THERMAL BEHAVIOR OF SINGLE-LEAF WALLS FOR BUILDINGS, MADE WITH LIGHTWEIGHT CERAMIC CLAY BRICKS

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Abstract: In recent years, several studies about factors influencing the heat transfer in single-leaf walls composed by lightweight ceramic bricks of large format have been made, in order to reduce energy losses. Separate works have highlighted the relevance of some parts composing the wall such as the different types of internal voids in the brick, different types of tongue and groove system and different types of horizontal joint. This paper seeks to integrate these studies in order to give an overview of factors that influence the heat transfer and study the importance of each one of them, from an energy point of view. For this purpose, the influence of every factor in the equivalent thermal transmittance of the external walls of building is compared.
It is remarkable that a single-leaf wall built with a geometrically optimized brick and thin horizontal joint gives masonry wall many significant advantages, because the amount of heat flux dissipated through the horizontal mortar joint is greatly reduced. Better insulated walls mean that there is less need to use home heating and cooling systems. This means less energy consumption and a proportional decrease in GHG emissions, in line with the objectives for 2020 set in the EEP.

Keywords: Lightweight clay block; energy efficiency; horizontal joint; thermal transmittance; tongue and groove system; single-leaf wall; grinding

1. INTRODUCTION

Currently, and as a necessary measure, is promoting the use of renewable energies [1], energy saving and energy efficiency in all sectors of all countries, to protect the environment, promote health, save money, and contribute to adequate sustainable development.

The construction industry has had to improve their constructive solutions for exterior walls to improve the characteristics of the materials that it use, so as to reduce energy losses and make a moderate use of it. Low-density, lightweight materials are now being used.

Recent studies have shown the influence of cladding materials used on building walls on CO_2 emissions and energy consumption [2]. Seeking to explore further improvements in wall construction materials, other studies have shown how the porous nature of clay bricks can improve thermal characteristics [3, 4].

Lightweight ceramic blocks in single-leaf walls [5], meet these new requirements well. Masonry walls built with such bricks blend good noise insulation, high mechanical strength, exceptional fire resistance and high levels of

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heat insulation and comfort (thermal inertia). They are also fully sustainable and environmentally-friendly, as they are made solely of baked clay and their useful lifetimes can be centuries long.

Nowadays we can find multitude of constructive solutions of exterior walls of buildings according to the execution.

Among them, we will focus on exterior walls built of a single thickness of 29 cm ceramic clay blocks with appropriate interior and exterior cladding. There are three sections of such single-leaf walls that can affect their thermal performance: the cross-section of the blocks with their air-filled voids (the "clay/air cross-section"), where the geometry of voids and the type of tongue and grooving system are influential, the cross-section of the blocks with the voids filled with bonding mortar (the "clay/mortar cross-section") and the cross section of the layer of bonding mortar itself, (the "tendel cross-section").

This paper aims to integrate the different studies found in bibliographic sources to provide an overview of factors that influence the heat transmission by single-leaf wall. Separate studies have characterized, in sections air-clay and clay-mortar, the influence of the type of internal voids of bricks [6 - 12] and the type of tongue and groove system [13, 14], and moreover, the influence of the horizontal joint [15].

Calculations of equivalent thermal transmittance, Ueq [W/m^{2}K] have been obtained in all cases according to the following standards: UNE Spanish Legislation [16], AENOR [17], European EN [18 - 25], and International ISO [18 - 19].

2. INFLUENCE OF INTERNAL VOIDS OF BRICK ON THERMAL BEHAVIOR OF SINGLE-LEAF WALLS

Recent studies [6 - 8] have emphasized the importance of breaking the heat flux as many times as possible throughout the brick. Thus, different distributions have been proposed with voids in a quincunx with the greater number of rows perpendicular to the flux of heat in the block [9 - 12]. It is remarkable the importance of maintaining a minimum thickness in the outer and inner walls of the brick, in order to keep consistency in the manufacturing process.

To allow comparison with other studies, we start with exterior walls built with ceramic bricks whose equivalent thermal transmittance, solved by finite elements [26, 27], is known.

The blocks are lightened clay bricks, 300 mm long, 290 mm thick and 250 mm high, with 8 mm of exterior wall and 5 mm of internal partitions [8]. The tongue and groove system is circular type. The wall has been executed with a standard clay (conductivity 0.5 W/m.K), without vertical joint (since there is a tongue and groove system) and discontinuous horizontal joint of standard mortar with a 30 mm wide air cavity in the middle. There is a 10 mm deep penetration of mortar in each brick and a height of horizontal joint about 10 mm between bricks. The wall is covered with outer coatings mortar conductivity 1.3 W/m.K and a thickness of 15 mm plaster lining conductivity 0.57 W/m.K with thickness 15 mm, usually used assembly.

Figure 1 shows the sections of the following bricks: a brick with rectangular voids in a quincunx with 17 rows perpendicular to the heat flux, a brick with combined rectangles and triangles voids with 21 rows perpendicular to the heat flux and a brick with only rhomboidal voids with 25 rows perpendicular to the heat flux, such as studies show [9 - 12].

Table 1 displays the thermal transmittance of the walls made with the indicated bricks and their percentages of improvement.

It is noteworthy that the larger the number of rows perpendicular to heat flux, the lower the thermal transmittance of the wall. Also worth mentioning that the thermal performance of wall improves when their interior walls present a not perpendicular trajectory to the heat flux. The influence of the type of internal voids is quite important, up to 8%.

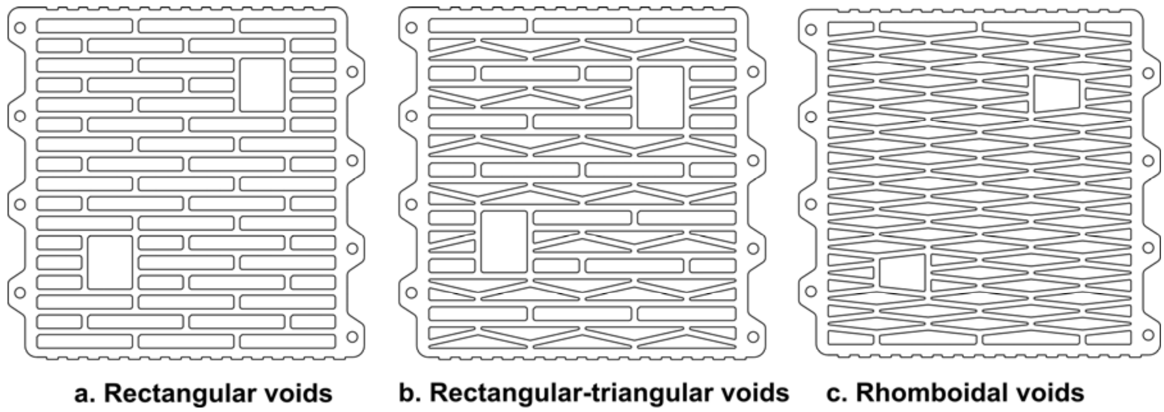

Fig. 1. Sections of bricks with different internal voids.

Table 1. Comparison chart of the three studied sections.

Brick with internal voids	Ueq ($W/m^2.K$)	% improvement
a) Rectangular	0.627	-
b) Rectangular-triangular	0.604	3.67%
c) Rhomboidal	0.575	8.29%

3. INFLUENCE OF TONGUE AND GROOVE SYSTEM ON THERMAL BEHAVIOR OF SINGLE-LEAF WALLS

Several authors [12 - 14] showed the importance of breaking the heat flux inside the brick and also in the tongue and groove system, without losing stability conditions of block mainly in processes of extrusion, palletizing and firing.

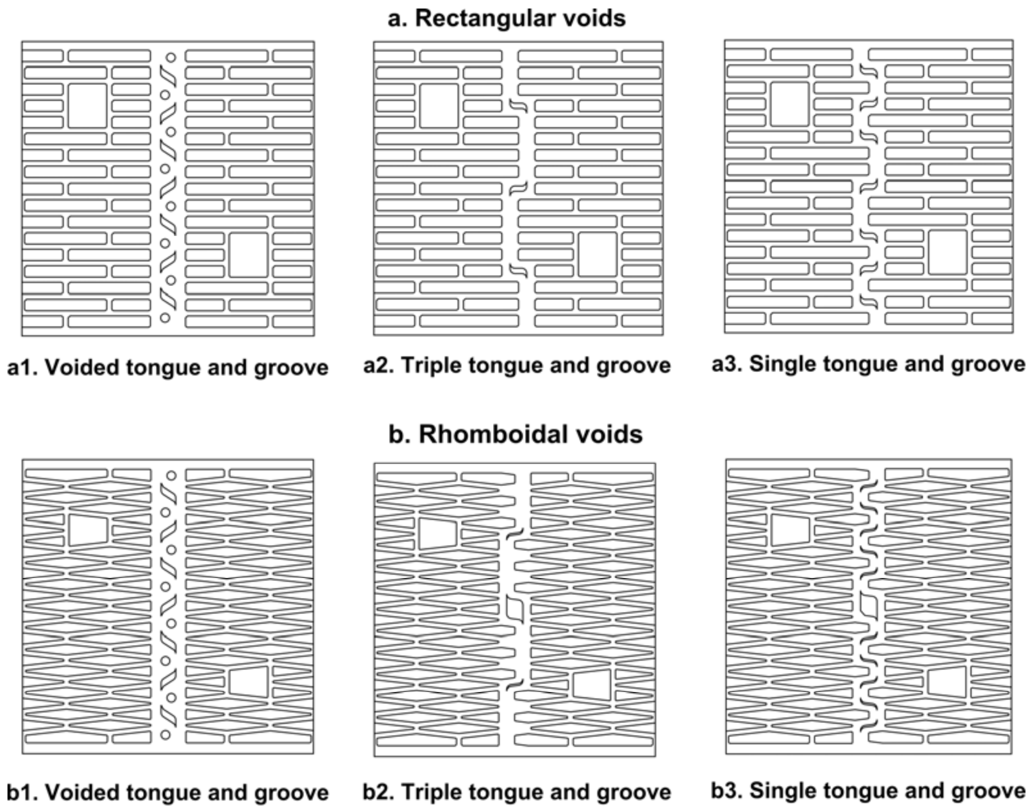

Fig. 2. Sections of the assembled blocks with different tongue and groove systems.

In previous section we have classified different brick geometries according to their thermal performance. In order to compare results we will use the worst (rectangular) and the best (rhomboidal) geometry when testing tongue and groove systems. Likewise, we will keep the same assembly of wall.

Figure 2 shows the characteristic sections of the assembly of two blocks to analyze the tongue and groove system in the wall. Thus, it shows each of the bricks with three types of tongue and groove system: the first one with circular perforations, which separates the void of tongue and groove system of the internal voids; the second and the third with the internal voids extended to the end of the tongue and groove system. From these last two we have considered two different types: the first one with three extended rows and the other one with just one.

Tables 2 and 3 show the thermal transmittance of walls made with rectangular or rhomboidal voids and their percentage of improvement.

Table 2. Thermal transmittance of the wall using bricks with rectangular voids as a function of the tongue and groove system.

a. Brick with rectangular voids	Ueq (W/m^2.K)	% improvement
a1. Voided tongue and groove system	0.627	-
a2. Triple tongue and groove system	0.587	6.38%
a3. Single tongue and groove system	0.586	6.70%

Table 3. Thermal transmittance of the wall using bricks with rhomboidal voids as a function of the tongue and groove system.

b. Brick with rhomboidal voids	Ueq (W/m^2.K)	% improvement
b1. Voided tongue and groove system	0.575	-
b2. Triple tongue and groove system	0.539	6.26%
b3. Single tongue and groove system	0.528	8.17%

As shown, it is verified that the more often the heat flux is broken by tongue and groove system the better thermal behavior the wall presents. The resulting values, between 6-8%, are also considered important.

If we compare the results of all parameters that affect the heat transfer, it can be seen that breaking the heat flux inside the block is as important as breaking it in the vertical assembly between the blocks, i.e., in the tongue and groove system. Moreover a better distribution of voids inside the brick, improves thermal behaviour, because more times heat flux in the tongue and groove system is broken.

If we compare the equivalent thermal transmittance of the brick with rectangular voids and the best tongue and groove system (0.586 W/m^2.K) to the brick with rhomboidal voids and the same tongue and groove system, (0.528 W/m^2.K) an improvement up to 9.90% in found.

4. INFLUENCE OF THE HORIZONTAL JOINT ON THE THERMAL BEHAVIOR OF SINGLE-LEAF WALLS

Although several studies pay great attention to the internal geometry of the block [9 - 14], a recent study has focused on the horizontal joint [15], since, as it will be shown later, most heat losses are produced through it.

In order to compare with previous works, we have characterized four of the previous geometries (see Figure 3). Bricks with rectangular and rhomboidal voids, and tongue and groove system with circular perforations and simple, have been studied.

The above mentioned study [15] reveals a relevant constructive solution: a thin horizontal joint with gripping mortar without penetration into the blocks. This type of assembly has two major advantages: the clay-mortar section disappears allowing a better isolation of the entire bricks (with the properties of clay-air section), and the thickness of mortar joint decreases. This type of solution required as a pretreatment of the brick: a grinding is necessary to implement this type of joint.

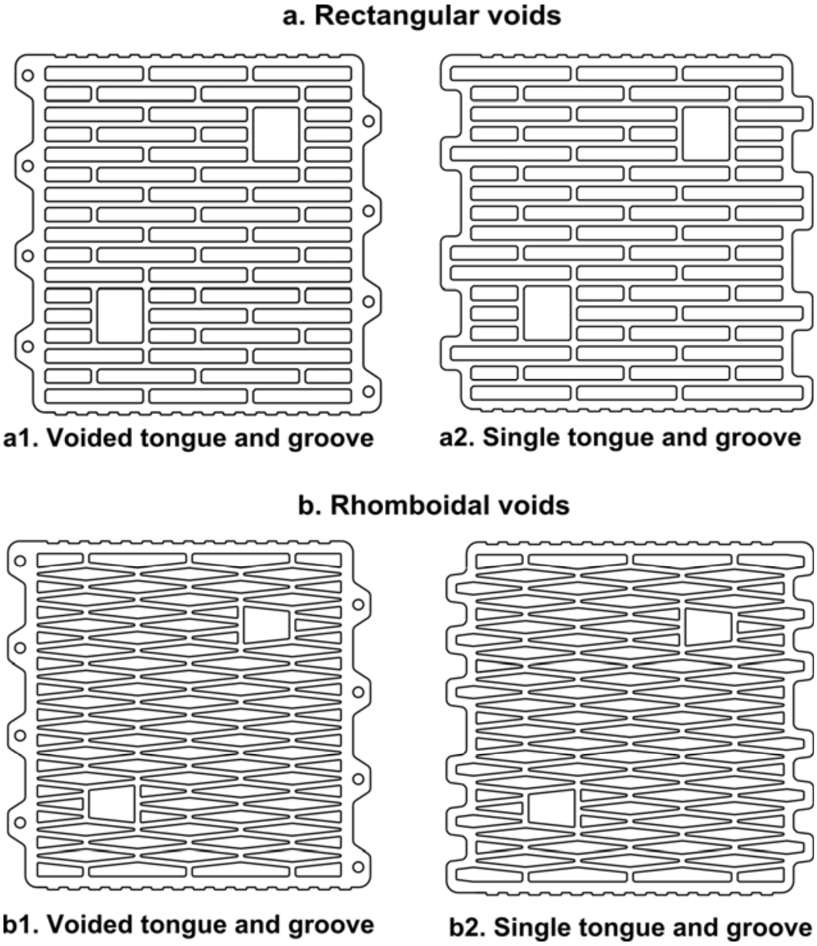

Fig. 3. Sections of considered brick made with thin joint.

We have compare the thermal transmittance of four blocks, executing the wall with standard mortar joint 30 mm furrowed bed joint with a height of 10 mm and bed joint penetration in blocks of 10 mm each, and the same wall executed with thin mortar conductivity 0.83 W/m.K without penetration into blocks and horizontal joint height of 3 mm.

Table 4 shows the thermal transmittances of wall for each of the assemblies and in depending on the brick used.

Table 4. Thermal transmittance of the wall depending on the type of brick.

U_{eq} (W/m^2K)	30 mm furrowed bed joint	Thin Joint	% improvement
a. Brick with rectangular voids			
a1. Voided tonge and groove system	0.627	0.509	18.82%
a2. Single tonge and groove system	0.586	0.464	20.82%
b. Brick with rhomboidal voids			
b1. Voided tonge and groove system	0.575	0.452	21.39%
b2. Single tonge and groove system	0.528	0.402	23.86%

We emphasize the important heat loss that occurs in the horizontal joint. Otherwise we can also see the influence of the internal geometry of the block and the type of tongue and groove system on the overall improvement when we use thin joint.

The main advantage of walls built with thin joints – without to consider the fact that they use less mortar - is that their insulating capacity is high. This is positive in two important aspects: better insulated walls mean that homes need to make less use of heating and cooling systems and thus consume less energy, which in turn reduces GHG emissions. Moreover, the level of thermal comfort provided is more stable, since less heat is lost through the walls.

An enclosure with a suitable geometric distribution of voids inside the brick with optimal tongue and groove system and thin horizontal joint, gives the wall an optimum performance from the thermal viewpoint, minimizing energy losses.

4. CONCLUSIONS

As reflected in studies mentioned above [6 - 14], it is important the internal distribution of the brick that forms the wall, but is this as important as the other parts that form the wall. The horizontal joint [15], is a key to improving the isolation of exterior walls executed today.

As it has been shown in several studies [6 - 11], the optimization of the geometry of internal voids of brick and the tongue and groove system [12 - 14], may involve energy savings close to 10%. However, additional improvements are limited by the manufacture procedures.

The importance of horizontal joint has been verified. Energy savings between 18% and 24% have been obtained, more than double that achieved by optimizing the geometry of the block.

From a global point of view, we can conclude that the horizontal joint used is more important than the internal geometry of brick. Both factors in conjunction provide the wall a better thermal performance and, therefore, a greater energy saving, up to 36%.

A wall built with a geometrically optimized brick and thin joint with pre-grinded bricks, has major advantages, because the amount of heat that dissipates through the horizontal mortar joints is greatly reduced.

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