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Comparative thermal analysis of extruded ceramic products between multi perforated brick and modified bricks in cells distribution

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Comparative thermal analysis of extruded ceramic products between multi perforated brick and modified bricks in cells distribution

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Abstract. The demand for cooling and heating systems to adapt spaces is a critical environmental problem due to the high energy consumption required for its operation. For this reason, the offer of products for architectural facades should consider constructive solutions that mitigate the heating of buildings. Thermal behavior of building materials is an elementary factor in the energy consumption of buildings. This paper presents the comparative thermal analysis of 4 ceramic product designs for masonry, of which, one represents the traditional multi perforated brick and the others, are proposed to prove whether shape affects the heat transfer processes. The research methodology is divided into 2 stages: product design and thermal validation by transfer and heat fluxes in the ANSYS R16 software using the finite element method. For the design process, modification of the internal cells and elimination of the thermal bridge was implemented. Simulations were configured under the highest values of solar radiation recorded in the city of San José de Cúcuta, Colombia to know the products performance in the most extreme conditions of the city. The results indicate that design varies energy performance of the product, since it reduces the temperature of the inner surface to 1.23 °C or increase it to 2.25 °C. The results show that the modification of cells distribution and elimination of thermal bridges are passive strategies for the reduction of heat transfer in the design of ceramic product for masonry. This research is a breakthrough for future research that develops constructive units focused on improving the quality of life of people from thermal comfort, energy efficiency and the use of local resources and technologies.

1. Introduction

The high levels of energy consumption by refrigeration and artificial heating systems fall on the buildings for not responding efficiently to the needs of the environment [1]. This behavior generates environmental alerts in the cities due to global warming. Studies highlight that the design of products should focus on the minimum generation of thermal bridges and the maximum thermal trajectory [2-4]. They even recommend the isolation of the joints on the thickness of the insulating layer or wall [5]. Since, the exposure of mortar linkages transfers energy to a greater extent into spaces, therefore requires intervention [6,7].

The development ceramic product research field must be consolidated and oriented towards innovation and energy efficiency of the element to solve the problem established [8]. Due to, energy behavior of a product is determined from the moment it receives the solar incidence on the outer surface, since the shape of the surface alters the absorption of energy inside the brick [9]. In Norte de Santander, Colombia there is a ceramic industry recognized for the quality of the raw materials of the products conventionally offered in the construction market [10]. However, very few entities have been committed to research and innovation of product development.

This research focuses on the study of architectural product design influence as a determining factor to achieve energy efficiency. This research promotes innovation in the regional and national ceramic industry because it presents methodological bases that allow validating the energy performance of a product prior to its manufacture. The initiative explores the energy performance of 3 masonry products, designed under key criteria, through simulations carried out in the ANSYS R16 software under extreme conditions in San José de Cúcuta, Norte de Santander, Colombia. The results of this exercise are summarized in heat transfer and heat fluxes diagrams of the designs. In this way, there is a significant thermal behavior improvement in some geometric patterns.

2. Methodology

The comparative thermal analysis of extruded ceramic products aims to demonstrate the influence of design on the energy efficiency of a constructive element, through simulations of heat transfer and heat fluxes. The research is divided into two stages: product design and thermal validation to conclude the thermal benefit of each product compared to traditional brick.

In the product design stage, the multi perforated brick (MB) is selected as pattern of traditional bricks and 3 proposals of modified bricks in cells distribution (MBCD) are presented to show how shape determines and varies the energy behavior. The criteria considered in the design phase are the modification of the distribution of cells [4] and the elimination of thermal bridges in the mortar joints [7].

Thermal validation is performed by the finite element method in the ANSYS R16 software to identify the behavior by heat transfer and heat fluxes. From the results obtained in the simulations, the information of the pattern is compared with the new designs to identify the thermal benefit in the interior surface of each product. Likewise, the shape of each unit is related to the concentration of heat fluxes, in this way, it is possible to identify the scope of the design at the time of thermally isolating a space delimited by itself.

The thermal validation by heat transfer and heat fluxes describes the energy behavior at the temperature level using the finite element method in the software ANSYS R16 [2]. To carry out the simulations, material data such as the thermal conductivity of clay and mortar [11] and the specific environment such as average maximum temperature, average maximum solar radiation, time period and average wind speed of the specific environment, that is, San Jose de Cúcuta, Norte de Santander, Colombia [12].

The maximum values of the environment were selected to identify the behavior in the most extreme scenario of the city, taking into account that San Jose de Cúcuta, Norte de Santander, Colombia shows considerably high temperatures throughout the year according to the "Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM)" [12].

Additionally, other values for air convection in ceramic products are taken into account. The heat transfer coefficient by convection (C) and the heat flow by radiation (B) are applied to the external surface and the internal conditions (A) of natural convection are applied to the inner surface (Table 1).

Table 1. Data provided for thermal validation

Materials	Environment	Other values
k clay = 0.30 Wm °C	Average max. T = 33 °C	A = 5 Wm² °C
k Mortar = 0.88 Wm °C	Average max. solar radiation = 796.8 Wh.m^2	B = 796.8 Wm²
	t= 12:00-13:00	C = 25.903 Wm² °C
	$Q_{solar=}$ 796.8 Wm^2	
	Average wind speed = 4 m/s	

3. Product design

The product design phase is an exploration of geometries and shapes from a base mesh of rows of interleaved circles, which is contained in a rectangular area, corresponding to MB design. MBCD

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proposes 3 ceramic product design options with formal characteristics that vary in cells distribution and mortar joint shape. In order to recognize how energy is distributed and stored according to the geometry of the brick, presented in Figure 1.

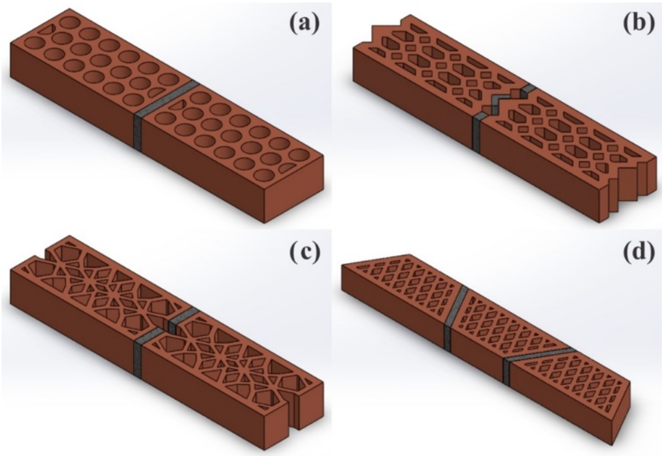


Figure 1. Types of design ceramic product: (a) MB, (b) MBCD 1, (c) MBCD 2, (d) MBCD 3.

MBCD 1 design is a geometry composed mainly of hexagons that are linked through regular rhombuses of smaller size; the design of the linkage is divided into 3 connection points to block the direct transfer of energy through 2 trapezoidal vacuum chambers.

Followed by the design of MBCD 2, the geometry is much more complex with thinner joints. The shape of the cells is a set of irregular trapezoids, rhombuses and triangles that are distributed around two fused crosses formed by rhombuses, the cells of greater area are located towards the edges while the smaller cells are in the center; Like MBCD 1, the MBCD 2 board interferes with direct heat transfer, generating a hexagonal vacuum chamber between the two points where the mortar is applied.

Finally, MBCD 3 proposes a mesh of regular rhombuses contained in a trapezoid; the design of the gasket MBCD 3 preserves the direct passage of energy, however, the shape of the product increases the path of the mortar joint. MB and MBCD 1-2-3 were subjected to simulation to validate them thermally according to their behavior by transfer and heat fluxes.

4. Thermal validation by heat transfer and heat fluxes

Thermal validation by heat transfer assumes the values of the temperature transferred from the internal surface through the different thermal bridges of the cells and the mortar joints of the products, presented in the Figure 2. On the other hand, the thermal validation by heat fluxes registers the specific points where the energy is stored, making possible the understanding of how heat is distributed according to the form, be it a point of concentration or dissipation of energy (Figure 3).

According to the data recorded in Table 2, thermal validation by heat transfer and heat fluxes, a variation in the inner surface temperature of the MBCD products compared with MB is evidenced. Likewise, the heat fluxes images confirm the influence of the form as a determining factor for the concentration of energy, mainly in the mortar thermal bridges.

Table 2. Thermal validation by heat transfer and heat fluxes.

Design	Heat transfer (°C)		Heat fluxes (Wh/m²)	
	Ext.	Int.	Max.	Min.
MB – Pattern	63.00	37.56	149.40	3.08
MBCD 1	63.20	36.94	134.13	0.44
MBCD 2	63.31	36.33	157.05	2.72
MBCD 3	63.32	39.81	135.55	8.14

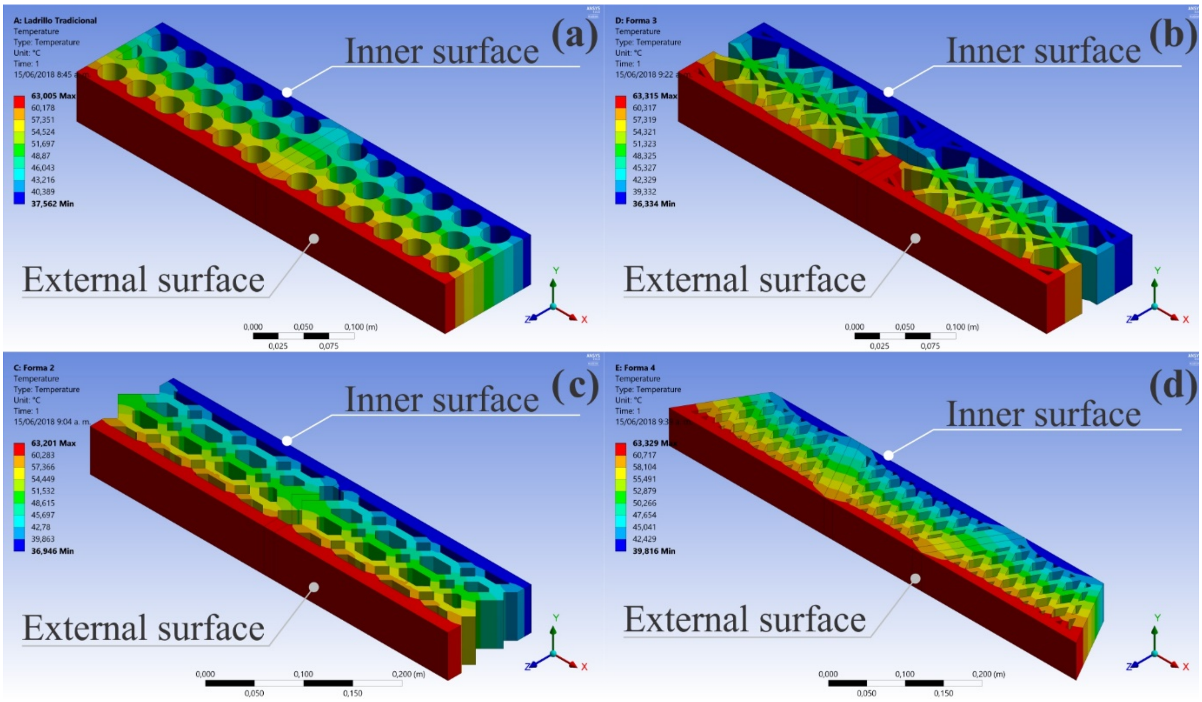


Figure 2. Thermal validation by heat transfer: (a) MB, (b) MBCD 1, (c) MBCD 2, (d) MBCD 3.

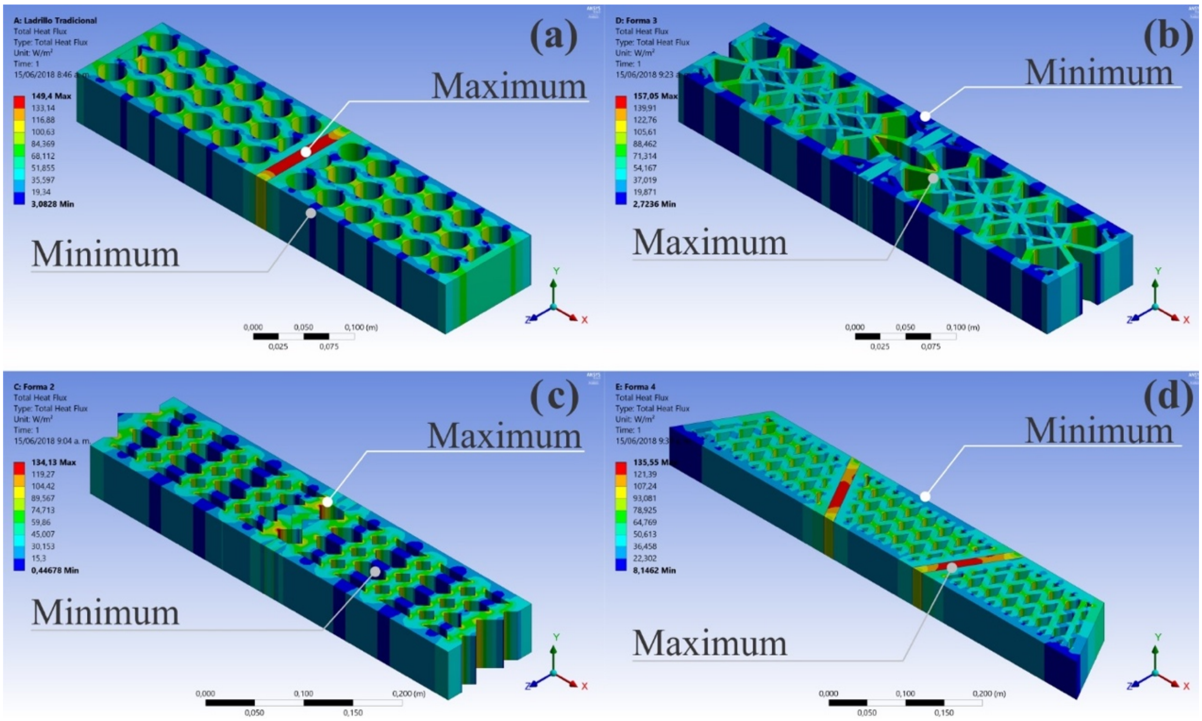


Figure 3. Thermal validation by heat fluxes: (a) MB, (b) MBCD 1, (c) MBCD 2, (d) MBCD 3.

5. Thermal benefit by transfer and heat fluxes

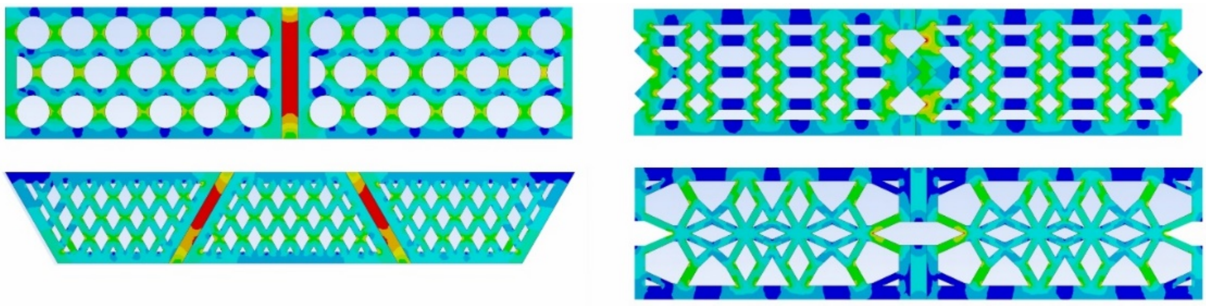
The energy performance assessment of a product addresses different variables. The results vary depending on the research focus. For example, the thermodisipador block simulates the solar incidence and concludes that the block shape reduces exposure to direct solar radiation by 24.5%, compared to the traditional block [4]. On the other hand, in Egypt, there is a research dedicated to the comparative thermal evaluation of perforated brick filled with alternative materials in their holes and they have proven a 45% decrease in thermal conductivity in those who used polyurethane foam in the perforations [8]. Due to the limited literature on the subject addressed, the comparative thermal analysis selects MB as a pattern so that, based on its behavior, it is possible to compare the performance of MBCD and conclude the thermal benefit.

The external temperature of MB registers 63 °C while MBCD 1, MBCD 2 and MBCD 3 exceeds this value between 0.20 °C and 0.32 °C, that is, the outer surface of the new designs is heated more than a traditional brick. Nevertheless, the temperature values of the interior surfaces vary between the products in favor of MBCD 1, MBCD 2 and against MBCD 3, seen in Table 3. Starting with MB as a pattern with an interior temperature of 37.56 °C, MBCD 1 only reduces 0.62 °C while MBCD 2 reduces to 1.23 °C, achieving a greater internal thermal benefit, the above means, 1.66% and 3.28% respectively. However, MBCD 3 increases 6% the temperature of the interior surface of the product, which means 2.25 °C.

Table 3. Thermal benefit by heat transfer and heat fluxes.

Design	Heat transfer (°C)	Heat fluxes (Wh/m²)
MB Pattern	37.56	3.08
MBCD 1	- 0.62	- 2.64
MBCD 2	- 1.23	- 0.36
MBCD 3	+ 2.25	+ 5.06

There are 2 strategies considered in the design stage to obtain thermal benefit: Cell distribution modification and mortar joints locking. The first strategy is traslated to complex geometries in the ceramic product design, Figure 4. The advantage lies in the generation of longer paths that delay the transfer of heat by conduction from the outside to the interior of the element. The main characteristics of complex geometries (MBCD 2) are the composition of irregular cells of different sizes and thin partitions that generate long distances between the external and internal surfaces. On the other hand, simple geometries (MB, MBCD 3) are characterized by having equal and regular cells, thick walls and direct paths between the outer and inner surface.



(a) (b)

Figure 4. Geometric compositions schemas of the ceramic products cells. (a) Simple geometries. (b) Complex geometries.

The second strategy to thermally isolate a space delimited with ceramic product is the blocking of thermal bridges by mortar joints through vacuum chambers, seen in the Figure 5. According to the thermal benefit table by heat transfer and heat fluxes, the most insulated products are those that have vacuum chambers to block the direct conduction of energy through the mortar. While products with direct thermal bridges not only transfer more energy, but they also concentrate it in the bridging joints, Figure 6.

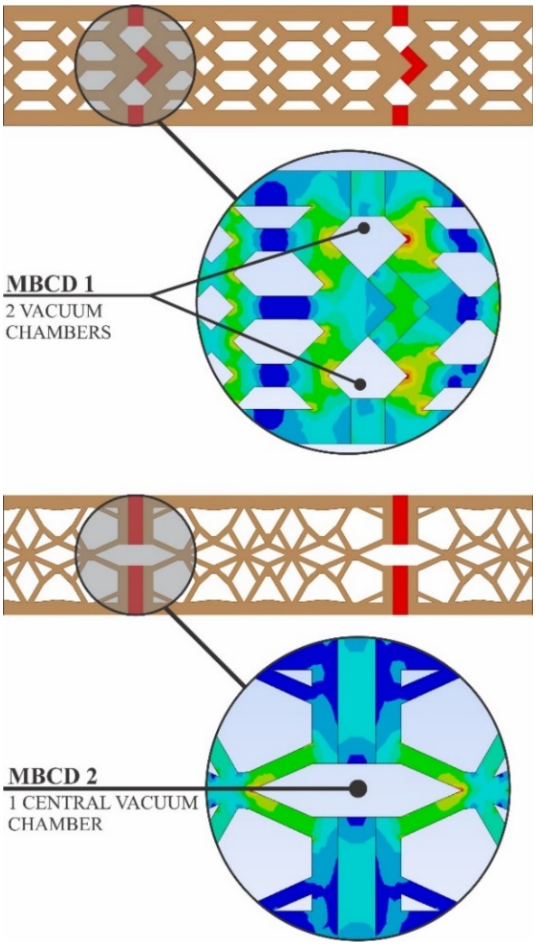


Figure 5. Indirect thermal bridges. The direct heat transfer between the outer and inner surface through vacuum chambers is blocked. Stored energy is reduced to 104.42 Wh/m² in MBCD 1 and 54.16 Wh/m² in MBCD 2.

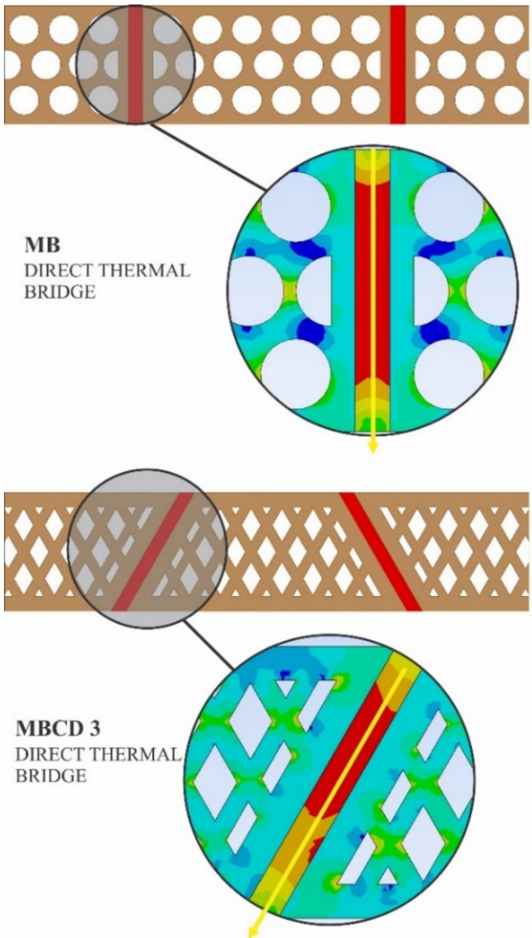


Figure 6. Direct thermal bridges. The heat transfer is direct between the outer and inner surface of the brick. The concentration of energy in the mortar joint stores 149.40 Wh/m² in MB and 135.55 Wh/m² in MBCD 3.

6. Conclusions

Comparative thermal analysis of modified bricks in cells distribution and multi perforated brick is a great exercise to prove the impact of design on energy conduction and to recognize that brick shape can make it efficient and sustainable. The generation of longer runs is a strategy to delay the transfer of heat in ceramic products. According to the results of multi perforated brick and modified bricks in cells distribution, the complexity of the geometries manages to increase the thermal insulation capacity as demonstrated by modified bricks in cells distribution 2. The interference of the mortar joints through vacuum chambers is another strategy to mitigate the heat transfer, since the conductivity of the mortar is greater than the clay, it conducts the heat much faster; therefore, it stores and transfers more energy as can be seen in multi perforated brick and modified bricks in cells distribution 3.

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