/2,3

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)]			
		with a mortar with a conductivity of [W/(m·K)]			
		0,16	0,32	0,80	[a]
0,25	0,199	0,50/ 0,20	0,44/ 0,23	0.35/ 0,29	(0,32)/ (0,31)
0,34	0,280	0,38/ 0,26	0,34/ 0,29	0,27/ 0,37	(0,26)/ (0,39)
0,42	0,341	0,32/ 0,31	0,29/ 0,34	0,24/ 0,42	(0,23)/ (0,44)
0,51	0,414	0,27/ 0,37	0,25/ 0,40	0,21/ 0,48	(0,20)/ (0,50)
0,60	0,479	0,24/ 0,42	0,22/ 0,45	0,18/ 0,54	(0,18)/ (0,55)/

[a] Values in brackets are where there is a vertical mortar joint.

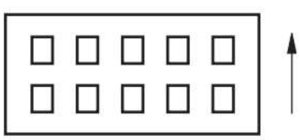
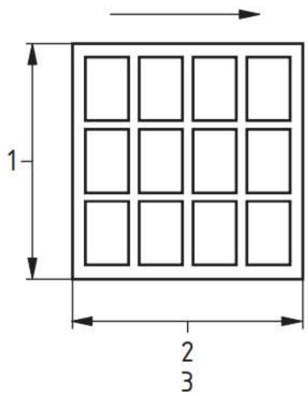


Figure B.10 — Vertically perforated clay masonry units — Geometry 1,9/2,3

(transverse web portion: 54,5 %; percentage of voids: 17,3 %)
basic dimensions: l = 220 mm, w = 105 mm, h_{unit} = 55 mm, h_{mor} = 12 mm



Key
1 height
2 width
3 vertical cross section

Figure B.11 — Horizontally perforated clay Masonry — Geometry units 2/1,5

(transverse web portion: 16 %; percentage of voids: 63,9 %)

Table B.11 — Horizontally perforated clay masonry — Geometry units 2/1,5

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m^2·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]			
		0,16	0,32	0,80	[a]
0,34	0,222	0,45/ 0,22	0,44/ 0,23	0,39/ 0,25	(0,37)/ (0,27)
0,42	0,243	0,42/ 0,24	0,40/ 0,25	0,37/ 0,27	(0,35)/ (0,28)
0,51	0,257	0,40/ 0,25	0,38/ 0,26	0,34 0,29	(0,33)/ (0,30)
0,60	0,282	0,36/ 0,28	0,36/ 0,28	0,32/ 0,31	(0,31)/ (0,32)/

[a] The values in brackets are for the case where there is a vertical mortar joint.

basic dimensions: l = 500 mm, w = 200 mm, h_{unit} = 200 mm, h_{mor} = 12 mm

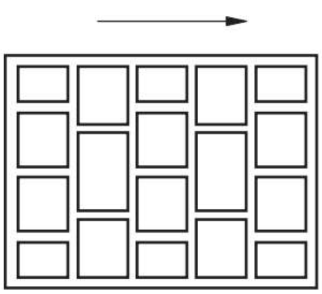


Figure B.12 — Horizontally perforated clay masonry units — Geometry 1,85/1,5

Table B.12 — Horizontally perforated clay masonry units — Geometry 1,85/1,5

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m^2·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/m·K] with a mortar with a conductivity of [W/m·K]			
		0,16	0,32	0,80	[a]
0,34	0,160	0,44/ 0,22	0,43/ 0,23	0.40/ 0,25	(0,38)/ (0,26)
0,42	0,169	0,42/ 0,24	0,40/ 0,25	0,37/ 0,27	(0,36)/ (0,28)
0,51	0,183	0,38/ 0,26	0,37/ 0,27	0,34/ 0,29	(0,33)/ (0,30)
0,60	0,201	0,36/ 0,28	0,34/ 0,29	0,33/ 0,31	(0,31)/ (0,32)

[a] The values in brackets are for the case where there is a vertical mortar joint.

(transverse web portion: 21,5 %; percentage of voids: 62,8 %)
basic dimensions: l = 500 mm, w = 270 mm, h_{unit} = 200 mm, h_{mor} = 12 mm

Table B.13 — Horizontally perforated clay masonry units — Geometry 3,7/1,5

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]			
		0,16	0,32	0,80	[a]
0,34	0,169	0,59/ 0,17	0,55/ 0,18	0.50/ 0,20	(0,48)/ (0,21)
0,42	0,183	0,55/ 0,18	0,51/ 0,19	0,46/ 0,22	(0,43)/ (0,23)
0,51	0,201	0,50/ 0,20	0,48/ 0,21	0,43/ 0,23	(0,40)/ (0,25)
0,60	0,222	0,46/ 0,22	0,43/ 0,23	0,40/ 0,25	(0,38)/ (0,26)

[a] The values in brackets are for the case where there is a vertical mortar joint.

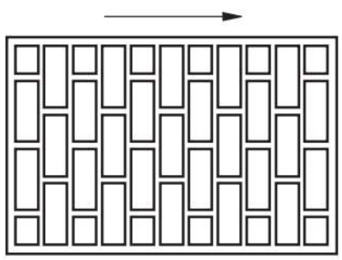


Figure B.13 — Horizontally perforated clay masonry units — Geometry 3,7/1,5

(transverse web portion: 18,5 %; percentage of voids: 61,8 %)
basic dimensions: l = 500 mm, w = 300 mm, h_{unit} = 200 mm, h_{mor} = 12 mm

Table B.14 — Horizontally perforated clay masonry units — Geometry 4,3/1

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)]			
		0,16	0,32	0,80 [a]	
0,34	0,151	0,64/ 0,15	0,61/ 0,16	0.53/ 0,19	(0,50)/ (0,20)
0,42	0,169	0,59/ 0,17	0,56/ 0,18	0,50/ 0,20	(0,48)/ (0,21)
0,51	0,186	0,53/ 0,19	0,53/ 0,19	0,46/ 0,22	(0,43)/ (0,23)
0,60	0,201	0,50/ 0,20	0,48/ 0,21	0,43/ 0,23	(0,41)/ (0,24)

[a] The values in brackets are for the case where there is a vertical mortar joint.

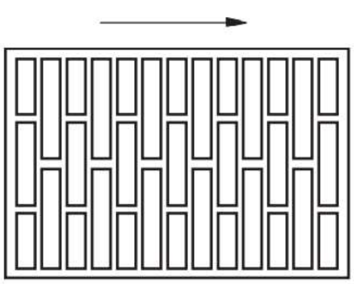


Figure B.14 — Horizontally perforated clay masonry units — Geometry 4,3/1

(transverse web portion: 15,4 %; percentage of voids: 56,3 %)
basic dimensions: l = 500 mm, w = 300 mm, h_{unit} = 200 mm, h_{mor} = 12 mm

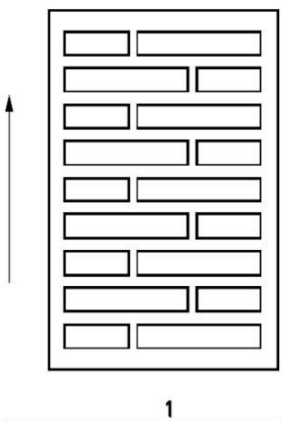


Table B.15 — Calcium silicate masonry units — Geometry 2,5/0,8

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)]			
		with a mortar with a conductivity of [W/(m·K)]			thin layer mortar
		0,16	0,32	0,80	
0,32	0,192	0,52/ 0,19	0,50/ 0,20	0,46/ 0,22	0,52/ 0,19
0,64	0,276	0,37/ 0,27	0,36/ 0,28	0,33/ 0,30	0,36/ 0,28

Key
1 horizontal cross section

Figure B.15 — Calcium silicate masonry units — Geometry 2,5/0,8

(transverse web portion: 20 %; percentage of voids: 46 %)
basic dimensions: l = 240 mm, w = 365 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

Figure B.15 — Calcium silicate masonry units — Geometry 2,5/0,8

(transverse web portion: 20 %; percentage of voids: 46 %)
basic dimensions: l = 240 mm, w = 365 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

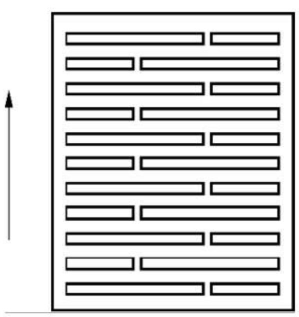


Figure B.16 — Calcium silicate masonry units — Geometry 3,7/0,8

Table B.16 — Calcium silicate masonry units — Geometry 3,7/0,8

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/m·K]			
		with a mortar with a conductivity of [W/m·K]			Thin layer mortar
		0,16	0,32	0,80	
0,32	0,178	0,57/ 0,18	0,54/ 0,19	0,49/ 0,20	0,57/ 0,18
0,64	0,259	0,40/ 0,25	0,38/ 0,26	0,35/ 0,29	0,39/ 0,26

(transverse web portion: 16 %; percentage of voids: 30 %)
basic dimensions: l = 247 mm, w = 365 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

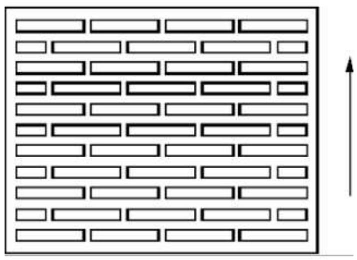


Figure B.17 — Calcium silicate masonry units — Geometry 3,7/1,1

Table B.17 — Calcium silicate masonry units — Geometry 3,7/1,1

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/m·K]			
		with a mortar with a conductivity of [W/m·K]			thin layer mortar
		0,16	0,32	0,80	
0,32	0,171	0,60/ 0,17	0,57/ 0,18	0,51/ 0,20	0,60/ 0,17
0,64	0,259	0,41/ 0,24	0,40/ 0,25	0,37/ 0,27	0,41/ 0,24

(transverse web portion: 19 %; percentage of voids: 34 %)
basic dimensions: l = 373 mm, w = 300 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

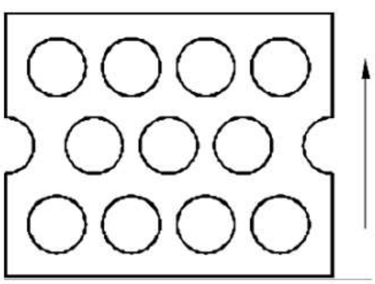


Figure B.18 — Calcium silicate masonry units — Geometry 1,3/1,3

Table B.18 — Calcium silicate masonry units — Geometry 1,3/1,3

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/m·K]	
		with a mortar with a conductivity of [W/m·K]	
		0,80	thin layer mortar
0,64	0,440	0,22/ 0,45	0,22/ 0,45
1,05	0,666	0,15/ 0,67	0,15/ 0,67

(transverse web portion: 39 %; percentage of voids: 28 %)
basic dimensions: l = 300 mm, w = 240 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

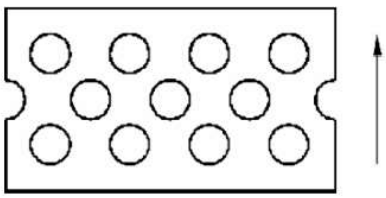


Figure B.19 — Calcium silicate masonry units — Geometry 1,7/1,3

Table B.19 — Calcium silicate masonry units — Geometry 1,7/1,3

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m^2·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]	
		0,80	thin layer mortar
0,64	0,430	0,20/ 0,50	0,20/ 0,50
1,05	0,666	0,13/ 0,77	0,13/ 0,77

(transverse web portion: 59 %; percentage of voids: 17 %)
basic dimensions: l = 300 mm, w = 175 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

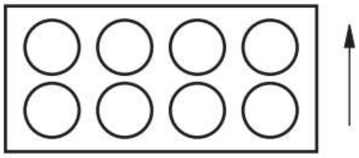


Figure B.20 — Calcium silicate masonry units — Geometry 1,7/1,7

Table B.20 — Calcium silicate masonry units — Geometry 1,7/1,7

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m^2·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)] 0,80
0,64	0,411	0,23/ 0,43
1,05	0,621	0,16/ 0,63

(transverse web portion: 33 %; percentage of voids: 36 %)
basic dimensions: l = 240 mm, w = 115 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

Table B.21 — Calcium silicate masonry units — Geometry 2,1/1,3

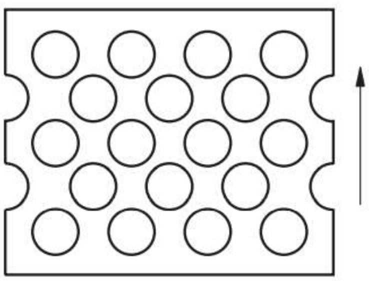


Figure B.21 — Calcium silicate masonry units — Geometry 2,1/1,3

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m^2·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/m·K] with a mortar with a conductivity of [W/m·K]	
		0,80	thin layer mortar
0,64	0,405	0,23/ 0,43	0,25/ 0,40
1,05	0,625	0,16/ 0,63	0,16/ 0,63

(transverse web portion: 49 %; percentage of voids: 32 %)
basic dimensions: l = 300 mm, w = 240 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

Table B.22 — Calcium silicate masonry units — Geometry 2,1/1,7

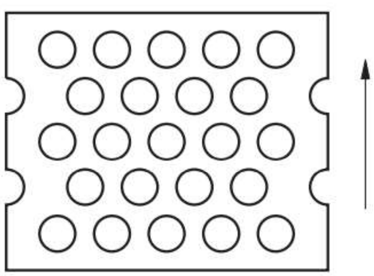


Figure B.22 — Calcium silicate masonry units — Geometry 2,1/1,7

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m^2·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]	
		0,80	thin layer mortar
0,64	0,430	0,22/ 0,45	0,23/ 0,43
1,05	0,666	0,15/ 0,67	0,15/ 0,67

(transverse web portion: 50 %; percentage of voids: 25 %)
basic dimensions: l = 300 mm, w = 240 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

Table B.23 — Calcium silicate masonry units — Geometry 2,6/1,7

$\lambda_{10,dry,mat}$	$\lambda_{10,dry,unit}$	R [m^2·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/m·K]
[W/(m·K)] of the units	[W/(m·K)] of the units	with a mortar with a conductivity of [W/m·K] 0,80
0,64	0,391	0,23/ 0,43
1,05	0,612	0,16/ 0,63

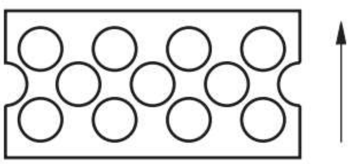


Figure B.23 — Calcium silicate masonry units — Geometry 2,6/1,7

(transverse web portion: 50 %; percentage of voids: 31 %)
basic dimensions: l = 240 mm, w = 115 mm, h_{unit} = 113 mm, h_{mor} = 12 mm

Table B.24 — Calcium silicate masonry units — Geometry 2,6/2,1

$\lambda_{10,dry,mat}$	$\lambda_{10,dry,unit}$	R [m^2·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/m·K]
[W/(m·K)] of the units	[W/(m·K)] of the units	with a mortar with a conductivity of [W/m·K] 0,80
0,64	0,501	0,19/ 0,53
1,05	0,833	0,12/ 0,83

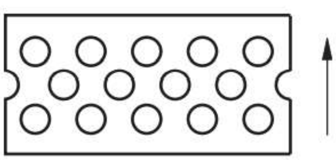


Figure B.24 — Calcium silicate masonry units — Geometry 2,6/2,1

(transverse web portion: 63 %; percentage of voids: 14 %)
basic dimensions: l = 240 mm, w = 115 mm, h_{unit} = 113 mm, h_{mor} = 12 mm

NOTE Tables B.23 to B.28 inclusive were calculated without vertical mortar joints. Tables B.29 to B.33 inclusive were calculated with mortar pockets. Table B.34 is based on a continuous vertical mortar joint.

The values in Tables B.29 to B.33 inclusive are valid for more than one shape, the drawings shown are only examples for the geometries covered.

Table B.25 — Lightweight concrete masonry units — Geometry 1/1,2

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)] 0,16	0,32	0,80 [a]
0,35	0,315	0,32/ 0,31	0,31/ 0,32	0,29/ 0,34
0,50	0,378	0,27/ 0,37	0,27/ 0,37	0,25/ 0,40
0,67	0,431	0,24/ 0,42	0,24/ 0,42	0,22/ 0,45
0,83	0,484	- -	0,21/ 0,48	0,20/ 0,50
1,00	0,515	- -	- -	0,19/ 0,53
1,25	0,579	- -	- -	0,17/ 0,59
1,50	0,663	- -	- -	0,15/ 0,67

[a] These values are valid, if there is no mortar in the vertical joint (which means that the rows of voids are not interrupted in the vertical joint).

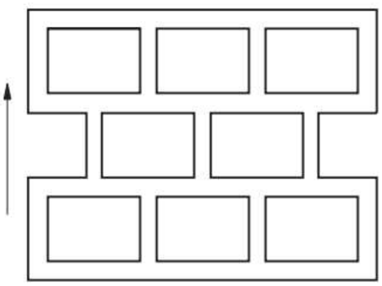


Figure B.25 — Lightweight concrete masonry units — Geometry 1/1,2

(transverse web portion: 16 % to 21 %; percentage of voids: 58,9 %)
basic dimensions: l = 380 mm, w = 300 mm, h_{unit} = 221 mm, h_{mor} = 12 mm

Table B.26 — Lightweight concrete masonry units — Geometry 1,7/1,2

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]		
		0,16	0,32	0,80 [a]
0,35	0,241	0,42/ 0,24	0,41/ 0,24	0,37/ 0,27
0,50	0,273	0,36/ 0,28	0,35/ 0,29	0,33/ 0,30
0,67	0,315	- -	0,31/ 0,32	0,29/ 0,34
0,83	0,357	- -	0,28/ 0,36	0,26/ 0,38
1,00	0,399	- -	- -	0,24/ 0,42
1,25	0,431	- -	- -	0,22/ 0,45
1,50	0,484	- -	- -	0,20/ 0,50

[a] These values are valid, if there is no mortar in the vertical joint (which means that the rows of voids are not interrupted in the vertical joint).

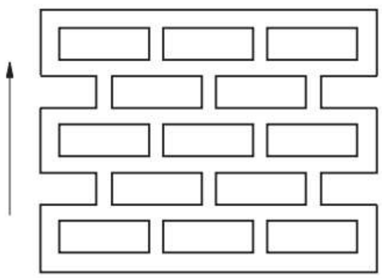


Figure B.26 — Lightweight concrete masonry units — Geometry 1,7/1,2

(transverse web portion: 13 % to 19 %; percentage of voids: 54,4 %)
basic dimensions: l = 380 mm, w = 300 mm, h_{unit} = 221 mm, h_{mor} = 12 mm

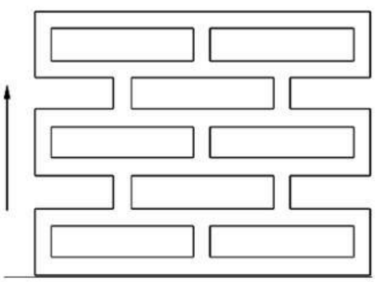


Figure B.27 — Lightweight concrete masonry units — Geometry 1,7/0,8

Table B.27 — Lightweight concrete masonry units — Geometry 1,7/0,8

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)] 0,32	0,80 [a]
0,35	0,231	0,41/ 0,24	0,38/ 0,26
0,50	0,273	0,35/ 0,29	0,33/ 0,30
0,67	0,315	0,31/ 0,32	0,29/ 0,34
0,83	0,347	0,29/ 0,34	0,27/ 0,37
1,00	0,378	- -	0,25/ 0,40/
1,25	0,431	- -	0,22/ 0,45
1,50	0,463	- -	0,21/ 0,48

[a] These values are valid, if there is no mortar in the vertical joint (which means that the rows of voids are not interrupted in the vertical joint).

(transverse web portion: 11 % to 16 %, percentage of voids: 51,8 %)

basic dimensions: l = 380 mm, w = 300 mm, h_{unit} = 221 mm, h_{mor} = 12 mm

Table B.28 — Lightweight concrete masonry units — Geometry 3/1,2

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)] 0,16	0,32	0,80 [a]
0,17	0,125	0,77/ 0,13	0,73/ 0,14	0,64/ 0,16
0,35	0,178	0,55/ 0,18	0,53/ 0,19	0,48/ 0,21
0,50	0,210	0,47/ 0,21	0,45/ 0,22	0,41/ 0,24
0,67	0,241	- -	0,40/ 0,25	0,37/ 0,27

[a] These values are valid, if there is no mortar in the vertical joint (which means that the rows of voids are not interrupted in the vertical joint).

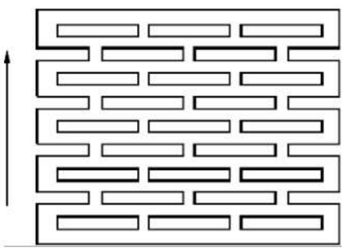


Figure B.28 — Lightweight concrete masonry units — Geometry 3/1,2

(transverse web portion: 11 % to 18 %; percentage of voids: 40,9 %)
basic dimensions: l = 380 mm, w = 300 mm, h_{unit} = 221 mm, h_{mor} = 12 mm

Table B.29 — Lightweight concrete masonry unit — Geometry 3/0,8

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)] 0,16	0,32	0,80 [a]
0,17	0,125	0,78/ 0,13	0,73/ 0,14	0,64/ 0,16
0,35	0,167	0,57/ 0,18	0,54/ 0,19	0,49/ 0,20
0,50	0,199	0,49/ 0,20	0,47/ 0,21	0,43/ 0,23

[a] These values are valid, if there is no mortar in the vertical joint (which means that the rows of voids are not interrupted in the vertical joint).

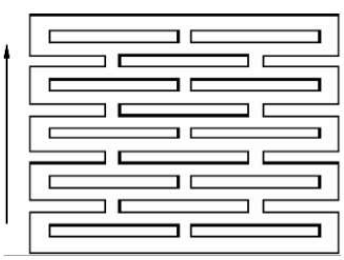


Figure B.29 — Lightweight concrete masonry unit — Geometry 3/0,8

(transverse web portion: 7 % - 14 %; percentage of voids: 42,7 %)

basic dimensions: l = 380 mm, w = 300 mm, hunit = 221 mm, hmor = 12 mm

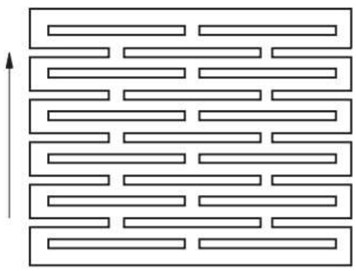


Figure B.30 — Lightweight concrete masonry units — Geometry 3,7/0,8

Table B.30 — Lightweight concrete masonry units — Geometry 3,7/0,8

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]		
		0,16	0,32	0,80 [a]
0,17	0,125	0,79/ 0,13	0,74/ 0,14	0,64/ 0,16
0,35	0,167	0,57/ 0,18	0,55/ 0,18	0,49/ 0,20
0,50	0,199	0,49/ 0,20	0,47/ 0,21	0,43/ 0,23

[a] These values are valid, if there is no mortar in the vertical joint (which means that the rows of voids are not interrupted in the vertical joint).

(transverse web portion: 7 % to 14 %; percentage of voids: 35,9 %)
basic dimensions: l = 380 mm, w = 300 mm, h_{unit} = 221 mm, h_{mor} = 12 mm

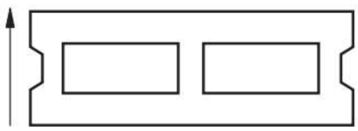


Figure B.31 — Lightweight concrete masonry units — Geometry 0,6/x

Table B.31 — Lightweight concrete masonry units — Geometry 0,6/x

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m^2·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]		
		0,16	0,32	0,80
0,10	0,151	0,75/ 0,13	0,71/ 0,14	0,65/ 0,15
0,17	0,231	0,51/ 0,20	0,49/ 0,20	0,45/ 0,22
0,25	0,309	0,38/ 0,26	0,37/ 0,27	0,34/ 0,29
0,40	0,408	0,28/ 0,36	0,27/ 0,37	0,29/ 0,40
0,55	0,523	0,23/ 0,43	0,22/ 0,45	0,21/ 0,48
0,75	0,631	- -	- -	0,17/ 0,59
1,00	0,746	- -	- -	0,14/ 0,71
1,25	0,847	- -	- -	0,12/ 0,83
1,50	0,940	- -	- -	0,11/ 0,91

(transverse web portion: 20,2 %; percentage of voids: 30 %)
basic dimensions: l = 495 mm, w = 175 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

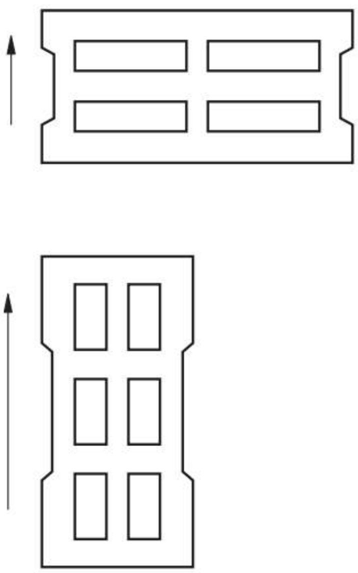


Figure B.32 — Lightweight concrete masonry units — Geometry 0,8/x

Table B.32 — Lightweight concrete masonry units — Geometry 0,8/x

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m^2·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]		
		0,16	0,32	0,80
0,10	0,215	0,74/ 0,14	0,68/ 0,15	0,59/ 0,17
0,17	0,314	0,52/ 0,19	0,48/ 0,21	0,42/ 0,24
0,25	0,410	0,40/ 0,25	0,38/ 0,26	0,34/ 0,29
0,40	0,562	0,29/ 0,34	0,28/ 0,36	0,25/ 0,40
0,55	0,698	0,23/ 0,43	0,22/ 0,45	0,20/ 0,50
0,75	0,865	- -	- -	0,16/ 0,63
1,00	1,062	- -	- -	0,13/ 0,77
1,25	1,252	- -	- -	0,11/ 0,91/
1,50	1,437	- -	- -	0,10/ 1,00

(transverse web portion: 21,2 % to 40,8 %; percentage of voids: 30,8 % to 31,4 %)
basic dimensions: l = 495 mm, w = 240 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

Table B.33 — Lightweight concrete masonry units — Geometry 1,0/x

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]		
		0,16	0,32	0,80
0,10	0,080	0,77/ 0,13	0,72/ 0,14	0,63/ 0,16
0,17	0,117	0,54/ 0,19	0,51/ 0,20	0,46/ 0,22
0,25	0,153	0,42/ 0,24	0,40/ 0,25	0,36/ 0,28
0,40	0,207	0,31/ 0,32	0,30/ 0,33	0,28/ 0,36
0,55	0,252	0,26/ 0,38	0,25/ 0,40	0,23/ 0,43
0,75	0,305	- -	- -	0,19/ 0,53
1,00	0,364	- -	- -	0,16/ 0,63
1,25	0,418	- -	- -	0,14/ 0,71
1,50	0,479	- -	- -	0,12/ 0,83

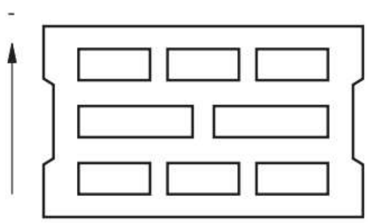


Figure B.33 — Lightweight concrete masonry units — Geometry 1,0/x

(transverse web portion: 25,9 %; percentage of voids: 35,4 %)
basic dimensions: l = 495 mm, w = 300 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

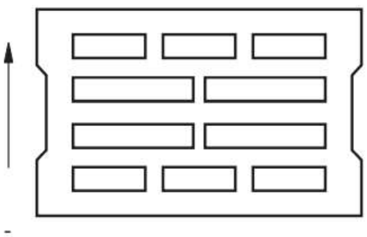


Figure B.34 — Lightweight concrete masonry units — Geometry 1,3/x

Table B.34 — Lightweight concrete masonry units — Geometry 1,3/x

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m^2·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]		
		0,16	0,32	0,80
0,10	0,086	0,83/ 0,12	0,77/ 0,13	0,67/ 0,15
0,17	0,122	0,59/ 0,17	0,56/ 0,18	0,49/ 0,20
0,25	0,155	0,47/ 0,21	0,44/ 0,23	0,40/ 0,25
0,40	0,205	0,35 0,29	0,34/ 0,29	0,31/ 0,32
0,55	0,246	0,29/ 0,34	0,28/ 0,36	0,26/ 0,38
0,75	0,294	- -	- -	0,21/ 0,48
1,00	0,349	- -	- -	0,18/ 0,56
1,25	0,397	- -	- -	0,16/ 0,63
1,50	0,445	- -	- -	0,14/ 0,71

(transverse web portion: 21,2 % to 48 %; percentage of voids: 35,5 %)
basic dimensions: l = 495 mm, w = 300 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

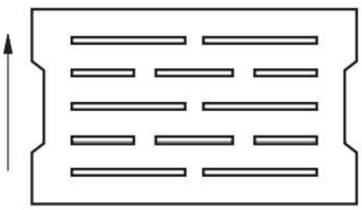


Figure B.35 — Lightweight concrete masonry units — Geometry 1,7/x

Table B.35 — Lightweight concrete masonry units — Geometry 1,7/x

$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]		
		0,16	0,32	0,80
0,10	0,062	1,01/ 0,10	0,92/ 0,11	0,78/ 0,13
0,17	0,092	0,69/ 0,14	0,64/ 0,16	0,55/ 0,18
0,25	0,120	0,52/ 0,19	0,49/ 0,20	0,43/ 0,23
0,40	0,160	0,37/ 0,27	0,36/ 0,28	0,32/ 0,31
0,55	0,195	0,30/ 0,33	0,29/ 0,34	0,26/ 0,38

(transverse web portion: 20,6 %; percentage of voids: 11,8 %)
basic dimensions: l = 495 mm, w = 300 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

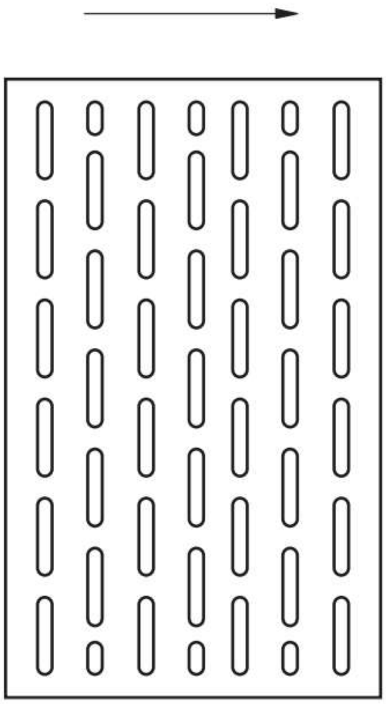


Table B.36 — Lightweight concrete masonry units — Geometry 3,0/x

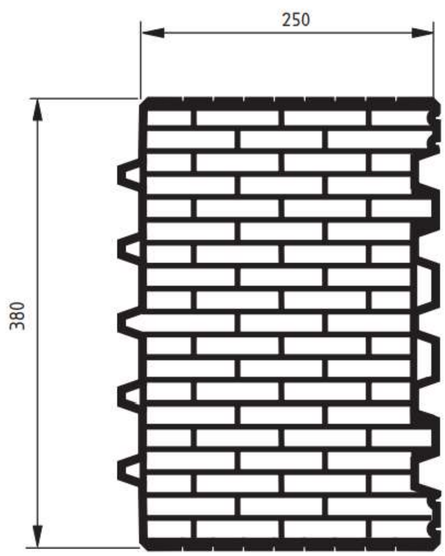
$\lambda_{10,dry,mat}$ [W/(m·K)] of the units	$\lambda_{10,dry,unit}$ [W/(m·K)] of the units	R [m²·K/W] per 100 mm thickness/ $\lambda_{10,dry,mas}$ of the masonry [W/(m·K)] with a mortar with a conductivity of [W/(m·K)]		
		0,16	0,32	0,80
0,10	0,091	1,06/ 0,09	0,96/ 0,10	0,79/ 0,13
0,17	0,133	0,75/ 0,13	0,70/ 0,14	0,60/ 0,17
0,25	0,171	0,59/ 0,17	0,56/ 0,18	0,49/ 0,20
0,40	0,234	0,44/ 0,23	0,42/ 0,24	0,38/ 0,26

(transverse web portion: 24,2 %; percentage of voids: 23,1 %)
basic dimensions: l = 495 mm, w = 300 mm, h_{unit} = 238 mm, h_{mor} = 12 mm

Annex E
(informative)

Example of how to use the tables in Annex B

Dimensions in millimetres



A vertical perforated clay unit with the dimensions $l \times w \times h_{unit}$ = 250 mm × 380 mm × 238 mm has a dry mass of approximately 13,6 kg. The horizontal joint is made with a thermal insulating mortar with a thermal conductivity $\lambda_{10,dry,mat}$ of 0,16 W/m·K. The net dry density of the brick is approximately 1 500 kg/m^3, which can be derived from the mass and the net volume of the unit (the net volume needs to be determined according to EN 772-3).

Figure C.1 — Example of a vertically perforated clay unit

The unit has 19 rows of holes, which means 5 rows of holes per 100 mm thickness, and either 3 or 4 holes per row, which means 1,2 or 1,6 holes per 100 mm length. There is no geometry class 5/1,2, therefore the relevant table is Table B.3 - Geometry 5/1,6. The values from this table are on the safe side, because of the number of voids per row and also because of the thickness of the webs. From Annex A the $\lambda_{10,dry,mat}$-value for a clay unit material with a density of 1 500 kg/m^3 can be taken as 0,43 W/m϶K (if an individual test measurement for λ is available the measured value can be taken). From the first column in Table B.3 ($\lambda_{10,dry,mor}$ = 0,16 W/mK) a resistance per 100 mm thickness of 0,58 m^{2}K/W and a $\lambda_{10,dry,mas}$of 0,17 W/m϶K is obtained. As the unit has a thickness of 38 cm, the *R*-value for the dry masonry is 0,58 × 3,8 = 2,204 m^{2}K/W. The unit has a tongue and groove system in the vertical joint, therefore no mortar correction is necessary (even if there was a vertical mortar joint, it could be neglected, because a thermal insulating mortar is used).

No correction is necessary for deviating dimensions, because the length and height of the unit are identical with the "basic dimensions" of geometry in Table B.3).

To produce a design thermal value, the dry resistance has to be corrected according to moisture. The moisture correction coefficient is taken as 6 % per volume percent change of moisture as no individual measurement is available. Therefore, for a practical moisture content of 1 % by volume the dry resistance has to be multiplied by 0,94, which leads to a design resistance of 2,204 × 0,94 = 2,072 m^2K/W; a practical moisture content of 1,5 % by volume leads to a design resistance of 2,204 × 0,91 = 2,006 m^2K/W. The design *U*-value would then be in the first case 0,45 $W/(m^2 \epsilon K)$ in the second case 0,46 $W/(m^2K)$.

Annex F
(informative)

Requirements for appropriate calculation procedures

F.1 Capabilities of the program

The user shall be supplied with the necessary information about the capability of the program to simulate the relevant characteristic properties of the physical component under considerations. Therefore, the following aspects of the heat flow model shall be defined:

- 2 or 3 dimensional;
- rectangular or non-rectangular shape;
- isotropic or non-isotropic conductivity. In this case:
  - general anisotropy;
  - partial anisotropy (with respect to the eigenvalues or eigenvectors of conductance);
- voids;
  - equivalent conductivity or resistance (convective and radiative part);
  - radiation exchange and equivalent conductivity (convective part);
  - radiation exchange and internal air flow model;
  - the thermal resistance of the voids has to be calculated according to EN ISO 6946;
- mass transfer (air-, moisture-transport from environment to environment);
- surface resistances to be taken from EN ISO 6946.

There is no specific preference related to the numerical methods incorporated; on the other hand, the user shall be informed about the advantages and restrictions of each method.

F.2 Input data and results

Input data shall be presented, to make it possible for a third party to do the same calculation.

The following calculation results shall at least be provided:

— minimum surface temperature of the test component on all sides;

— maximum surface temperature of the test component on all sides;

— 2D or 3D thermal coupling coefficient (W/(m·K) or W/K respectively);

— number and type of elements.

F.3 Testing of the program accuracy

The program shall be tested by calculating reference cases according to EN 10211.

F.4 Reference cases

D.4.1 Case 1: Calculation of thermal resistance R and thermal conductivity $\lambda_{10,dry,unit}$ of a masonry unit (vertically perforated unit).

Given:

Geometry of masonry unit: see Figure D.1

Material: $\lambda_{10,dry,mat} = 0{,}35$ W/(m·K)

Boundary conditions: $R_{si} = 0{,}13$ m²·K/W

$R_{se} = 0{,}04$ m²·K/W

Preparation of input data:

Thermal resistance of voids in the unit:

$d = 0{,}014\ 2$ m; $b_1 = 0{,}047\ 5$ m : $\lambda_{10,dry,unit} = 0{,}082$ W/(m·K)

$b_2 = 0{,}017\ 7$ m : $\lambda_{10,dry,unit} = 0{,}074$ W/(m·K)

Cut off planes:

Symmetry planes perpendicular to surface planes;

smallest distance of symmetry planes: $w = 125$ mm.

Result of 2-DIM calculation:

thermal coupling coefficient: $L^{2D} = 0{,}070\ 7$ W/(m·K)

DERIVATION OF THERMAL VALUES R, $\lambda_{10,dry,unit}$:

$$U = L/w = \frac{0{,}070\ 7}{0{,}125} = 0{,}565\ 6 \quad \mathrm{W/m^2K}$$

$$R_{mas} = \frac{1}{U} = 1{,}768\ 0\ \mathrm{m^2K/W}$$

$$R_t = R_{mas} - R_{si} - R_{se} = 1{,}598\ \mathrm{m^2\ K/W}$$

$$\lambda_U = \frac{d}{R_t} = \frac{0{,}300\ 2}{1{,}598} = 0{,}188\ \mathrm{W/mK}$$

NOTE Definitions and symbols are given in EN ISO 10211.

Dimensions in millimetres

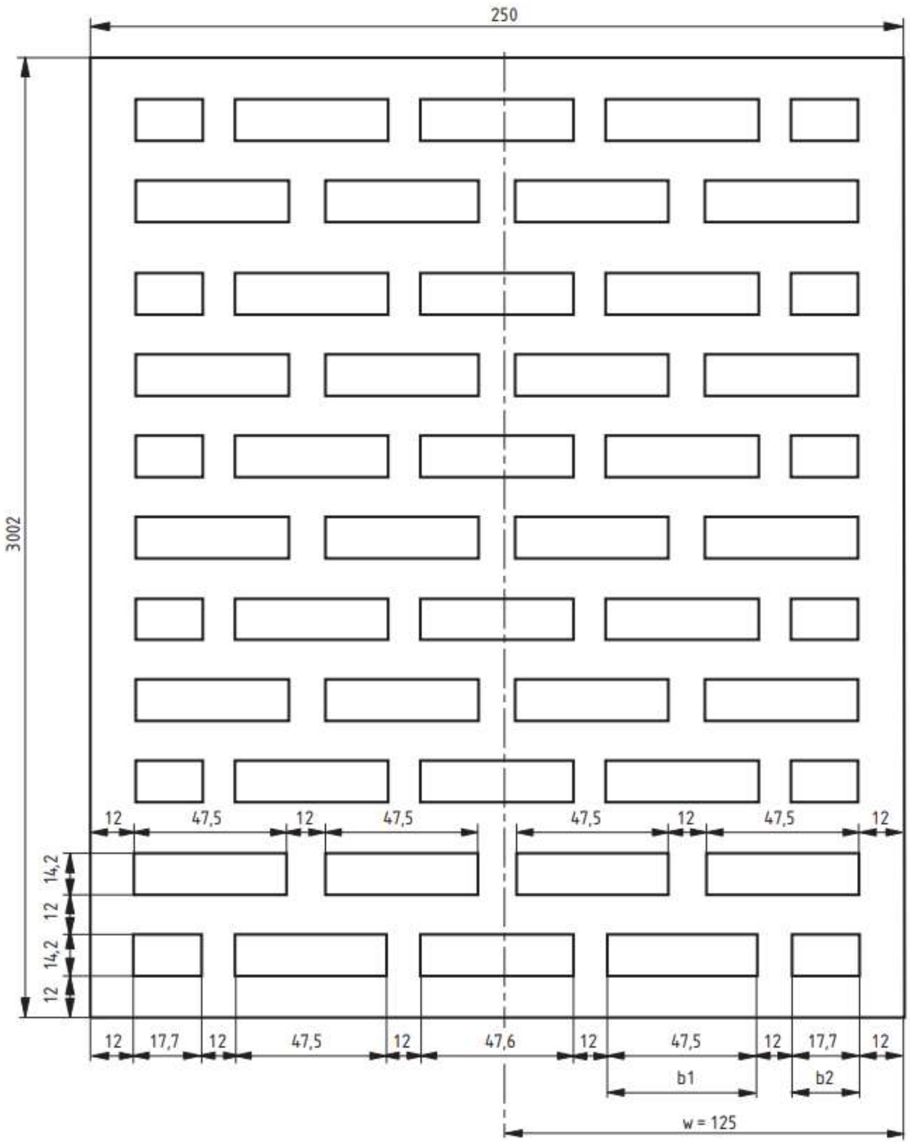


Figure D.1 — Geometry of a masonry unit, vertically perforated

D.4.2 Case 2: Calculation of thermal resistance $R_{dry,mas}$ of masonry consisting of vertically perforated masonry units and internal/ external plaster layers.

Given:

Geometry of the building component: see Figures D.1 and D.2

Material:	masonry units:	$\lambda = 0{,}35$ W/(m·K);
	masonry mortar:	$\lambda = 0{,}20$ W/(m·K);
	plaster - external:	$\lambda = 0{,}45$ W/(m·K);
	- internal:	$\lambda = 0{,}10$ W/(m·K);
	boundary conditions:	$R_{si} = 0{,}13$ m^2·K/W.

$R_{se} = 0{,}04$ m^2·K/W

Preparation of input data:

Thermal resistance of voids in the masonry unit:

$d = 0{,}014\ 2$ m;	$b_1 = 0{,}047\ 5$ m :	$\lambda_{10,dry,unit} = 0{,}082$ W/(m·K);
	$b_2 = 0{,}017\ 7$ m :	$\lambda_{10,dry,unit} = 0{,}074$ W/(m·K).

Cut off planes:

Vertical cut off planes are symmetry planes : $w = 125$ mm;

horizontal cut off planes are symmetry planes : $h = 250$ mm.

Result of 3-DIM calculation:

thermal coupling coefficient : $L^{3D} = 0{,}015\ 9$ W/K

Derivation of thermal value *R* of masonry:

$$U_{mas} = \frac{L}{A} = \frac{0{,}015\,9}{0{,}125 \times 0{,}25} = 0{,}508\,8 \text{ W/m}^2\text{K}$$

$$R_{mas} = \frac{1}{U_{mas}} = 1{,}965\,4 \text{ m}^2\text{K/W}$$

$$R_{t,mas} = R_{mas} - R_{si} - R_{se} - \frac{d_i}{\lambda_i} = 1{,}539\,9 \text{ m}^2\text{K/W}$$

Where: $R_{t,mas}$ is the true thermal resistance of the masonry.

NOTE The term $\frac{d_i}{\lambda i}$ relates to the twplaster layers

Symbols and definitions given in EN ISO 10211.

Symbols and definitions given in EN ISO 10211.

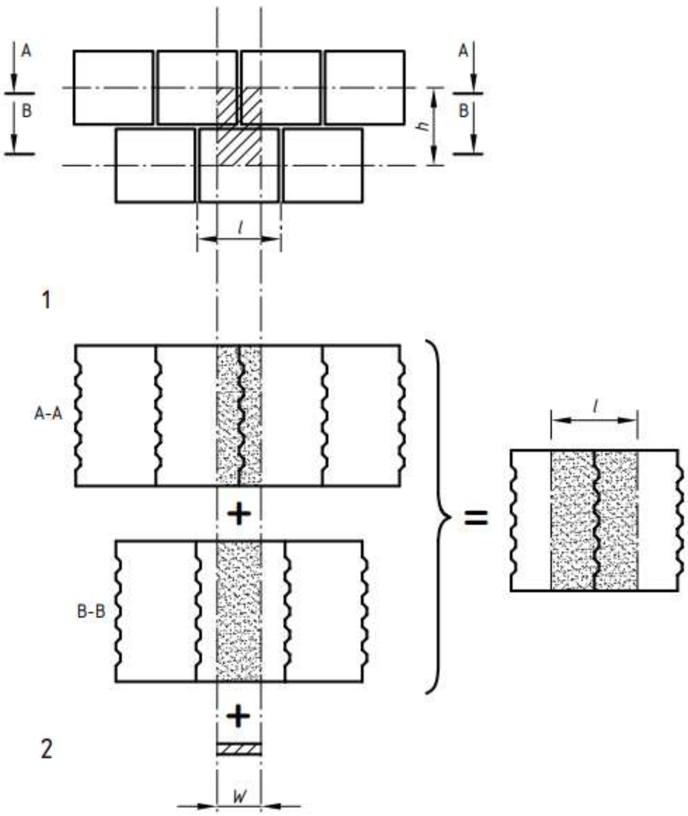


Figure D.2 — Geometry of masonry consisting of vertically perforated masonry units, bed joints with mortar layers, head joints without mortar but with interlocking system

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.

D.4.3 CASE 3: Calculation of thermal resistance Rt of masonry consisting of masonry units, horizontal mortar layers, vertical mortar pockets and additional external insulation layer.

Given:

Geometry of the building component: see Figure D.3.

Material:	masonry units:	λ = 0,65 W/(m·K);
	mortar (joints, pockets):	λ= 1,00 W/(m·K);
	plaster - external:	λ = 0,50 W/(m·K);
	- internal:	λ = 0,40 W/(m·K);
	adhesive mortars:	λ = 0,30 W/(m·K);
	insulation material:	λ = 0,041 W/(m·K);
	boundary conditions:	R_{si} = 0,13 m^2·K/W;
		R_{se} = 0,04 m^2·K/W.

Preparation of input data:

Thermal resistance of voids in the masonry unit:

d = 0,036 mm; b = 0,095 mm: $\lambda_{10,dry,unit}$ = 0,174 W/(m·K)

Cut off planes:

— Vertically- there exist symmetry planes at distance of 125 mm;

— horizontally - no symmetry planes exist due to asymmetry of the masonry unit.

For testing the influence of the selection of cut off planes disregarding symmetry, calculations were carried out for two masonry elements of different height:

Type	**height** [mm]	
1	250	(1 layer)
2	500	(2 layers)

Result of 3-DIM calculation:

Type	L^{3D} [W/K]
1	0,013 14
2	0.026 28

Derivation of thermal values *U*, *R*:

Using:

$$U_{mas} = \frac{L^{3D}}{A}; \quad R_{mas} = \frac{1}{U_{mas}}$$

and

$$R_{t,mas} = R_{mas} - R_{si} - R_{se} - \frac{d_i}{\lambda_i}$$

where

$R_{t,mas}$ is the true thermal resistance of the masonry,

we get the thermal values listed in the following table:

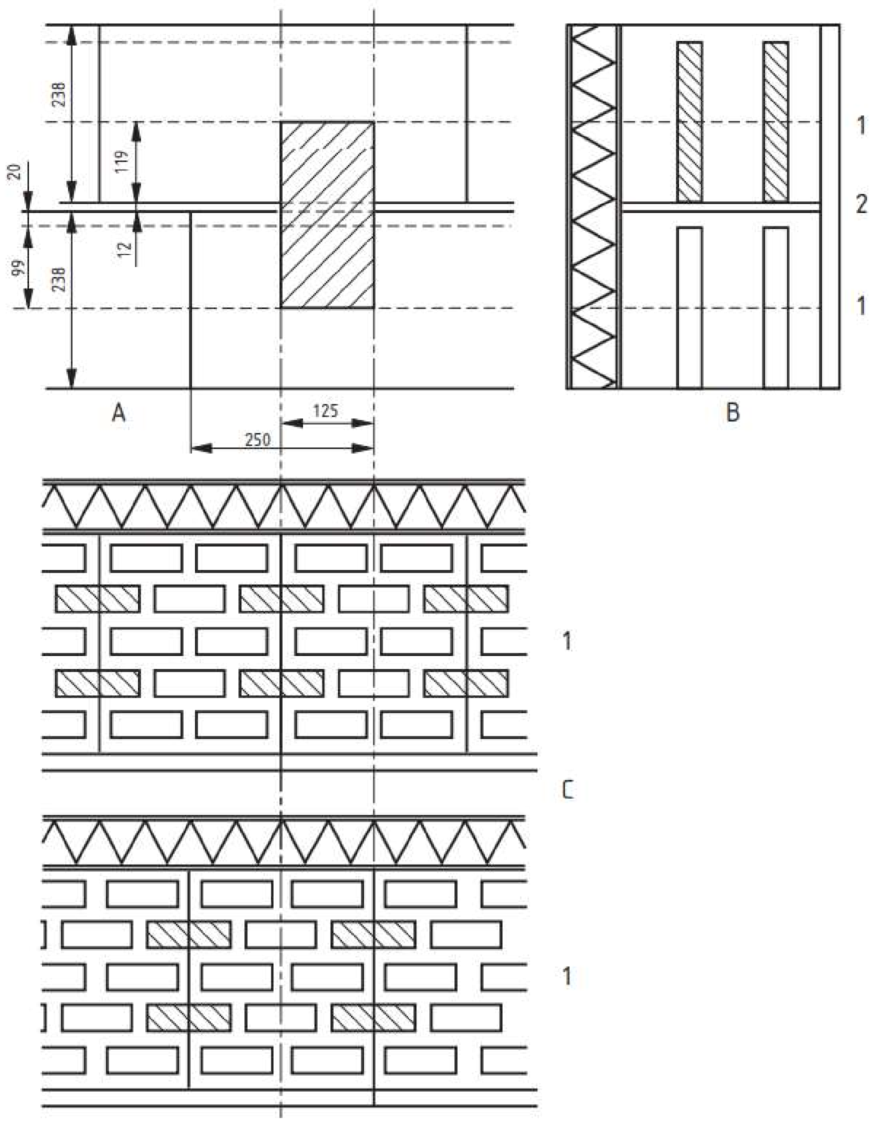
Table D.1 — Results of case 3

Type	height [mm]	U_{mas} [W/(m²·K)]	R_t [m²·K/W]
1	250	0,420 5	0,668 2
2	500	0,420 5	0,668 2

NOTE The result shows, that in this special case the influence of the selection of cut off planes disregarding symmetry on the calculation result is so small, that it cannot be seen within the calculation accuracy.

Symbols and definitions are given in EN ISO 10211.

Dimensions in millimetres



Key

A	view	B	vertical section	C	horizontal section
1	layer of masonry units	2	mortar		

Figure D.3 — Geometry of masonry consisting of masonry units, horizontal mortar layers and vertical mortar pockets and an external insulation layer

Dimensions in millimetres

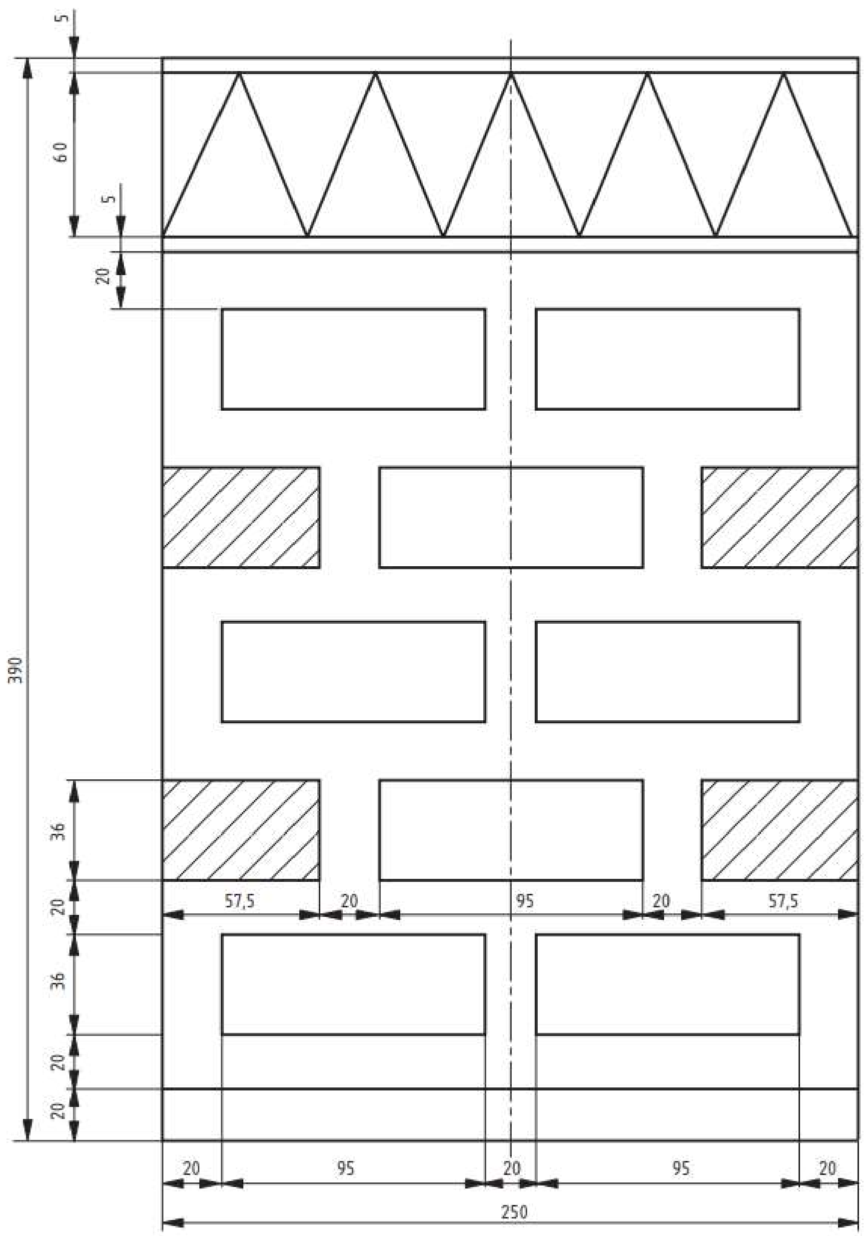


Figure D.4 — Geometry of cement bound unit

Annex G
(informative)

Evaluation of conformity

Information about in what way the parameters used in the determination of the $\lambda_{10,dry,unit}$ or equivalent $\lambda_{10,dry,unit}$–values will be part of the evaluation of conformity system is given in the following table:

Table E.1 — Parameters for evaluation of conformity

Model	Initial type testing (ITT)	Factory production control (FPC)
S1	Net dry density	Net dry density
S2	Net dry density $\lambda_{10,dry,\ mat}$/net dry density relationship [a]	Net dry density
S3	Net dry density Thermal transmittance of masonry	Net dry density
P1	Net dry density Configuration Thermal conductivity of the masonry unit material	Net dry density Configuration
P2	Net dry density Configuration	Net dry density Configuration
P3	Net dry density Configuration Thermal conductivity of the masonry unit material	Net dry density Configuration
P4	Net dry density Configuration	Net dry density Configuration
P5	Gross dry density Configuration $\lambda_{10,dry,unit}$ /gross dry density relationship [b]	Gross dry density Configuration

If the net dry density of the unit under consideration deviate less than 2 times the declared tolerance from the net dry density forming the basis for the established relationship, then the $\lambda_{10,dry,mat}$ /net dry density relationship does not need to be repeated.

If the pattern is the same and the gross dry density of the unit under consideration deviates by less than twice the declared tolerance from the gross dry density forming the basis for the established relationship, then the $\lambda_{10,dry,unit}$/ gross dry density relationship does not need to be repeated.

As part of a FPC system the $\lambda_{10,dry}$, mat–value for a batch of masonry unit may be determined based on direct testing of thermal conductivity. If so the following procedure should be used:

Establish a correlation between results and the alternative test method. The $\lambda_{10,dry}$,unit–value may be based on the value obtained from the alternative test method after applying the established correlation correction.

NOTE Care should be taken that the test specimens are representative of the masonry product itself. An appropriate way to ensure this is to cut specimens from masonry units.

Annex H
(informative)

Alternative procedure for the moisture correction of units with formed voids

The principle of this method is to correct the design moisture content according to the percentage of voids. It is a safe approximation and may be used as an alternative to procedure 2 in Clause 6.

From the moisture correction coefficient and the design moisture content, the following formulae can be used:

$$u_{corrected} = u_{design} \times (1 - v/100) \quad \text{or alternatively} \quad \psi_{corrected} = \psi_{design} \times (1 - v/100)$$

$$\lambda_{design} = \lambda_{10,dry} \times F_m \quad \text{or alternatively} \quad R_{design} = \frac{R_{10,dry}}{F_m}$$

with

$$F_m = e^{f_u \times u_{corrected}} \quad \text{or alternatively} \quad F_m = e^{f_\psi \times \psi_{corrected}}$$

with

$$\rho_{g,dry} / \rho_{n,dry} = \left(1 - \frac{v}{100}\right)$$

NOTE It is possible to use the term (gross dry density / net dry density) instead of (1- v/100) in the corrected equation above.

where

f_ψ	is the moisture coefficient by volume	m³/m³;
f_u	is the moisture coefficient by mass	kg/kg;
$\rho_{g,dry}$	is the gross dry density	kg/m³;
ψ_{design}	is the design moisture content volume by volume	m³/m³;
μ_{design}	is the design moisture content mass by mass	kg/kg;
$\rho_{n,dry}$	is the net dry density	kg/m³;
v	is the voids ratio	%.

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