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THERMAL BRIDGES AT MASONRY WALLS MADE WITH CERAMIC BLOCKS FORESEEN WITH VERTICAL HOLLOWS

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Abstract: The paper presents results of numerical analysis for determination of the equivalent thermal conductivity for vertical hollow ceramic blocks and for masonry made from them. The heat flow crossing through the existing thermal bridges at walls made of vertical hollow ceramic blocks, respectively the linear heat transfer coefficients, the corrected average thermal resistance and corrected average thermal transmittance, can be determined based on the plane temperature field in stationary thermal regime, which takes into consideration the thermal conductivity of the air existing in the gaps, which is variable with temperature. The working method and the developed calculus program are useful for a correct energy design of new types of hollow ceramic blocks, of new buildings made with masonry structure of vertical hollow ceramic blocks and also in the rehabilitation process of existing buildings made with this type of structure, in order to ensure optimum thermal efficiency.

Key words: thermal technical characteristics, energy economics, mathematical modeling, simulation, heat transfer, dynamic modeling.

1. INTRODUCTION

The paper presents some of the researches done to determine the thermal performances of ceramic blocks with vertical hollows. The mathematical modeling and the calculus method used in the research and in the development of the calculus program are those given in standards, which will be mentioned in the following chapters.

Fig. 1 Examples of studied types of ceramic blocks with vertical hollows

2. DETERMINATION OF THE THERMAL TRANSMITTANCE FOR CERAMIC BLOCKS WITH VERTICAL HOLLOWS

Air gaps existing in the structure of ceramic blocks are environments with variable thermal conductivity, which for each calculus step of the temperature field, is changing according to the air temperature in the hollow and with the temperature of the surfaces that are surrounding the air gap. These calculations were performed with the computer program "PSILamVarPLAN" developed for this purpose. Determination of the variable thermal conductivity of the air layer is made automatically by the program in accordance with the stipulations of SR EN 6946:2009 [1] standard, section 5.3.2 and SR EN 10211-1:1998 standard, Annex B [2].

2.1 Theoretical calculation algorithm

To determine the bi-dimensional thermal coupling coefficients L^{2D} used to calculate the thermal transmittance U and for determining the linear thermal transfer coefficient ψ , is necessary to solve the plane temperature field in stationary thermal regime for complex sections with variable thermal conductivities, depending on the temperature layer.

$$\frac{\partial}{\partial x}\left[\lambda(x,y)\cdot\frac{\partial\theta(x,y)}{\partial x}\right]+\frac{\partial}{\partial y}\left[\lambda(x,y)\cdot\frac{\partial\theta(x,y)}{\partial y}\right]=0 \tag{1}$$

where:

θ is the temperature in the node coordinates (x,y);

$\lambda(x,y)$ has constant values for the ceramic skeleton of the section;

$\lambda(x,y)$ for non-ventilated air cavities, is the equivalent thermal conductivity determined according to those which will be present in the next subchapter.

For numerical solving of the 2nd order partial differential equation mentioned above, the geometrical model extent between horizontal and vertical cutting planes, was divided with the help of sectioning axis parallel with the axis of the cartesian plane system, with discretization steps Δx and Δy, thus forming the orthogonal calculus network of the plane temperature field. The calculus network was taken with steps between 1 and maximum 10 mm in all directions. Discretization is done automatically by one of the subroutines of the computer program.

Temperature field calculus was performed considering that the lateral cutting planes are adiabatic surfaces. The high volume of calculations required for solving the plane equation of heat transmission with variable thermal conductivities in steady state regime, required the development of the calculus program "PSILamVarPLAN". This program uses high precision numerical method of heat balance in the nodes of the calculus network in accordance with SR EN ISO 10211-1:1998 standard, annex A, section A.2 [2].

2.2 The method for determining the equivalent thermal conductivity

To calculate the heat flow through the vertical hollows of the ceramic blocks, the air from the gap is taken into account through an equivalent thermal conductivity λ_{ech}. When determining the equivalent thermal conductivity, the heat flow by conduction, convection and radiation is taken into account. Also, the thermal conductivity value depends on the cavity geometry and on the calculus thermal conductivities of the ceramic skeleton.

To model the heat transfer at the surface of the elements and through the air layers the general principles set out in SR EN 6946:2009 standard [1], 5.3.2 section and SR EN 10211-1:1998, Annex B [2], were taken into account.

The equivalent thermal conductivity for non-ventilated cavities is given by:

$$\lambda_{ech} = \frac{d}{R_s} \tag{2}$$

where:

d is the cavity dimension on the direction of the heat flow

R_s is the thermal resistance of the cavity: $R_s = \dfrac{1}{h_a + h_r}$

The convective heat exchange coefficient:

$$h_a = \max\left\{\frac{C_1}{d}; C_2 \Delta T^{1/3}\right\} \tag{3}$$

where: $C_1 = 0{,}025\dfrac{W}{m \cdot K}$ şi $C_2 = 0{,}73\dfrac{W}{m^2 \cdot K^{4/3}}$

ΔT- maximum temperature difference in the cavity.

Radiant heat exchange coefficient:

$$h_r = 4 \cdot \sigma \cdot T_m^3 \cdot E \cdot F \tag{4}$$

where: $\sigma = 5{,}67 \times 10^{-8}\dfrac{W}{m^2 \cdot K^4}$ Stefan- Boltzmann constant

$E = \left(\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1\right)^{-1}$ the emittance between opposing surfaces;

$F = \dfrac{1}{2}\left(1 + \sqrt{1 + \left(\dfrac{d}{b}\right)^2} - \dfrac{d}{b}\right)$ form factor for a rectangular section

ε_1 and ε_2 are the emissivities of the surfaces from the figure

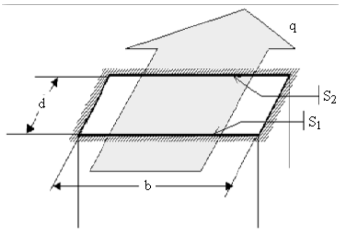


Fig. 2 Rectangular cavity and the direction of the heat flow

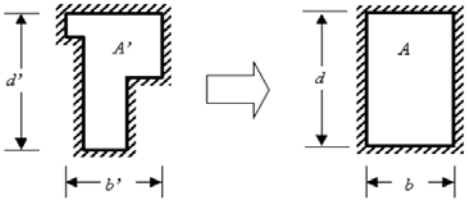


Fig. 3 Transforming non-rectangular cavities in rectangular cavities

Non-ventilated cavities with irregular shapes (T, L, D, O, etc...), become rectangular cavities with the same area (A = A') and the same form ratio (d/b=d'/b'), as it can be seen in the figure and in the below relations.

Cavities should be treated separately if they have a size less than 2 mm or when cavities communicate with each other by interstices which are not greater than 2 mm.

For transformation the next formulas are used: $b = \sqrt{\dfrac{A' \cdot b'}{d'}}$ $d = \sqrt{\dfrac{A' \cdot d'}{b'}}$

A – the surface of the equivalent rectangular cavity

A'- the surface of the effective rectangular cavity

d, b –the dimensions of the equivalent air cavity
d', b'–dimensions of the smallest rectangle surrounding the irregular cavity

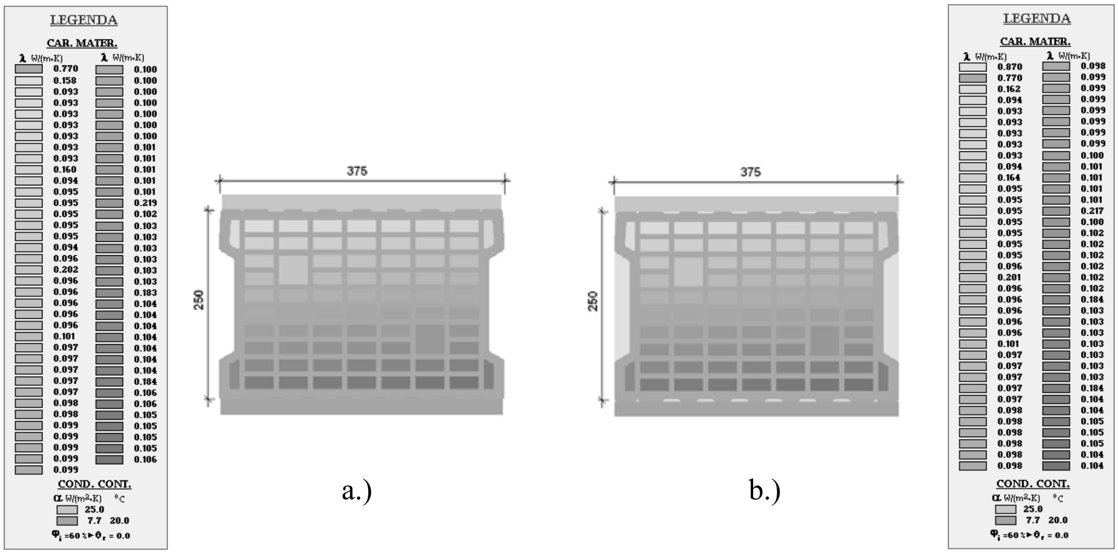
3. CASE STUDIES

The paper presents numerical and graphical results obtained for one type of ceramic blocks with vertical hollows produced in our country, respectively the one having the dimensions of 375x250x230 mm.

For the cases which will be next presented, the interior ambient temperature was considered Θ_i=20°C and the outdoor temperature Θ_e=0°C, and also surface thermal resistances were taken the standard ones, respectively R_{si}=0,13 (m^2·K)/W and R_{se}=0,04 (m^2·K)/W. The two studied cases:

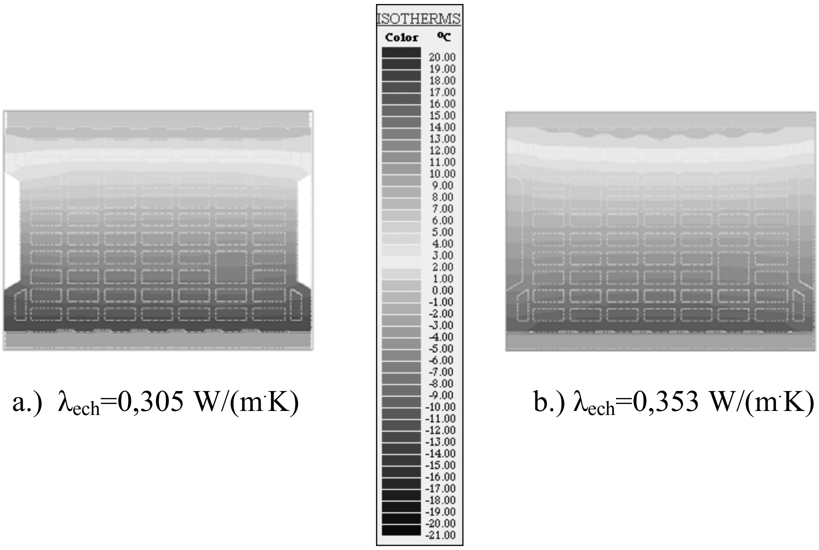
a.) The ceramic block located between the ambient environments;

b.) The ceramic block placed in the masonry mortar and located between the ambient environments.



a.) b.)

Fig. 4 The geometrical model-dimensions in mm



a.) λ_{ech}=0,305 W/(m·K) b.) λ_{ech}=0,353 W/(m·K)

Fig. 5 Graphical and numerical results

4. NUMERICAL AND GRAPHICAL RESULTS FOR MASONRIES MADE WITH VERTICAL HOLLOWS CERAMIC BLOCKS

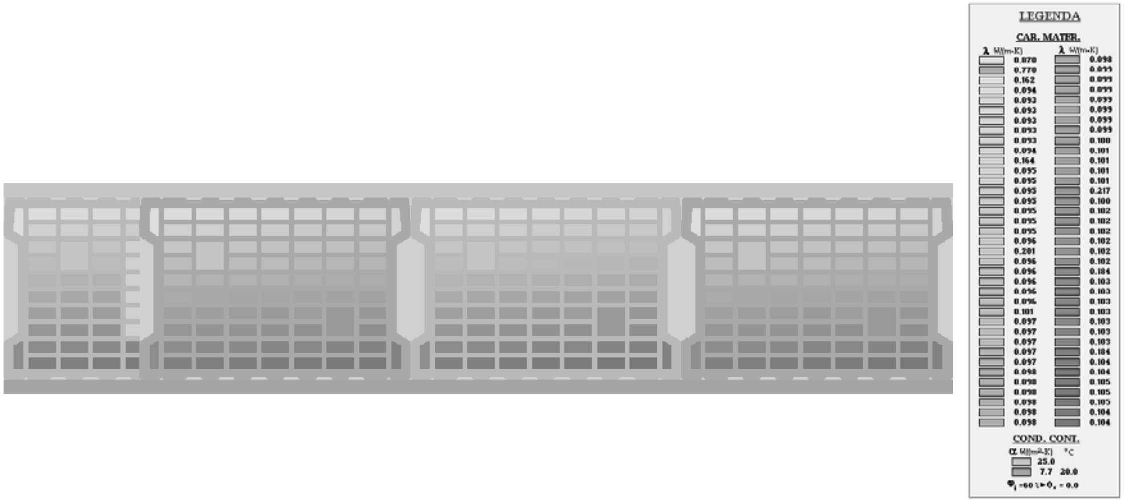


Fig. 6 Geometrical modeling of a masonry row made of ceramic blocks with vertical hollows

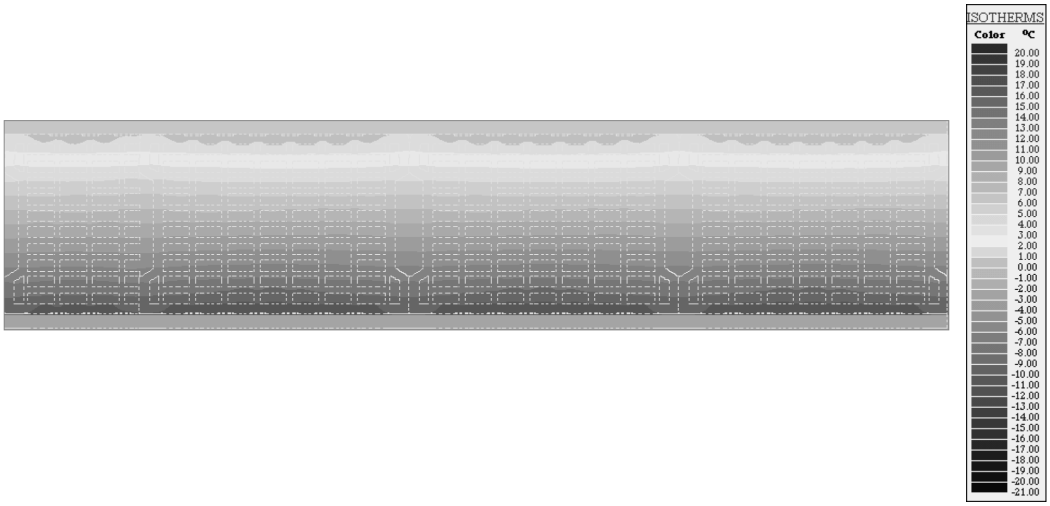


Fig. 7 Graphical results

To determine the thermal conductivity of a masonry made with vertical hollow ceramic blocks, a vertical wall with a height of 1m and an equivalent length of three bricks, the mortar in the horizontal joints of 12 mm high and the joint mortar between the bricks, were considered.

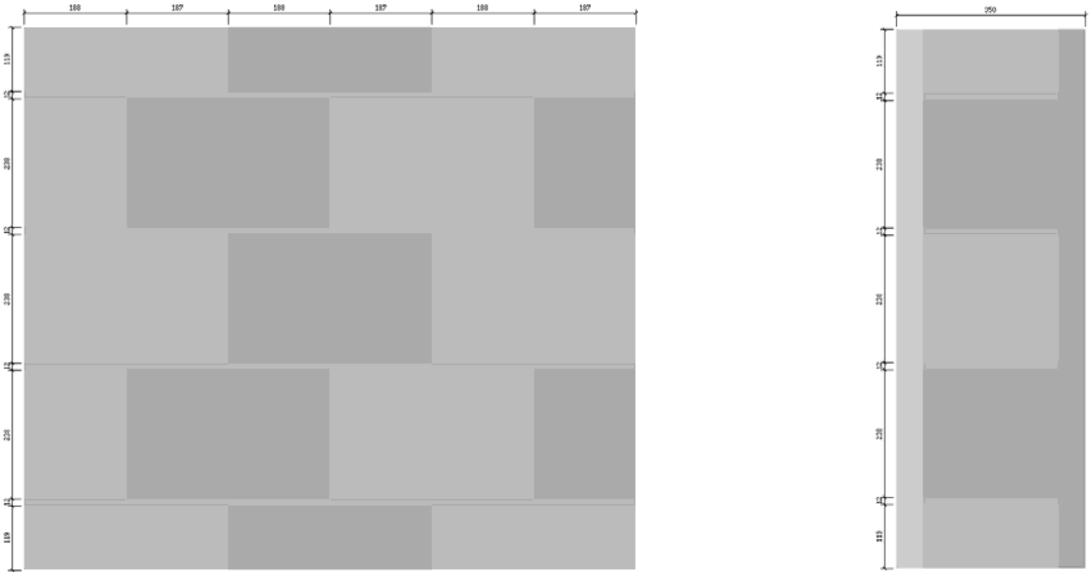


Fig. 8 View of the wall and the vertical section

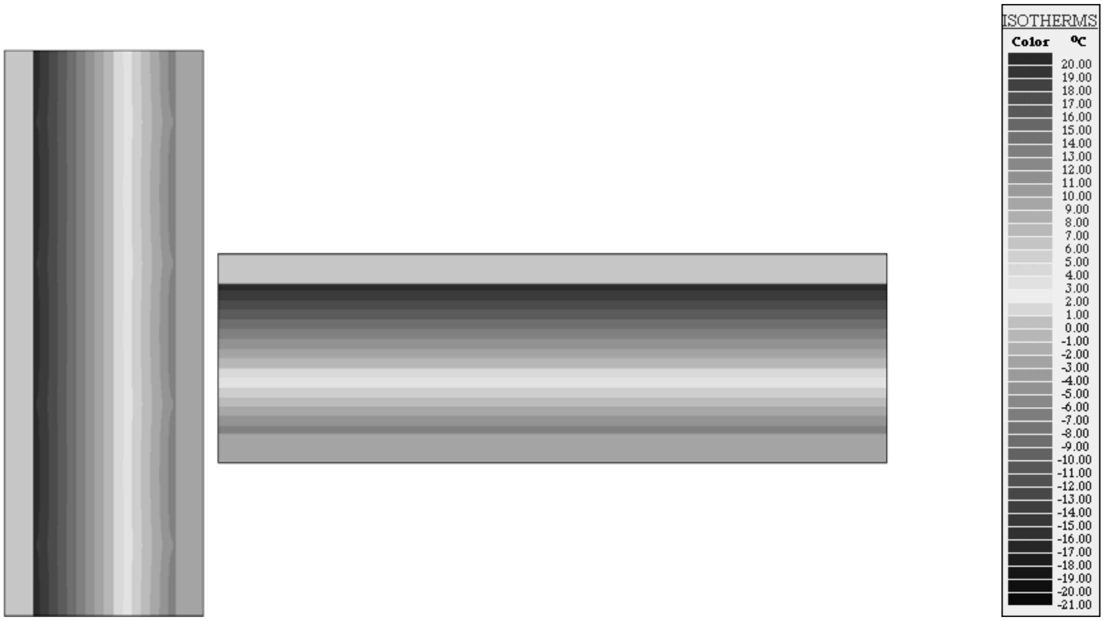


Fig. 9 Graphical results in the masonry section

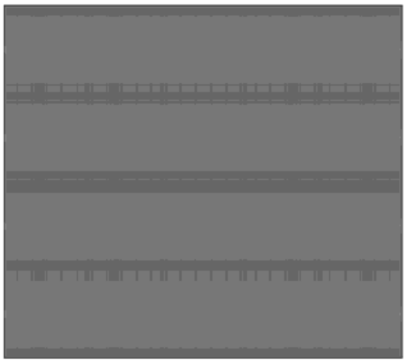


Fig. 10 Numerical and graphical results on the interior surface of the masonry λ_{ech}=0,397 W/(m·K)

5. PRACTICAL APPLICATION FOR WALLS INTERSECTION

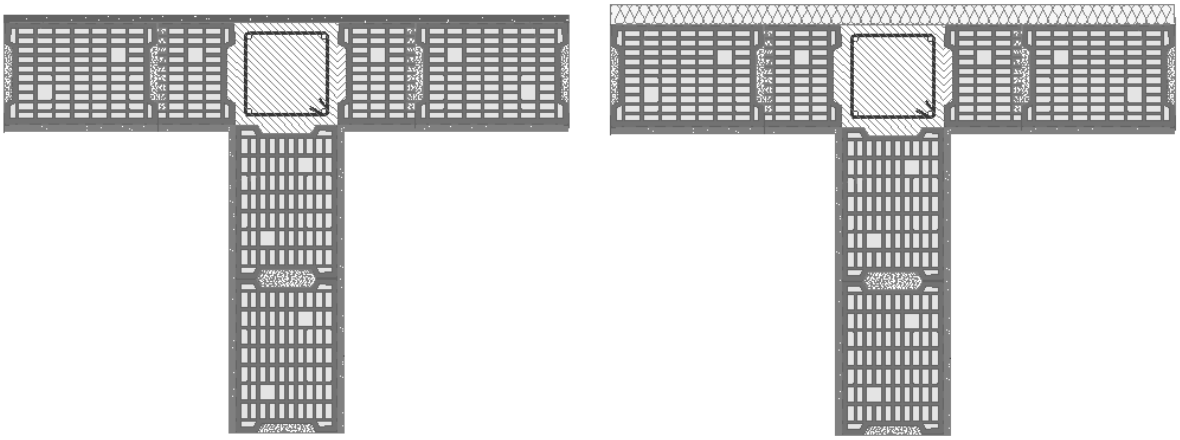


Fig. 11 Horizontal intersection with reinforced concrete core of 25 cm, in the thermal insulated and uninsulated variant

Fig. 12 Geometric modeling of the uninsulated and thermal insulated intersection using the equivalent thermal conductivity of the masonry λ_{ech}

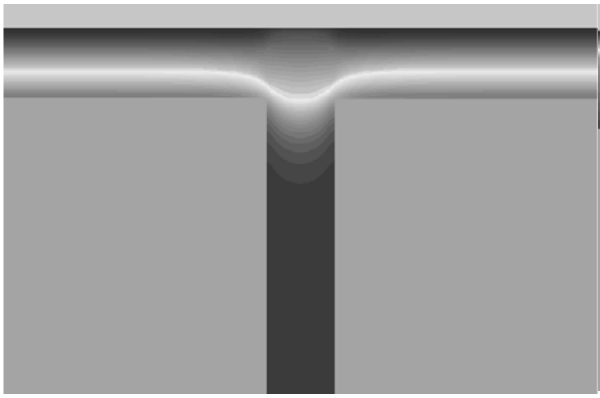


Fig. 13 Uninsulated case

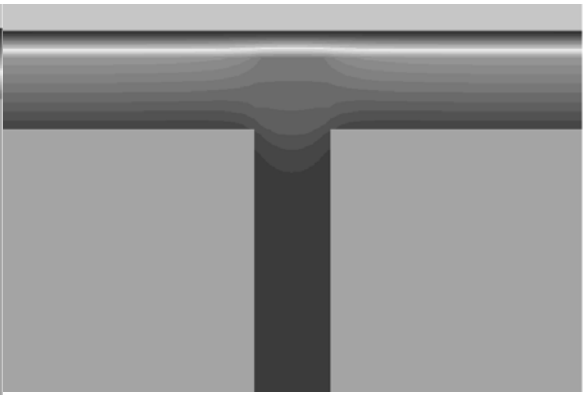


Fig. 14 Thermal insulated case

$\Psi 1 = \Psi 2 = 0.184$ W/(m·K) $\mathbf{f_{0,25}} = 0.618$ [-]

10 cm $\Psi 1 = \Psi 2 = 0.007$ W/(m·K) $\mathbf{f_{0,25}} = 0.912$[-]

16 cm $\Psi 1 = \Psi 2 = 0.003$ W/(m·K) $\mathbf{f_{0,25}} = 0.940$[-]

20 cm $\Psi 1 = \Psi 2 = 0.002$ W/(m·K) $\mathbf{f_{0,25}} = 0.950$[-]

6. CONCLUSIONS

Knowing the values of the thermal conductivities of ceramic blocks with vertical hollows allows the determination for various structural combinations (such as horizontal intersections of walls with poles, junctions between intermediate floors with walls, wall intersections with roof slabs, etc…) of the linear thermal coefficients ψ, of the thermal transmittances of the building envelope elements made of ceramic blocks masonries and also the linear temperature coefficients f_{Rsi} for assessing the risk of mold.

The "PSILamVarPLAN" program determines the thermal performance of ceramic blocks with various forms of vertical hollows. This computer program, likewise, may determine the thermal performance of ceramic elements with horizontal hollows for floors, like the example in the figure.

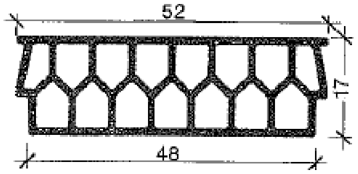


Fig. 15 Ceramic block for floors

In order to build buildings with low energy consumption as required by requirements of the current European norms, is essential an accurate knowledge of the thermal performance of each component of the building envelope. The methodology and the computer program presented in the paper, allows the design of new types of ceramic components for masonries or floors with various forms of air hollows, targeting the highest thermal performances.

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