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THERMAL BEHAVIOR OF DIFFERENT TYPES OF BRICKS PRODUCED BY THE CERAMIC CLUSTER OF NORTE DE SANTANDER

Jorge Sánchez-Molina[1], Jessica Viviana Sánchez-Zúñiga [2],
Julio Alfonso González- Mendoza [3]

Abstract

In a warm climatic context, the construction pieces produced for ceramic envelopes in the region of Norte de Santander, Colombia, require a thermal characterization to define the models that present the best physical behavior for the energy flows that can be captured by a masonry enclosure subjected to temperature conditions above 33°C in a standard construction system. As a research objective, four types of fired red clay bricks produced by the ceramic cluster of Cúcuta are comparatively evaluated, analyzing the temperature distribution in the different variables of mass, percentage of air in internal chambers and shape of thermal bridges of each piece to determine the model that presents a lower heat transfer profile in the internal surface of the facing. The numerical method is used through thermal simulations in ANSYS R16 software to analyze the heat flows in the samples and compare the results. The research demonstrates that a 100% thermal mass in the sample represents high direct heat transfer profiles up to 51°C, and those products with internal air chambers present a better thermal resistance in proportion to the percentages of air and number of internal walls, as well as the arrangement and shape of their thermal bridges. The results provide information for the development processes of new parts and allow determining which traditional products have a better thermal response for enclosures in high-temperature climates.

Keywords: Ceramics, Brick, Thermal behavior.

1. Introduction

In a warm, semi-humid, semi-arid and arid climatic context characteristic of municipalities such as Cúcuta, El Zulia, Villa del Rosario and Los Patios, in the department of Norte de Santander, Colombia, where clay is a vernacular material from which excellent quality construction pieces are produced (Sánchez & Ramírez, 2013). In the department of Norte de Santander, Colombia, where clay is a vernacular material from which excellent quality construction pieces are produced for architectural masonry construction, the analysis of its thermal behavior based on its physical characteristics will define the heat flow profiles and the thermal transmittance capacity within the

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[1] *PhD in Avances in Materials and Energy Engineering, Director of Grupo de Investigación en Tecnología Cerámica GITEC, Orcid: https://orcid.org/0000-0002-9080-8526, E-mail: jorgesm@ufps.edu.co , Universidad Francisco de Paula Santander*

[2] [2] *Master in materials engineering and sustainable construction, Research Group in Ceramic Technology GITEC, Orcid: https://orcid.org/0000-0001-7831-127X, E-mail: arq.jessisanchez@gmail.com, Universidad Francisco de Paula Santander*

[3] *PhD in Business Administration, Director of the Zulima Science Research Group, Orcid: https://orcid.org/0000-0001-6329-3347, E-mail: alfonsogonzalez@ufps.edu.co, Universidad Francisco de Paula Santander*

enclosure systems, an aspect especially relevant under temperatures up to 40°C, relative humidity of 80% and high solar irradiance indexes in low cloudiness skies that can reach 796.8 W/m² in average daylight hours. (IDEAM, 2020).

Within the construction ceramics sector in the region, 19% of the production corresponds to units for vertical brick-type enclosures (Sánchez & Ramírez, 2013), commonly manufactured by the extrusion method, whose final pieces have a thermal conductivity between 0.391 W/m°C (Rozo-Rincón *et al*., 2014) and 0.407 W/m°C (Peña-Rodriguez *et al*., 2014) in sizes between 80mm and 120mm thick. These construction units are used in masonry systems with large surface areas (Colmenares-Uribe *et al*., 2020) and mortar joints exposed to high heat fluxes, thus functioning as high thermal transmittance envelopes (Narvaez-Ortega *et al*., 2018).

In the region, there are four types of ceramic bricks of different dimensions, texture and finish, the most common being the multiperforated brick of 60mm high, 120mm wide and 250mm long, used in the construction of low-cost walls, generally with an exposed finish. In the construction system, the rectangular shape of the screen formed by the masonry is exposed to solar radiation, which is absorbed by the material, accumulating and being transferred to the interior of the enclosure.

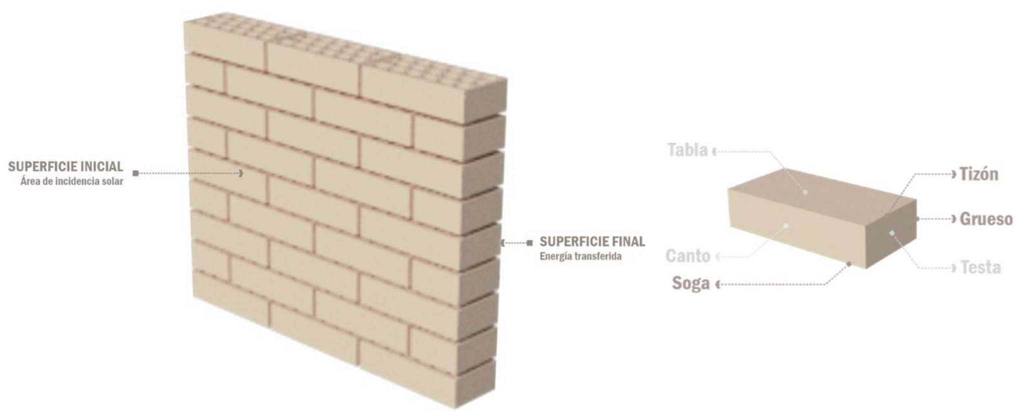
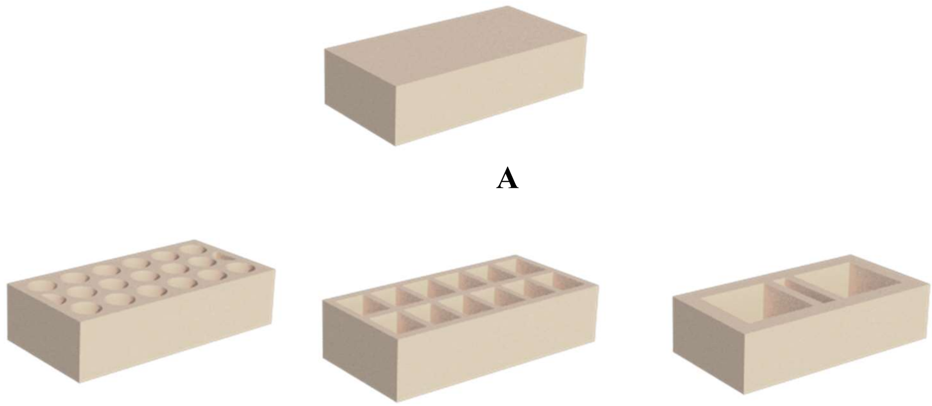


Figure 1. Ceramic brick construction system.

The four most common types of ceramic bricks are taken as the object of analysis in order to analyze the thermal behavior of the pieces, evaluating the percentage of mass, thermal bridge shape and percentage of air in the internal cavities within the market offer, the L-1 piece is a type of solid brick that does not have any internal perforation, the multiperforated brick with vertical circular cavities is the most demanded product within its typology (L-2), the L-3 piece is a type of perforated brick with 12 rectangular cavities, and the structural brick type block is a product with three vertical cavities, one central rectangular and two lateral square cavities with high air capacity (L-4).



A

B C D

Figure 2. Typologies of ceramic bricks (A) L-1, (B) L-2, (C) L-3 and (D)l-4.

Part	Thickn ess	Number of Walls	Number of Partitions	Number of Air Chambers	Percent Air	Percent Ceramics
L-1	110mm	2	0	0	0%	100%
L-2	120mm	4	7	19	42,4%	57,6%
L-3	100mm	3	7	12	59,2%	40,8%
L-4	120mm	2	4	3	49,7%	50,3%

Table 1. Comparative Characteristics of Ceramic Bricks.

Comparing the physical characteristics of the ceramic bricks, it is more common to find a greater ceramic volume for the volume of air in pieces, exceeding 50% in most of the samples. However, the L-3 brick presents more air in 12 vertical cavities that represent 59.2% of the total volume of the piece; therefore, it is a product with physical qualities that could represent an advantage for thermal resistance. In addition, it is a piece that presents a high number of thermal bridges formed by seven partitions that join the initial face with the final surface of the piece, which could accelerate its efficiency in transmitting heat through its structure.

The L-4 product, with an air volume of 49.7%, is a particularly outstanding piece as it has a larger air chamber area and the smallest number of partitions within the samples, with two lateral and two central partitions, advantages that may allow a decrease in the transferred energy. On the other hand, the L-2 product is composed of circular internal geometries that make up 19 air chambers distributed in 7 partitions, which presents a greater volume of ceramic mass for air by 57.6%, characteristics that make it very susceptible to thermal transmittance processes.

1.1. Thermal bridges

The rectangular face of the screen formed by the masonry made of ceramic bricks allows the pieces to be exposed to solar radiation, heat that is absorbed by the material, accumulated and transferred to the interior through the surfaces composed of walls and partitions, as points of direct heat flow.

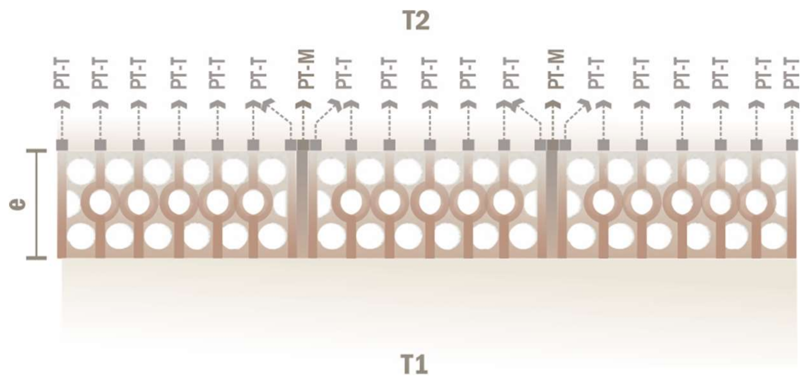
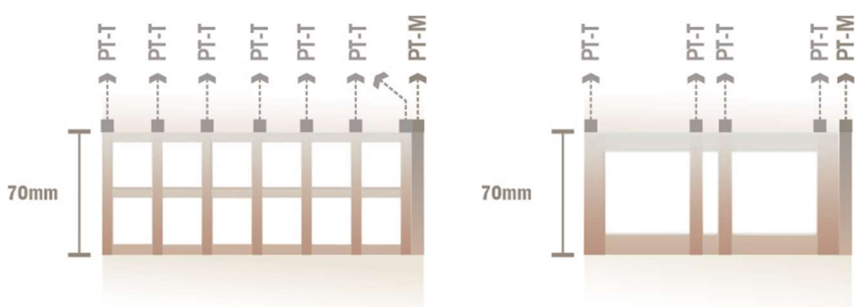


Figure 3. Horizontal view of the construction system with ceramic bricks, implementing L-2 brick.

Figure 3T1 defines the initial temperature of the solar incidence surface, PT-T represents the thermal bridges formed by the partitions of the parts, PT-M shows the thermal bridges formed by the mortar joints within the construction system, and the dimension (e) represents the thickness of the part.



A B

Figure 4. Thermal bridges in products type (A) L-3 brick (B) L-4 brick.

The bricks present vertical perforations, with a higher number of thermal bridges than other constructive pieces such as ceramic blocks (Narvaez-Ortega *et al.*, 2018) such as products L-2 and L-3 with seven partitions each or a smaller number such as L-4 with four partitions, the characteristics contained in L-4 constitute an advantage within a high thermal transmittance system.

2. Materials and Method

In the development of the research, this phase focuses on the validation of the designs from tests in digital format, using the finite element method to develop thermal simulations in ANSYS R16 software, and implementing parameters specific to the climate of the city of Cúcuta to establish the thermal behavior by heat transfer of the parts in conditions of 33°C as average maximum temperature, determining the temperature distribution and heat flows related to the shape and dimension of the parts.

The environmental data used are taken from the (IDEAM, 2020) for a geographical location of latitude: 7.9°N, longitude: 72.5°W, altitude: 298msnm in Cúcuta, taking as a reference point for the temporality the month of September as the period that presents the highest temperatures throughout the year, considering average maximum climate variables from 12:00 hours to 13:00 hours of a typical day, where, a wind flow presents a speed of 4 m/s and an average maximum solar irradiance of 796.8 W/ m².
The data used for the conductivity of the materials:
^{k} Clay = 0.407 $W / m. °C$
^{k} mortar = 0.88 $W / m. °C$

About the calculated data, the convective heat transfer coefficient is the value that depends on the wind speed and the temperature and pressure conditions in which it is found:

h = Nu∗k Lch = Nu∗k Lc Equation (1)

h: Convection heat transfer coefficient.
Nu: Nusselt number.
k: Thermal conductivity of air.
Lc: assumed characteristic length of 20 cm.

The Nusselt number is a dimensionless value that describes the increase in heat transfer over a surface. For rectangular cross-section and cross-flow, it is:

$$Nu = 0.102Re^{0,675} * Pr^{1/3} \text{ Equation (2)}$$

Re: Reynolds number.
Pr: Prandtl number.
The Reynolds number is a dimensionless value that describes the behavior of the airflow over the surface of the block:

Re = ρ∗V∗Lc μRe = ρ∗V∗Lc μ Equation (3)

ρ: Air density.

V: Wind speed.
μ: Dynamic viscosity of air.

The properties of air at a temperature of 33°C are described below (Cegel, 2007).

$\rho = 1.1526\ Kg\ /\ m^{3}$
$k = 0{,}026102\ W\ /\ m.\ °C$
$\mu = 0.000018858\ Kg\ /\ m.\ s$
$Pr = 0.72736$

Replacing the values in order of equations (3), (2) and (1), the result is a convective heat transfer coefficient of $h = 17.5154\ W/\ \mathrm{m}^2\ °C$ to be applied to the outer section of the geometry, where the wind speed takes effect, and assumes a heat transfer by natural convection of 5 W/ m² °C and a heat flux of 796.8 W/m². For surfaces that are not enclosed as internal air chambers, a heat transfer coefficient by natural convection of $h = 5\ W/\ \mathrm{m}^2$ is assumed. $°C$. The conditions to which the products are subjected are shown in Figure 5.

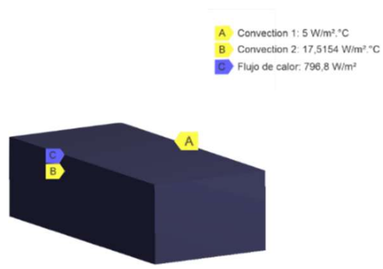
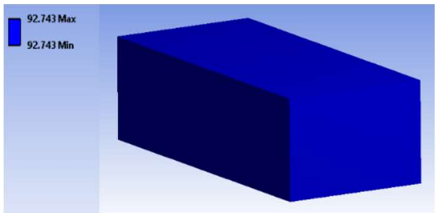
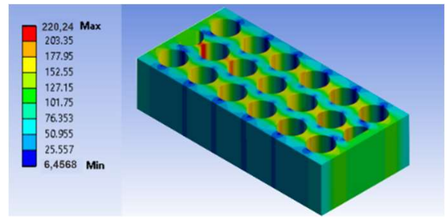


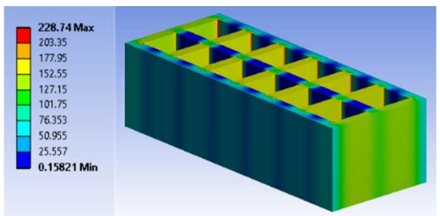
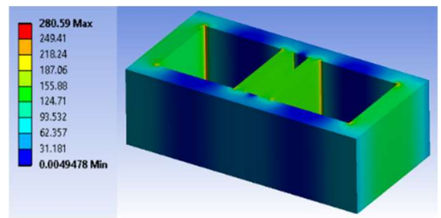
Figure 5. Conditions applied to the brick models of sample L-1.

3. Results

Figure 6 shows the initial results of energy flow in the samples, where a piece formed by 100% clay L-1 presents a constant heat flow of 92.74W/m^2, piece L-2 does not show accumulated heat profiles below 6.45W/m^2, whose circular thermal bridges that connect S1 with S2 present a constant of 159.16W/m^2 on average, and heat conditions in S2 not less than 52.26 W/m^2, in the case of L-3 with straight internal shapes from S1 to S2 its partitions show a heat of 152W/m^2 and 50.95 W/m^2 in S2 surface; for L-4, with thermal resistance characteristics derived from 3 thermal bridges and a good percentage of air in relation to mass, its S2 surface shows the lowest heat flow with 46.76 W/m^2 and 124.70 W/m^2 in thermal bridges. This structure presents formal advantages for the other traditional ceramic brick typologies.

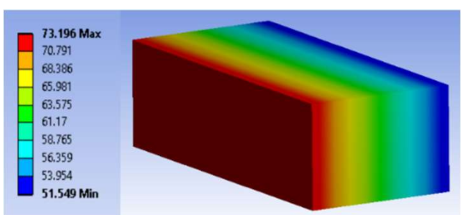
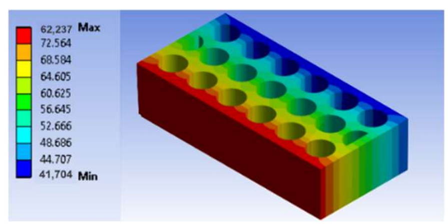



L-1 L-2

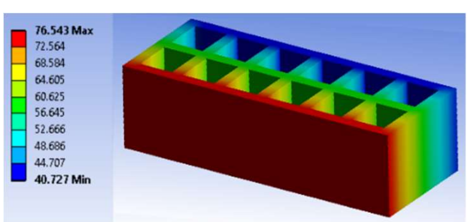
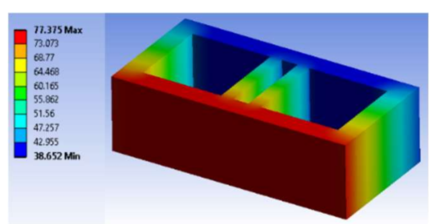



L-3 L-4

Figure 6. Heat flow results for brick-type products.

L-1 L-2

L-3 L-4

Figure 7. Results of temperature distribution of brick-type products.

The L-1 product of 100% ceramic mass, uniform in surface and volume, without internal air chambers, is the part that presents the highest heat profiles due to its physical characteristics, reaching 51.5°C on the internal surface of the part under external temperature conditions of 33°C. Table 2 presents the differences between the L-2, L-3 and L-4 multiperforated brick shapes.

Temperature in °C	L-2	L-3	L-4
Maximum in S1	62,23 °C	76,54 °C	77,37 °C
Minimum in S2	41,70 °C	40,72 °C	38,65 °C
Average in S1	65,56 °C	79,01 °C	72,87 °C
Average in S2	42,67 °C	41,21 °C	39,58 °C

Table 2. Temperature distribution results in S1 and S2 of L-2, L-3 and L-4.

Figure 7 presents the results of temperature distribution on the S1 and S2 surfaces of the different brick typologies, where L-4 shows a better thermal behavior with a temperature profile on the final surface of 39.58°C, a reduction between 3.09°C and 1.63°C for L-2 and L-3, respectively, a thermal resistance associated with the differences between the number and area of internal air cavities, where it is evident that the higher the air capacity and the lower the number of internal walls, the lower the temperature transferred, being L-4 with two internal cavities and a single thermal bridge the product with the best thermal performance.

Temperature in °C		L-2	L-3	L-4
PT-Tabiques	Maximum	64,72 °C	75,73 °C	76,00°C
	Minimal	45,54 °C	42,83 °C	41,16°C
PT-Walls	Maximum	65,75 °C	76,29 °C	77,35°C
	Minimal	43,65 °C	40,96 °C	39,46°C

Table 3. Temperature distribution results in partitions and walls of L-2, L-3 and L-4.

Regarding temperature behavior on surfaces formed by partitions and walls, L-4 reflects the lowest thermal load with 41.16°C on average on partitions and 39.46°C on walls connected to air chambers, a difference of up to 4.20°C on average compared to L-2 containing 19 cylindrical cavities, and of 1.5°C compared to walls and partitions of L-3.

The results establish a development opportunity in the L-4 piece, with a final competitive temperature for other types of products, such as ceramic blocks.

4. Conclusions

The results show that the traditional products do not work thermally for the local climate, registering final temperatures of up to 51.54°C as the L-1 piece, providing high thermal loads by heat transfer in the enclosures; the L-2 and L-3 products present similar behavior with average final temperatures of 41.2°C considering similar characteristics in several walls and partitions. However, L-2 registers higher temperatures as it contains circular shapes that allow a better heat transfer. As for the L-4 piece with better formal characteristics, it presents the best thermal behavior among all the samples, with a final transferred temperature of 38.6°C, whose dimensions in air cavities give them more significant advantages over other piece models, allowing more excellent thermal resistance to heat flow.

The data analyzed can serve as a basis for the correct selection of materials, as well as for the definition of guidelines in the development of new products that can effectively contribute to the mitigation of high-temperature climatic conditions, mainly considering a more significant proportion of air in the area of the internal cavities and a strategy that avoids or uses dissipative forms in thermal bridges.

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