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TEST REPORT

|SQM_471_2022|

NUMERICAL EVALUATION OF THE THERMAL DESIGN VALUE OF A PRODUCT NAMED "ORTHOBLOCK MK 250" AND OF THREE TYPES OF MASONRY COMPOSED OF IT, PRODUCED BY "KEBE S.A.", KILKIS (GREECE).

PLACE AND DATE OF ISSUE:	Faenza, 28th October 2022
COMPANY:	**Kebe S.A.**
ADDRESS:	Nea Santa – 61100 Kilkis, Greece
TYPE OF PRODUCT:	*Extruded Masonry Units*
STANDARD APPLIED:	EN ISO 6946, EN ISO 10456
DATE OF RECEIPT IN LABORATORY:	-
TESTS EXECUTED:	October 2022
TESTS EXECUTED BY:	CertiMaC, Faenza

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1 Introduction

This Test Report describes the numerical evaluation of thermal design values of a fired clay brick requested to CertiMaC Laboratory in Faenza by the Customer "Kebe S.A.", Kilkis, Greece (Ref. 2-a, 2-b).

Thermal design values were determined from what was measured in the document at Ref. 2-e and applying the instructions given in the standards at Ref. 2-c and 2-d.

2 References

a. Estimate: Reference Number 22389/lab dated 29th July 2022.

b. Order Confirmation: Mail dated 02nd August 2022.

c. EN 6946:2008. Building components and building elements – Thermal resistance and thermal transmittance – Calculation method.

d. EN ISO 10456:2007. Building materials and products - Hygrothermal properties -Tabulated design values and procedures for determining declared and design thermal values (ISO 10456:2007).

e. Test report SQM_246_2019 – 23rd July 2019: Determination of the equivalent thermal conductivity $\lambda_{10,dry,unit}$ of a product named "Orthoblock MK250" and of a masonry composed of it, produced by "Kebe S.A.", Kilkis (Greece).

f. CertiMaC calibration report 040219-C-17/Rev01. Calibration of a two-dimensional model for the calculation of the equivalent thermal conductivity of a masonry unit.

3 Description of calculation model of the design value of the masonry unit

The calculation model to determine the design value is the same used in the test report in Ref. 2-e: a Finite Element Model implemented in Ansys 18.2 (Ref. 2-f), applied to a planar cross section (unit length), perpendicular to the holes axis and parallel to the thermal flux (Figure 1). In this calculation, the input data have been modified taking into account the effect of humidity as indicated by the technical standard in Ref. 2-d.

In addition to the block, the thermal design parameters were also calculated on three types of masonry, considering horizontal mortar joints and plasters and a configuration without any external/internal plaster.

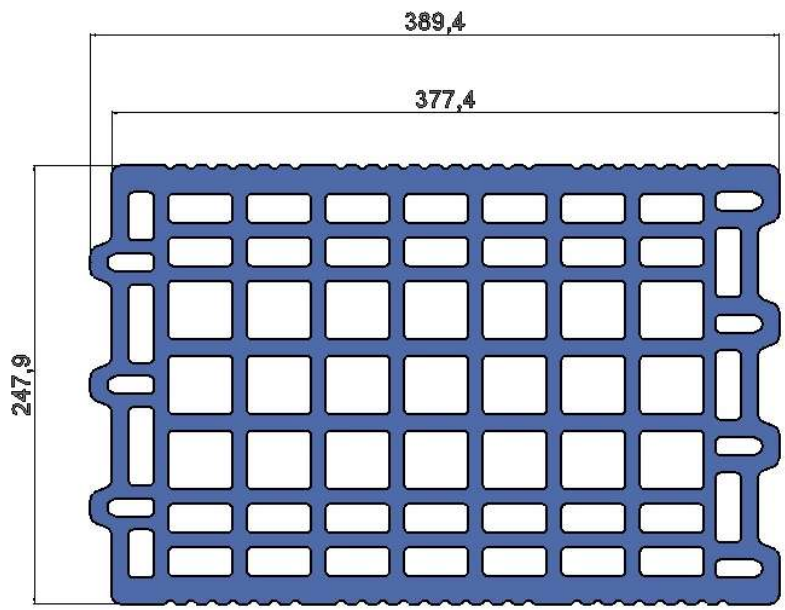

Figure 1. Geometry of the cross section employed for the calculation

4 Input data

The input data of the unit are taken from the test report at Ref. 2-e, while the masonry parameters are provided by the Client. Table 1 shows all the input data.

Input data (masonry unit)	
Physical quantity	**Nominal value**
Thermal conductivity of the fired clay	$\lambda_{10,dry,mat}$ **= 0.395 W/mK**
Equivalent thermal conductivity of voids	**See Test Report at Ref. 2-e**

Input data (masonry n. 1)	
Physical quantity	**Nominal value**
Horizontal mortar joints	Thickness = **3 mm** λ_{mortar} **= 0.87 W/mK**
Internal plaster	Thickness = **25 mm** λ_{mortar} **= 1.0 W/mK**
External plaster	Thickness = **25 mm** λ_{mortar} **= 1.0 W/mK**

Input data (masonry n. 2)	
Physical quantity	**Nominal value**
Horizontal mortar joints	Thickness = **3 mm** **λ_{mortar} = 0.87 W/mK**
Internal plaster	Thickness = **25 mm** **λ_{mortar} = 1.0 W/mK**
External plaster	Thickness = **30 mm** **λ_{mortar} = 0.08 W/mK**

Table 1. Input data

5 Determination of the Design Thermal Values

Thermal design values of the masonry are determined as defined by the standard of Ref. 2-d in accordance with the 2-c standard, increasing the thermal conductivity of the materials in relation to the moisture content, using the following conversion coefficient (1):

$$F_m = e^{f_\psi(\psi_2-\psi_1)} \tag{1}$$

(for moisture content volume by volume). The standard sets as operating conditions a temperature of 23 ° C and a relative humidity of 80% (precautionary hypothesis), which is related (1) to the test condition at 10 ° C, dry. This translates into an increase in the thermal conductivities of masonry units, mortar joints and internal/external plasters (Table 2):

Design Conditions - Thermal Conductivity corrective Factors		
Element	**F_m conversion factor (m^3/ m^3)**	**Design Thermal Conductivity λ_U (W/mK)**
Masonry unit (fired clay)	**1.127**	**0.445**
Horizontal mortar joints	**1.271**	**1.106**
Internal plaster	**1.271**	**1.271**
External plaster (Masonry n. 1)	**1.271**	**1.271**
External plaster (Masonry n. 2)	**1.271**	**0.102**

Table 2. Moisture Conversion Factors for calculation under design conditions

5.1 Calculation results on the masonry unit

The determination of equivalent thermal conductivity of the masonry unit, performed with design thermal values reported in Table 2, gave the following results, determined through Ansys output, which is heat flow (W/m) (Table 3).

RESULTS OF FEM CALCULATION					
Heat Flow (W/m)	Thermal coupling coefficient (W/mK)	Thermal Transmittance (W/m²K)	Total Thermal Resistance (m²K/W)	True Thermal Resistance of the masonry unit (m²K/W)	Equivalent thermal conductivity (W/mK)
Φ	$L^{2D}=\Phi/\Delta T$	$U= L^{2D}/w$	$R_T=1/U$	$R_t=R_T-R_{si}-R_{se}$	$\lambda_{10,dry,unit}=d/R_t$
5.8140	0.2907	0.7703	1.2982	1.1282	**0.2197**

Table 3. Results

5.2 Calculation scenarios

Table 4 summarizes the conditions of the three different configurations:

Calculation scenarios		
Configuration	**Element**	**Design Thermal Conductivity λ_U (W/mK)**
Masonry n. 1	Masonry Unit	**0.2197** (see Table 3)
	Horizontal Joints (3 mm)	**1.106**
	Vertical Joints	**Not present**
	Internal Plaster (25 mm)	**1.271**
	External Plaster (25 mm)	**1.271**
Masonry n. 2	Masonry Unit	**0.2197** (see Table 3)
	Horizontal Joints (3 mm)	**1.106**
	Vertical Joints	**Not present**
	Internal Plaster (25 mm)	**1.271**
	External Plaster (25 mm)	**0.102**
Masonry n. 3	Masonry Unit	**0.2197** (see Table 3)
	Horizontal Joints (3 mm)	**1.106**
	Vertical Joints	**Not present**
	Internal Plaster (25 mm)	**Not present**
	External Plaster (25 mm)	**Not present**

Table 4. Calculation scenarios

5.3 Calculation results on the three types of masonry

The thermal design values of the masonry are reported below (Table 5 and Table 6):

Results for Masonry n. 1	
Physical quantity	**Results**
Thermal resistance only of the layer $\mathbf{R_t}$ (m^2K/W)	**1.1143**
Equivalent thermal conductivity of the masonry $\boldsymbol{\lambda}_{\mathbf{equ}}$ (W/mK)	**0.2673**
Thermal resistance of the masonry including superficial thermal resistances $\mathbf{R_T}$ (m^2K/W)	**1.2843**
Thermal transmittance **U** (W/m^2K)	**0.7786**

Table 5. Results of the calculation for the masonry n. 1

Results for Masonry n. 2	
Physical quantity	**Results**
Thermal resistance only of the layer $\mathbf{R_t}$ (m^2K/W)	**1.3907**
Equivalent thermal conductivity of the masonry $\boldsymbol{\lambda}_{\mathbf{equ}}$ (W/mK)	**0.2178**
Thermal resistance of the masonry including superficial thermal resistances $\mathbf{R_T}$ (m^2K/W)	**1.5607**
Thermal transmittance **U** (W/m^2K)	**0.6407**

Table 6. Results of the calculation for the masonry n. 2

Results for Masonry n. 3	
Physical quantity	**Results**
Thermal resistance only of the layer $\mathbf{R_t}$ (m^2K/W)	**1.0617**
Equivalent thermal conductivity of the masonry $\boldsymbol{\lambda}_{\mathbf{equ}}$ (W/mK)	**0.2335**
Thermal resistance of the masonry including superficial thermal resistances $\mathbf{R_T}$ (m^2K/W)	**1.2317**
Thermal transmittance **U** (W/m^2K)	**0.8119**

Table 7. Results of the calculation for the masonry n. 3

6 Conclusions

On the basis of performed calculations, the product named "Orthoblock MK250" provided an equivalent design conductivity value of **0.2197 W/mK**. Calculations performed on the three types of masonry gave the results reported in Table 5 - Table 7.

7 Distribution list

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TEST REPORT

|SQM_246_2019|

DETERMINATION OF THE EQUIVALENT THERMAL CONDUCTIVITY $\lambda_{10,dry,unit}$ OF A PRODUCT NAMED "ORTHOBLOCK MK 250" AND OF A MASONRY COMPOSED OF IT, PRODUCED BY "KEBE S.A.", KILKIS (GREECE).

PLACE AND DATE OF ISSUE:	Faenza, 23 July 2019
COMPANY:	**Kebe S.A.**
ADDRESS:	Nea Santa – 61100 Kilkis, Greece
TYPE OF PRODUCT:	*Extruded Masonry Units*
STANDARD APPLIED:	UNI EN 1745, UNI EN ISO 6946
DATE OF RECEIPT IN LABORATORY:	24 June 2019
TESTS EXECUTED:	July 2019
TESTS EXECUTED BY:	CertiMaC, Faenza

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Revision -		Page 1 of 11

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1 Introduction

This Test Report describes the determination of thermal design values of the product "Orthoblock MK 250" requested to CertiMaC Laboratory in Faenza by the Customer "Kebe S.A.", Kilkis, Greece (Ref. 2-a, 2-b). Figure 1 reports a unit sent by the Customer.

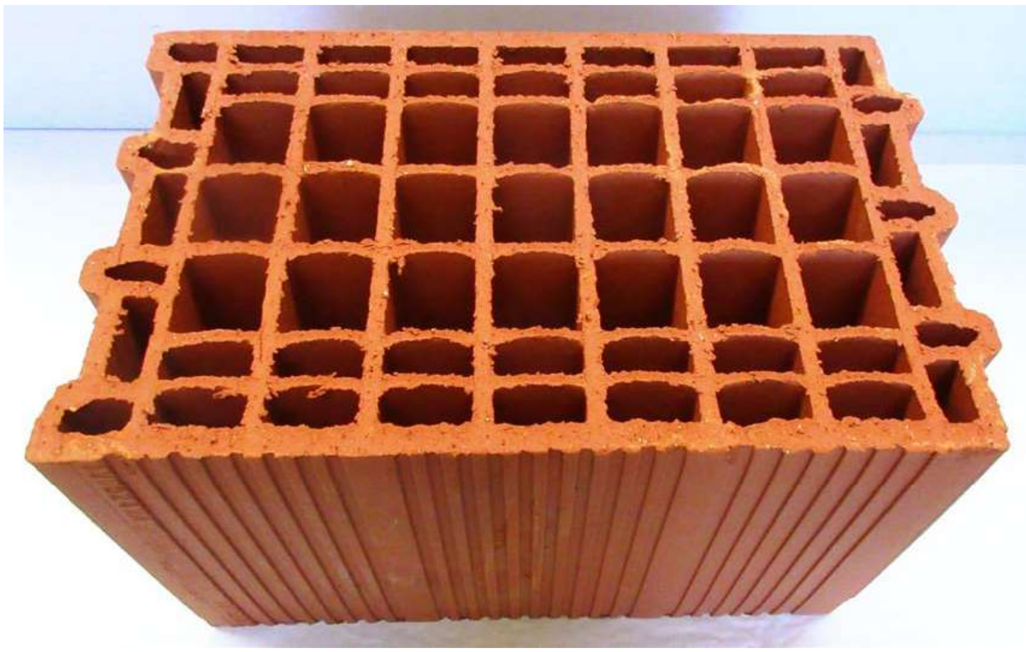


Figure 1. Example of the product

Thermal values for the type of product here described have been determined using the calculation methodology defined in Ref. 2-c, starting from the thermal conductivity and density values of the material determined experimentally (Ref. 2-d). The calculations were performed considering the thermal flow perpendicular to the longitudinal dimension of the block.

2 References

a. Estimate: Reference Number 19176/lab dated 20 June 2019.

b. Order Confirmation: Mail dated 17 July 2019.

c. UNI EN 1745:2012. Masonry and masonry products – Methods for determining thermal properties.

d. Test report SQM_244_2019 – 23 July 2019: Experimental determination of thermal conductivity and Test report SQM_245_2019 Determination of the $\lambda_{10,dry,mat}$ of a product named "Orthoblock MK 250", produced by "Kebe S.A.", Kilkis (Greece).

e. CertiMaC calibration report 040219-C-17/Rev01. Calibration of a two-dimensional model for the calculation of the equivalent thermal conductivity of a masonry unit.

f. UNI EN 772-13:2002. Methods of test for masonry units - Determination of net and gross dry density of masonry units (except for natural stone).

g. UNI EN 6946:2008. Building components and building elements – Thermal resistance and thermal transmittance – Calculation method.

3 Description of calculation model of the equivalent conductivity of the masonry unit

The equivalent thermal conductivity of the masonry unit $\lambda_{10,dry,unit}$ have been determined according to Ref. 2-c, by means of a Finite Element Model implemented in Ansys 18.2 (Ref. 2-e), applied to a planar cross section (unit length), perpendicular to the holes axis and parallel to the thermal flux (Figure 2).

4 Input data for the determination of the equivalent thermal conductivity of the unit

4.1 Geometry

In the absence of a reference drawing to obtain geometrical data to use for the implementation of the Finite Element Model, the following procedure was applied:

- Determination of the dimensions of the units sent to the Laboratory (Ref. 2-f) in order to determine the average dimensions typical of the examined product;
- Grinding of the masonry unit presenting the closest dimensions to the average values in order to even the surface. Grinding is necessary to remove burrs resulting from cutting during the extrusion procedure;
- Scanner acquisition of the cross section of the unit and conversion of the image in .jpg format. The geometry chosen to represent the product and to be used for the implementation of the calculation was rectified in order to respect the symmetry of the product resulting from the extrusion process.
- Measurement of the dimensions of voids (shape and interaxis) and of external profiles on the basis of average dimensions determined on the sampling set. Measures were performed using a centesimal caliper.
- Definition, based on aforementioned values, of average geometric dimensions of the product type to employ in the calculation (Figure 2).

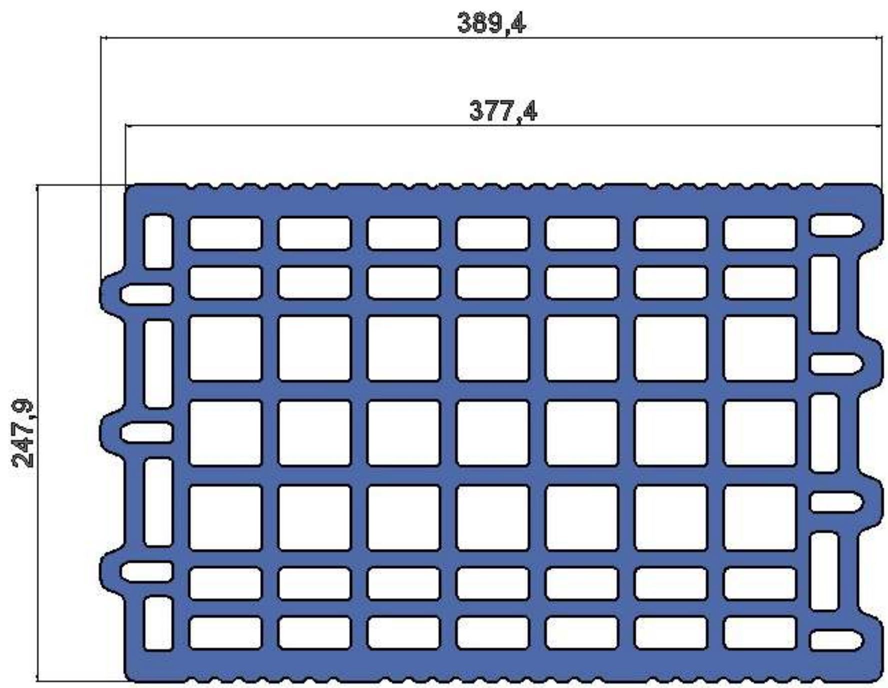


Figure 2. Geometry of the cross section employed for the calculation

4.2 Thermal conductivity of fired clay

Thermal conductivity $\lambda_{10,dry,mat}$ of fired clay was measured experimentally and then the value corresponding to the average density was determined, as described in Ref. 2-d. Hence, based on such elaborations, the following value was used to represent fired clay:

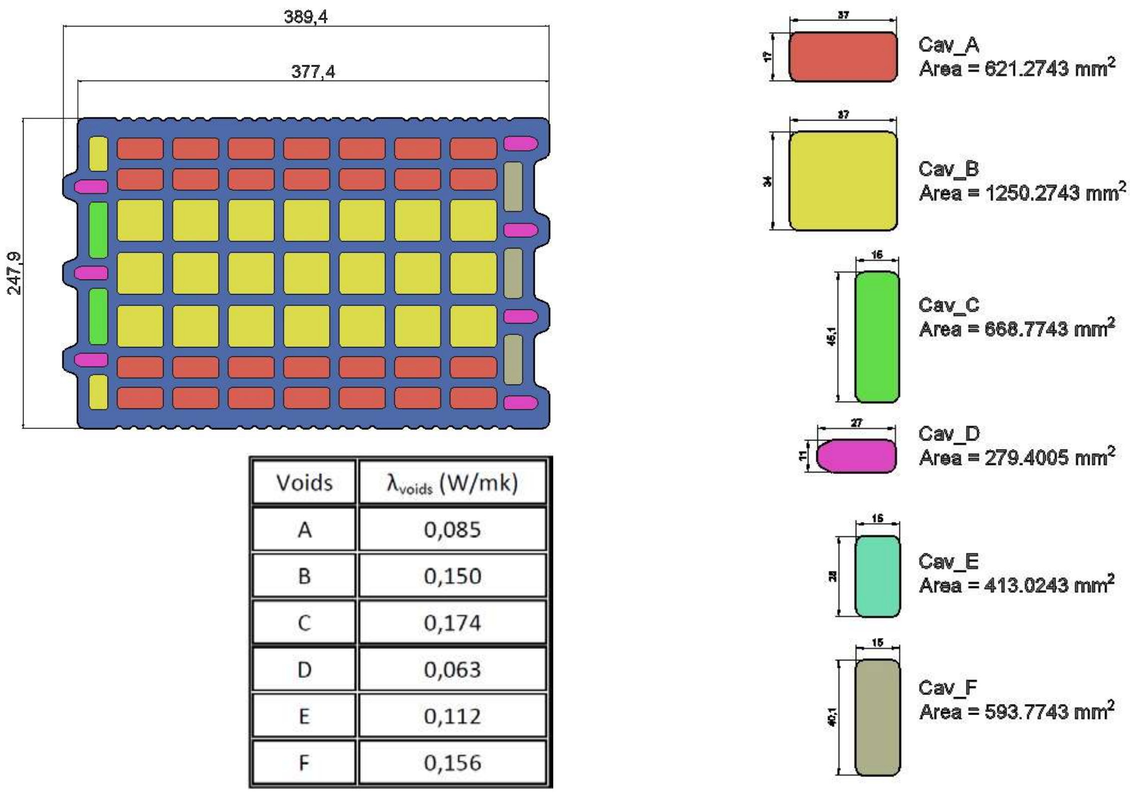
$$\boxed{\lambda_{10,dry,mat} = \mathbf{0.395\ [W/mK]}}$$

4.3 Equivalent thermal conductivity of voids

Equivalent thermal conductivity values of air voids were determined according to the methodology outlined in Ref. 2-c and reported in Appendix B of Ref. 2-g, approximating convective and radiative heat transfer inside the void.

The calculation was performed for the only installation mode possible for this product, i.e. with holes axis in vertical position and with the longest sides exposed on the inside and on the outside of the masonry. Air conductivity within voids was referred to 10 °C.

All data related to voids are shown in Figure 3.



Voids	λ_{voids} (W/mk)
A	0,085
B	0,150
C	0,174
D	0,063
E	0,112
F	0,156

Figure 3. Cross section of the block and air voids data

4.4 Boundary conditions

Ref. 2-c sets boundary conditions for the definition of the model. In particular, it refers to internal and external temperatures and to internal and external superficial thermal resistances. These latter refer to convection and radiation phenomena occurring on the surfaces of the masonry unit and are evaluated in par. 5.2 of Ref. 2-g as follows:

BOUNDARY conditions	
Physical quantity	**Nominal value**
Internal temperature T_i	**20 °C = 293.15 K**
External temperature T_e	**0°C = 273.15 K**
Internal superficial resistance R_{si}	**0.13 m²K/W**
External superficial resistance R_{se}	**0.04 m²K/W**

Table 1. Applied boundary conditions

Boundary conditions were applied considering the longest sides exposed to internal and external environments.

4.5 Type of element and mesh

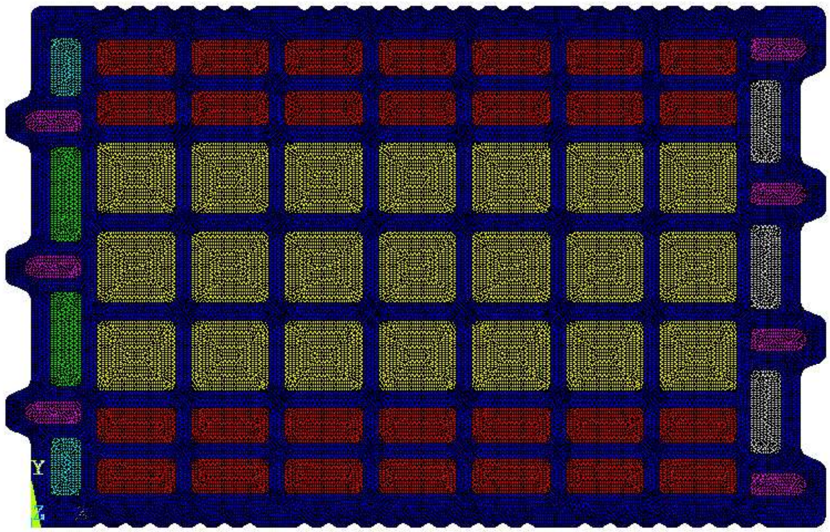


Figure 4. Meshed block

Considering the geometry of the block, the evaluation of its equivalent thermal conductivity by means of FEM was performed using triangular planar elements (plane 55 elements in Ansys 18.2). Mesh refinement (dimensions and distribution of elements) was defined, through the developed method of calculation certification, according to specifications regarding results accuracy reported in Ref. 2-c. Mesh discretization was performed with Ansys 18.2 (Ref. 2-e).

In order to guarantee an accuracy significantly lower than 2%, as required in Ref. 2-c a mesh for the masonry unit model was considered, according to specifications of Ref. 2-d, composed of 217815 elements and 109693 nodes (1 mm long edges on average) (Figure 4).

4.6 Results

The determination of equivalent thermal conductivity of the masonry unit $\lambda_{10,dry,unit}$, performed with thermal conductivity values of the fired clay $\lambda_{10,dry,mat}$ reported in par. 4.2, gave the following results, determined through Ansys output, which is heat flow (W/m) (Table 2).

RESULTS OF FEM CALCULATION					
Heat Flow (W/m)	**Thermal coupling coefficient (W/mK)**	**Thermal Transmittance (W/m²K)**	**Total Thermal Resistance (m²K/W)**	**True Thermal Resistance of the masonry unit (m²K/W)**	**Equivalent thermal conductivity (W/mK)**
Φ	$L^{2D}=\Phi/\Delta T$	$U= L^{2D}/w$	$R_T=1/U$	$R_t=R_T-R_{si}-R_{se}$	$\lambda_{10,dry,unit}=d/R_t$
5.49835	0.2749	0.7285	1.3728	1.2028	**0.2061**

Table 2. Results

Considering the installation of the units described, in the cross sections of the brick perpendicular to the direction of the thermal flow (1 unit thickness), the value of thermal flux resulting from the finite element model is Φ = 5.49835 W/m.

The entire series of calculations leading to the determination of equivalent conductivity is reported in Table 2. Dividing the heat flow that passes through aforementioned cross sections by the difference in temperature across the masonry (ΔT = 20°C), the thermal coupling coefficient is determined. In turn, dividing this coefficient by the masonry unit length leads to the determination of thermal resistance. Its inverse is the total thermal resistance, which, freed from the contribution of superficial resistances, gives the true thermal resistance of the masonry without convection and radiation. Considering the thickness (Figure 2), the equivalent dry thermal conductivity of the masonry unit can be determined $\lambda_{10,dry,unit}$ = 0.2061 W/mK (Table 2). A comparison between the thermal conductivity of the masonry unit with the one of the fired clay of which it is composed, reported in par. 4.2, it follows that the adopted layout allows reducing the equivalent conductivity of the masonry unit of 47.8%.

Obtained results are reported below, regarding the distribution of isotherms and of average heat flow vectors (Figure 5 and Figure 6).

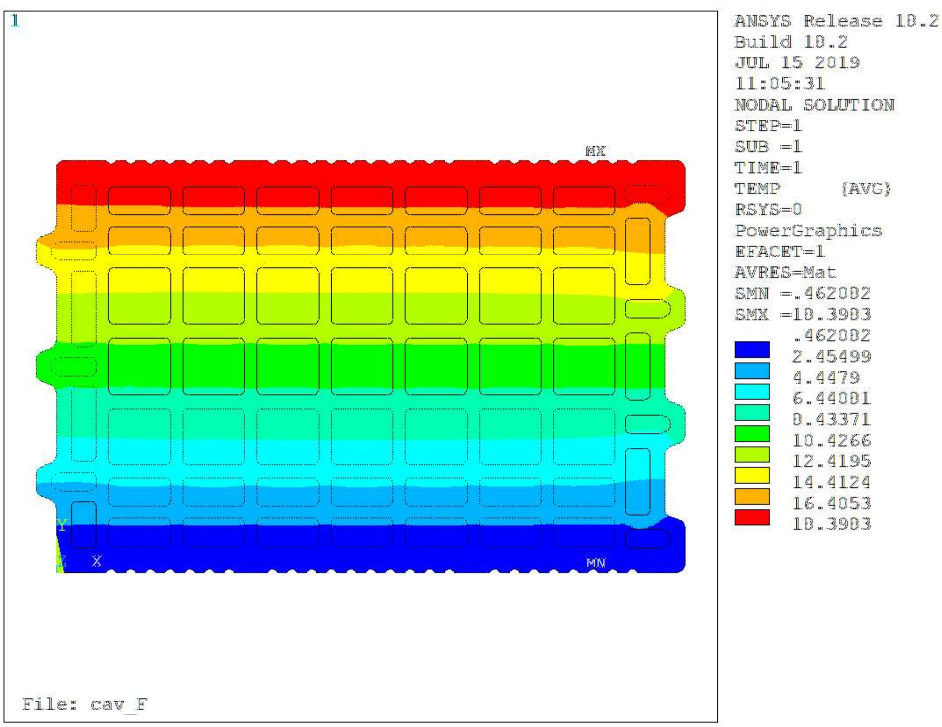


Figure 5. Distribution of isotherms in the block [°C]

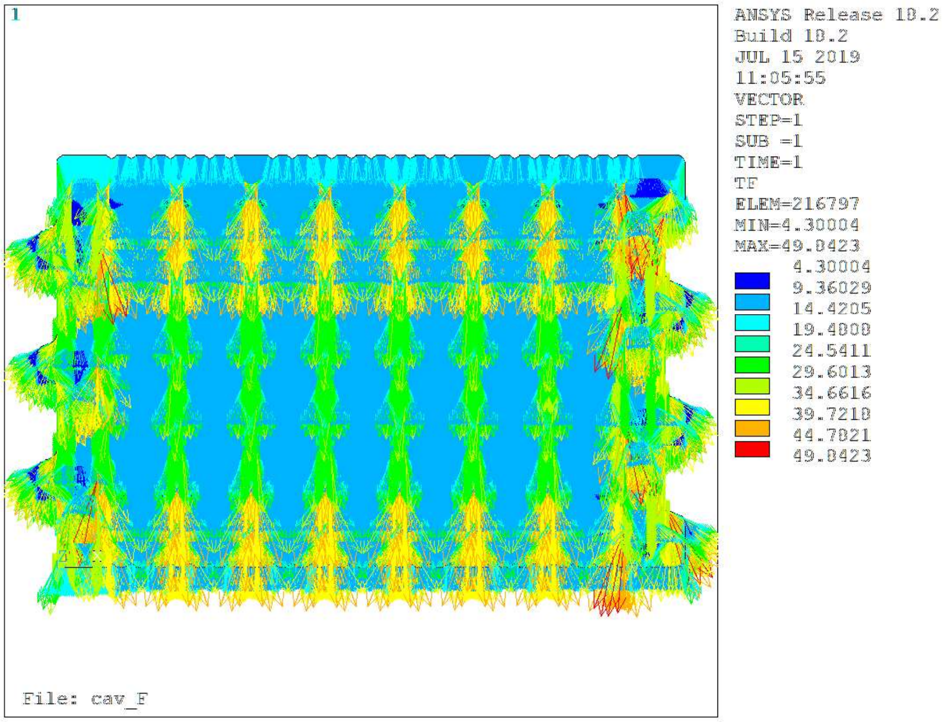


Figure 6. Average heat flow vectors [W/m²]

The calculation outlines an actual improvement of thermal characteristics of the block compared to the constituting material.

5 Determination of thermal values of the masonry

In order to evaluate the thermal values of the masonry, only horizontal mortar joints were considered, without plaster layers. Because of the interlocking block geometry, the vertical joint was not considered. For the evaluation of the thermal values of the masonry, three different configurations were studied:

- 12 mm thick horizontal joints,
- 3 mm thick horizontal joints,
- no horizontal joints.

In all configurations, a traditional mortar with thermal conductivity of 0.9 W/mK was considered.

The masonry was considered as presented in Figure 7.

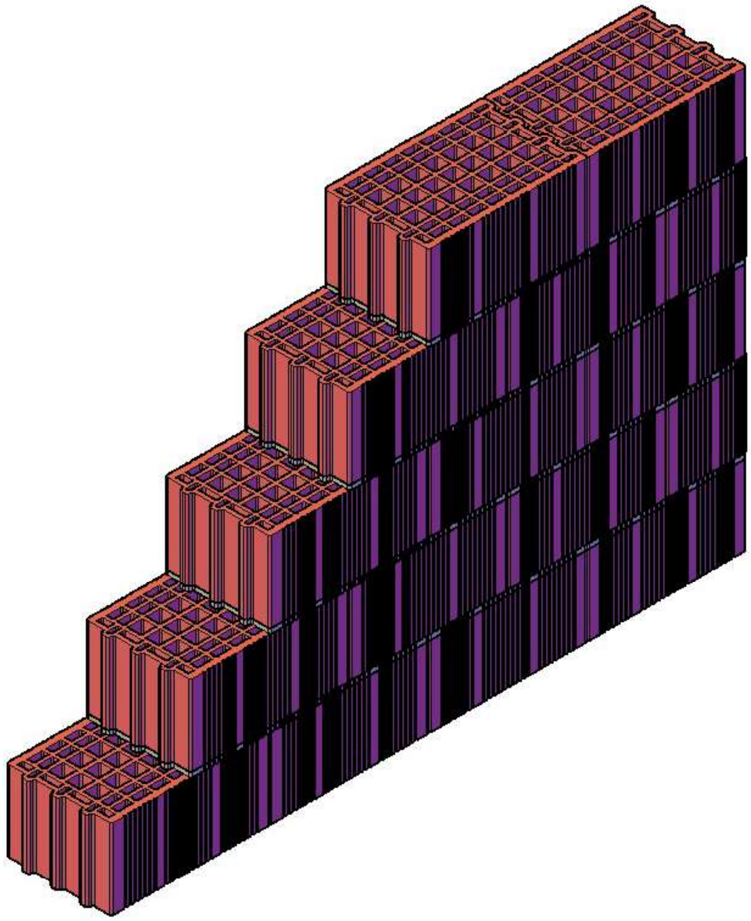


Figure 7. 3D composite masonry considered in the calculation

5.1 Input data

Based on the results of previous paragraphs, a calculation was performed starting from input data about the masonry:

Input data		
	Dimensions (mm)	**Thermal conductivity (W/mK)**
Masonry unit	**377.4 x 247.9 x 190**	**0.2061**
Horizontal traditional mortar joints	Thickness = **12 – 3 – 0**	**0.900**

Table 3. Input data for the calculation

5.2 Results of the calculation

the thermal values of the masonry, in the three configurations described above, are shown below.

a) Traditional configuration: (12 mm thick horizontal joints)

Results for the traditional configuration	
Physical quantity	**Results**
Thermal resistance only of the layer $\mathbf{R_t}$ (m^2K/W)	**1.0023**
Equivalent thermal conductivity of the masonry $\boldsymbol{\lambda}_{\mathbf{equ}}$ (W/mK)	**0.2473**
Thermal resistance of the masonry including superficial thermal resistances $\mathbf{R_T}$ (m^2K/W)	**1.1723**
Thermal transmittance **U** (W/m^2K)	**0.8530**

Table 4. Results of the calculation for the masonry with 12 mm thick horizontal joints

b) Thin bed mortar configuration (3 mm thick horizontal joints)

Results for the traditional configuration	
Physical quantity	**Results**
Thermal resistance only of the layer $\mathbf{R_t}$ (m^2K/W)	**1.1430**
Equivalent thermal conductivity of the masonry $\boldsymbol{\lambda}_{\mathbf{equ}}$ (W/mK)	**0.2169**
Thermal resistance of the masonry including superficial thermal resistances $\mathbf{R_T}$ (m^2K/W)	**1.3130**
Thermal transmittance **U** (W/m^2K)	**0.7616**

Table 5. Results of the calculation for the masonry with 3 mm thick horizontal joints

c) No joints configuration

Results for the traditional configuration	
Physical quantity	**Results**
Thermal resistance only of the layer $\mathbf{R_t}$ (m^2K/W)	**1.2028**
Equivalent thermal conductivity of the masonry $\boldsymbol{\lambda}_{\mathbf{equ}}$ (W/mK)	**0.2061**
Thermal resistance of the masonry including superficial thermal resistances $\mathbf{R_T}$ (m^2K/W)	**1.3728**
Thermal transmittance **U** (W/m^2K)	**0.7284**

Table 6. Results of the calculation for the masonry without mortar joints

6 Conclusions

On the basis of performed calculations, an equivalent value of thermal conductivity for the masonry unit equal to **0.2061 W/mK** was obtained. Calculations performed on the masonry gave a transmittance value of **0.8530 W/m²K** using 12 mm thick horizontal joints, **0.7616 W/m²K** with 3 mm thick horizontal joints and **0.7284 W/m²K** without mortar joints.

7 Distribution list

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