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Physical-thermal isolation strategies for the design of sustainable ceramic building units

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Abstract. The architectural envelope constitutes more than the aesthetic expression of the building, currently it represents one of the most important challenges in the configuration of energy efficiency in buildings, the materials that build this skin are responsible for the energy flows that enter the built space, an aspect that becomes especially relevant in tropics climates with warm temperatures up to 33 °C; From this context, the design as an innovation tool allows the configuration of strategies to grant physical properties to the construction units capable of reducing heat transfer through the optimization of its components. Within this investigation, the addition of passive cooling strategies in ceramic pieces designed with sustainable principles is analyzed. As a methodology, thermal simulations are carried out by finite element method considering a thermal conductivity of a ceramic of 0.407 W/m•k applied to three pieces with thermal insulating design to analyze the comparative results in relation to the behavior of temperature distribution and heat flow. This paper presents the results of applying design criteria in innovative pieces for masonry enclosures from the perspective of sustainability based on the thermal properties of a vernacular material, clay, in the Norte de Santander, Colombia.

1. Introduction

From the field of research in ceramic technologies an exploration niche is the development of sustainable models for the design of construction pieces that respond efficiently to the thermal requirements of the environmental context, in warm weather conditions the strategies are structured based on systems of isolation that integrate properties capable of controlling the transfer of energy from a vision of low consumption that can reflect a reduction in the use of artificial thermal conditioning mechanism for comfort in the building. From the literature they are considered as passive strategies for the development of thermo-insulating products: the increase in the thickness of the pieces, the decrease of thermal bridges through the morphological complexity of the partitions extending the routes to delay or prevent the transfer of heat, with results that vary a decrease of 0.98 °C on average [1], specifically modifying the shape of the frame without changing the dimensions or weight of the pieces; likewise, the increase in the number of internal cavities of each construction unit, the addition of passive ventilation systems on the surface of greater solar incidence to dissipate energy and the formal exploration of the external face to control the percentages of uptake of heat [2,3].

This research applies the results of previous studies that analyze different techniques in ceramic blocks from Norte de Santander industry as a regional product of great impact within the local



construction materiality [4,5] and part of a cooked block of red clay type H- 10 to progressively add strategies that optimize thermal performance in ceramic masonry enclosures subjected to high temperatures of 33 °C - 40 °C on average [6], evaluating the influence of design on the development of innovative products with energy efficient building solutions of warm climate in Colombia, whose results could contribute positively to the advance in new technologies for the academic-scientific community, the ceramics sector and the construction industry. The exploration process analyzes profiles of temperature distribution and heat flow in three ceramic units with the same geometric pattern (Figure 1) to determine the influence of the design on thermal behavior from the comparison of surface temperature data internal parts, a methodology that allows to establish the effectiveness of passive cooling techniques in the control of the thermal loads of the enclosure and its reflection on the total loads of the building, a study that strengthens the principles for the development of ceramic skins in the architecture and materials engineering.

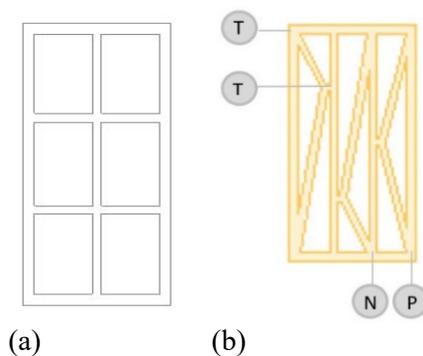


Figure 1. (a) standard H10 ceramic block (b) geometric pattern: partitions (T), walls (P) and internal nerves (N).

2. Design process

The dimensions of a block type product L: 300 mm, W: 100 mm, H: 200 mm and 6 horizontal cavities are used as an initial model as a ceramic product of low thermal conductance with a total conduction of 35.821 °C of final temperature under ambient conditions of warm climate [5], considering that it has an advantage in relation to a multi-perforated brick that generates a final temperature of 37.560 °C [7] with a difference of 1.7 °C; starting from this background as two of the most demanded construction products in the ceramic sector in the Norte de Santander, Colombia [8], three pieces with geometric characteristics of insulation in the internal cells [9-11] are designed and passive natural ventilation is added [12-14].

As a technique that proves effectiveness in generating thermal efficiency [15,16], this analysis is presented as a method of studying a design process that seeks to interpret the optimal dimensions and characteristics that prove to be more efficient in an insulating construction unit. The design has the same thermal bridge dissipation geometry with three variations: in the A-1 piece, dimensions of L: 200 mm, W: 100 mm, H: 200 mm, in the B-part L: 200 mm, W: 150 mm are implemented, H: 200 mm, and the C-piece uses the same dimensions as the B-piece with a concave inclination geometry on the front surface that has an air chamber in the horizontal cavities of the outer surface; between each model the number of internal cells, the total thickness of the piece and the shape of the outer surface are increasing, the results are shown in Figure 2.

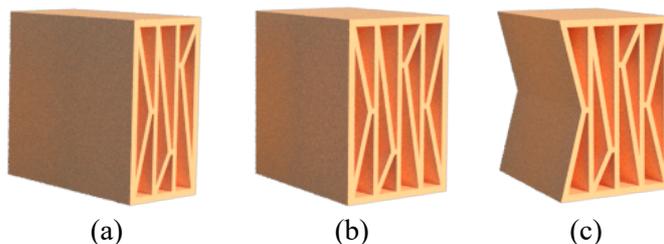


Figure 2. Designs of ceramic building units; (a) Part A-1, (b) Part A-2, (c) Part A-3.

3. Process

For the analysis, finite element method was implemented to perform simulations in ANSYS R16 software, using computer-assisted design (CAD) models to integrate computer assisted engineering (CAE) in three cases: Part A-1, Part A-2 and Part A-3 with the objective of characterizing the thermal behavior of each construction unit, assuming the same conductivity value ($0.407 \text{ W/m}\cdot\text{k}$) considering a ceramic baked at $1000 \text{ }^\circ\text{C}$ [5] with the objective of comparatively assessing the differences in the applied thermal insulation techniques. For the thermal analysis, the month of September was evaluated using local environmental data from the “Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM)” [6], for the city of San José de Cúcuta, Colombia; Using a stationary method, the time of day with the highest solar radiation and the highest air temperatures was selected, exactly at noon, between 12: 00-13: 00 and an average wind speed of 4 m/s :

- Average maximum temperature = $33 \text{ }^\circ\text{C}$.
- Average maximum solar radiation = $796.8 \text{ W}\cdot\text{h/m}^2$.
- A: convection 1 ($5 \text{ W/m}^2\cdot^\circ\text{C}$).
- B: heat flow (796.8 W/m^2).
- C: convection 2 ($17.5154 \text{ W/m}^2\cdot^\circ\text{C}$).

The convection heat transfer coefficient is $h = 17.5154 \text{ W/m}^2\cdot^\circ\text{C}$ that will be applied to the outer section of the geometry, where the wind speed has an effect. For piece A-3 a variable of natural ventilation flow is used using an average wind speed of 5.5 m/s for a convection in ventilation holes of $5 \text{ W/m}^2\cdot^\circ\text{C}$ [17]. The external wind and solar radiation condition are applied to the front faces, and the natural convection interior condition is applied to the rear face.

4. Results

In Figure 3 the results show very few differences between the final temperatures of the pieces: with a divergence of $0.076 \text{ }^\circ\text{C}$ between part A-1 and A-2, as well as $0.291 \text{ }^\circ\text{C}$ between parts A-2 and A-3 showing a moderate temperature decrease due to the dissipating effect of the air in the external cavity of part A-3, where, from nerves N1, N2, temperatures of $37 \text{ }^\circ\text{C}$ and N3 values around the minimum temperature begin to appear (Table 1).

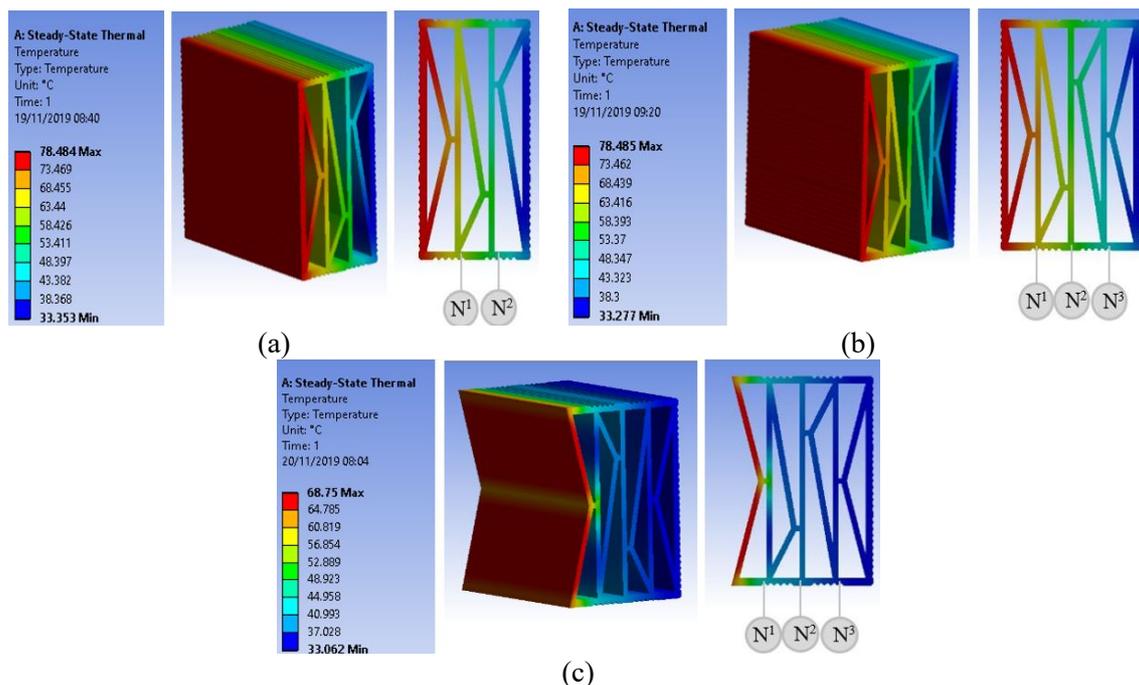


Figure 3. Temperature distribution results (a) Part A-1, (b) Part A-2 (c) Part A-3.

Table 1. Comparative results.

Design	Temperature distribution (°C)	
	Initial	Last
Part A-1	78.484	33.353
Part A-2	78.485	33.277
Part A-3	68.775	33.060

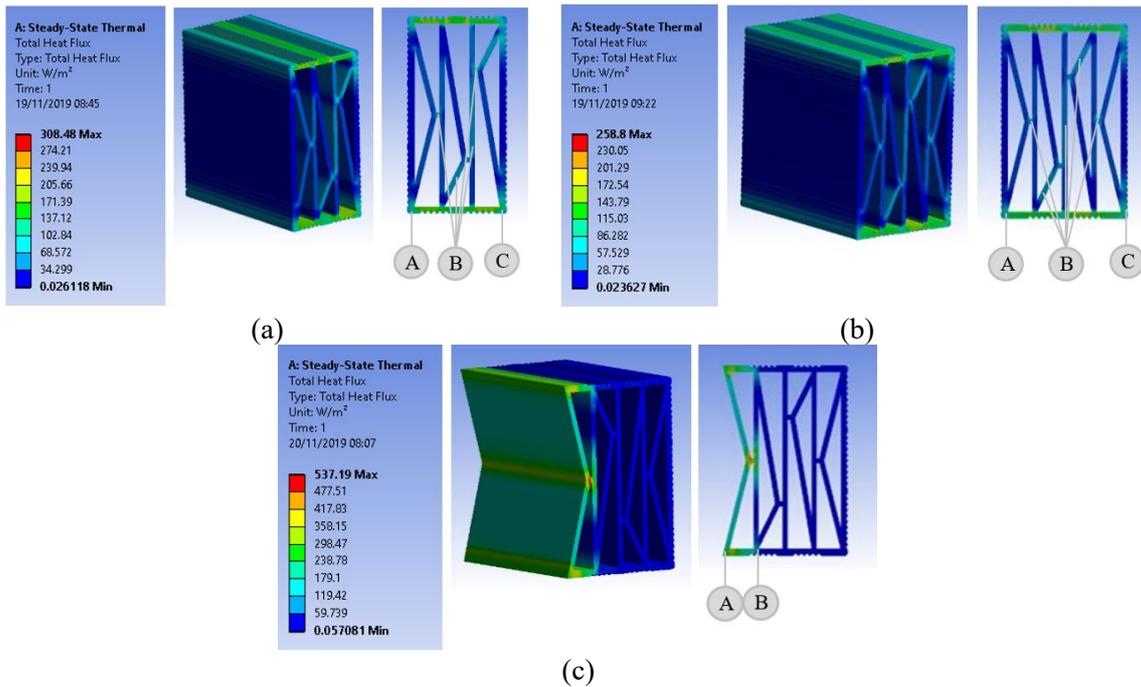


Figure 4. Heat flow results, (a) Part A-1(b) Part A-2 (c) Part A-3.

The accumulated energy values at each point of the structure in relation to the morphology of each piece are reported in Figure 4 and Table 2. It is evident how the highest concentration of energy condenses on the external partitions in parts A-1 and A-2 that have heat accumulation from point (A) to point (C) that runs through the entire partition, exposing a bridge direct thermal; on the contrary, in part A-3 the highest percentages of accumulated heat are presented on the cavities subjected to passive natural ventilation, where the energy dissipates due to the effect of air and decreases the heat that crosses the first nerve to the final surface; the highest levels of heat accumulation in this case goes from point (A) to point (B) only.

Table 2. Comparative results.

Design	Heat flow (°C)	
	Maximum	Minimum
Part A-1	308.48	0.026
Part A-2	258.80	0.236
Part A-3	638.54	0.003

5. Discussion

When comparing the results with previous studies of thermal behavior of a standard H-10 block that transmits a final temperature of 35.821 °C [1] we can find a significant decrease in heat transferred in all the cases evaluated, thus achieving a reduction of 2.468 °C in case A-1, 2.544 °C in case A-2 and up to 2.759 °C in case A-3, verifying that the application of thermal insulation techniques from the product

design can achieve thermal efficiency in derived products of red clay, which generate a reduction in thermal conductance with complex geometries that propagate energy dissipation [5,18] and do not necessarily require air channels to be effective (Table 3).

Table 3. Temperature decrease of the designs compared to a traditional H-10 block.

Design	Temperature (°C)	Temperature decrease (°C)
Block H-10	35.821	-
Part A-1	33.353	2.468
Part A-2	33.277	2.544
Part A-3	33.060	2.759

However, as can be seen in Figure 5, the morphologies presented by the air chambers also have an aesthetic component within the development of architectural closings whose forms can present multiple constructive dispositions adaptable to the aesthetic function of the envelope [3] as an added value that complements the thermal insulation function that a construction piece could have.

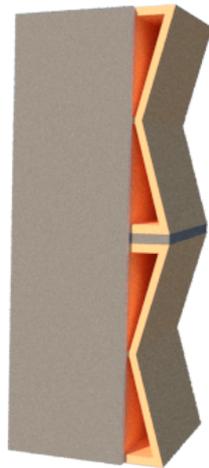


Figure 5. Construction system.

This research considers the design of self-supporting products, which represent a maximum of W: 150 mm in thickness in light elements for the construction of thermally effective masonry systems, viable for national construction, which respond to environmental requirements that represent 80% of Colombia's climatic conditions [6], warm climates. The results allow evaluating the contributions to the physics of the materials that the modification of the shape of a ceramic product presents through the design of dissipating internal geometries, sustainable criteria that respond to the challenges in terms of thermal efficiency, using thermal validations of the temperatures obtained by heat transfer and stored energy to understand the impact of form on the energy behavior of a product, the results of which are positive for the ceramic sector in Colombia [19] and present a contribution in the development of thermal insulation for sustainable construction [20].

6. Conclusions

Considering the variables within the design, there is no significant difference in the final temperatures with a reduction of between 0.076 °C - 0.291 °C between the three cases, the strategy that proved to be more effective is natural ventilation in regard to the increase in thickness; however, the difference does not reach 0.5 °C; on the other hand, when comparing the results with a traditional H-10 block, an efficiency from 2.4 °C in heat transfer transferred is evidenced in either case. In this sense, this research allows evaluating the effectiveness of thermal insulation strategies in alternative construction units, with the potential to be implemented for efficient masonry systems in relation to the development of

innovative ceramics in relation to sustainability in construction. This work presents an opportunity for the development of physical properties in ceramic pieces capable of generating thermal insulation as a contribution to the innovation processes of efficient construction units for enclosures in hot tropical climates.

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