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DEVELOPMENT OF A THERMALLY INSULATING CERAMIC CONSTRUCTION UNIT FOR MASONRY ENVELOPES IN HOT TROPICAL CLIMATES

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Abstract

The new technological development processes for building products must contain a design component that takes responsibility for the energy consumption problems faced by buildings, especially the parts that make up the envelope as responsible for the energy flows between the exterior and the interior of the enclosures; in climates with high solar radiation, where the architectural skin presents surface temperatures above 65°C, the main challenge will be the implementation of thermal insulation strategies to prevent or contain heat transfer to the interior of the built space, reducing the heat energy to be dissipated with active cooling mechanisms. The present research develops a new product under thermo-insulating principles, with characteristics in the internal and external shape of the part capable of passively mitigating unwanted thermal loads; the design process assumes a model with high thermal mass, which in turn interrupts the internal thermal bridges and generates ventilated air chambers in the first layer of the part to contain and dissipate the transferred energy. The efficiency of the results is demonstrated with thermal simulations of temperature distribution and heat flow that allow the determination of the heat energy profiles through the part and the final surface temperatures of heat transferred to the interior of the enclosure. This design process makes it possible to develop new models of thermally efficient ceramic facades for extremely hot climates.

Keywords: Ceramics, Design, Thermal insulation.

1. Introduction

In architectural practice, energy efficiency is translated as the generation of responsible design and construction practices in terms of sustainability, with responses that interpret the conditions of the external environment to apply various technical and technological resources to minimize the impact on the environment. Noting that mechanized refrigeration represents 15% of global electricity consumption [1], from the scientific framework, one of the most significant discussions is the implementation of passive technologies for thermal conditioning [2], described as those

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techniques and technologies that do not use mechanical systems [3] and represent one of the most effective tools in sustainable development due to the proven influence they exert on energy yields reducing up to one-third of the operational requirements in construction [4].

In the case of passive cooling systems for envelopes in hot climates, the literature focuses on the prevention, control and dissipation of heat gains from thermoresistance parameters [5], applying principles such as the generation of dissipative shapes [6], the interruption of thermal bridges [7,8,9], the use of transparent, reflective and porous finishes such as ceramic materials, the minimization of direct radiation with shading factor and controlled airflow over openings for heat dissipation from the use of prevailing winds [10,11] as initial methods to achieve a balance in energy flows, protecting the interior space from adverse weather conditions to provide comfort conditions.

In this sense, the parts that make up the enclosure systems must consider passive cooling strategies from the shape, shading and energy dissipation by natural ventilation are the fundamental tools to give the envelope properties to reduce heat transfer through the optimization of its components; these strategies represent a way to solve the challenges of climate change, with the increasing increase in atmospheric temperatures and the effect of increased electricity consumption, especially in hot tropical climates.

This work studies the results of applying efficient design criteria in construction systems for masonry enclosures as an assertive approach from the perspective of sustainability, contemplating thermal insulation properties through shape, thickness, constructive layout and physical properties of materials, with a focus on vernacular ceramic products; implementing natural ventilation effects and dissipative geometries to reduce the percentages of absorption and heat transfer to the interior space, in order to provide comfort conditions with minimum environmental impact; adding value to the traditional aesthetic expression, with an industrializable product, viable from its structural form, its performance within the constructive system and keeping a low cost for greater adaptability to the market.

2. Ceramics

The most significant proportion of products manufactured by the clay companies corresponds to different types of masonry construction pieces, of which 19% correspond to ceramic bricks and 15% to fired red clay blocks[12], pieces that have a low production cost, which has adaptable dimensions and formats that are functional in different architectural constructions, mainly used in exterior enclosures and interior partitions, are manufactured in different chromatic scales and textures, whose characteristics work perfectly in masonry construction systems for civil works. Figure 1 shows the typologies of bricks and blocks traditionally produced by the local ceramic industry, and Table 1 shows the physical characteristics of each of the samples.

(a) (b) (c)

Figure 1. Typologies of ceramic pieces (a) Multi-perforated brick (b) H10 block (c) H15 block.

Product	Dimension	Weight	Yield m^2
Multiperforated Brick	120mm*60mm*240mm	2 kg	56 U
Block H10	100mm*200mm*300mm	4kg	16 U
Block H15	150mm*200mm*300mm	6kg	16 U

Table 1. Characterization of the different types of ceramic pieces.

The shape of the traditional clay block used in facade enclosures has been characterized by its rectangular shape, allowing the entire wall, boards and joints, to be exposed to solar radiation for extended periods; the radiation is absorbed by the material and accumulated in the enclosure. In addition, the heat is transferred unidirectionally by conduction, thanks to the fact that the horizontal surfaces that make up the block, the ribs, become thermal bridges that quickly carry the temperature to the interior of the building.

From a thermal perspective, in a warm semi-arid climate, within the pieces offered by the local ceramic industry masonry market, block type products such as H10 block and H15 block stand out as construction units with excellent thermal performance under high conditions of direct solar radiation, registering a thermal transmittance of 37.91°C [13] and 34.95 [14] respectively under conditions of solar irradiance of 695.4W/m^2; likewise, pieces such as the traditional multiperforated brick have demonstrated a thermal performance of 41.70°C on the interior surface [15].

Product	Thermal Behavior

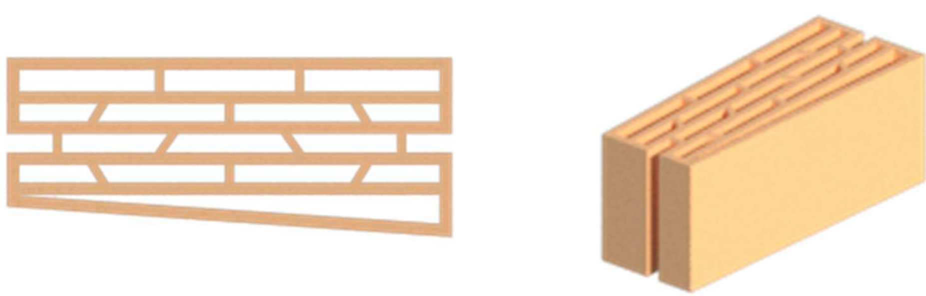
Multiperforated Brick	41,70°C
Block H10	37,91°C
Block H15	34,95°C

Table 2. Thermal behavior of the different types of ceramic pieces.

3. Design

In the literature related to building envelopes, passive strategies for the development of thermal insulating products are considered as passive strategies: the increase of the thickness in the parts, the reduction of thermal bridges through the morphological complexity of the partitions by lengthening the routes to delay or prevent heat transfer [16, 17], the increase in the number of internal cavities of each construction unit [18], the addition of passive ventilation systems in the surface of greater solar incidence to dissipate energy [19] and the formal exploration of the external face to control the percentages of heat gain [20].

Based on the study of the thermal behavior of traditional pieces and considering principles of passive thermal resistance from the morphology of the piece, Figure 2 presents a design that recognizes a more significant number of internal cavities with an air chamber, with 15 cavities, some dissipative forms in thermal bridges formed by seven walls that divide the initial surface of the final surface and 12 discontinuous partitions, with measures of 290mm long, 130mm thick and 150mm high, the piece segments the mortar its horizontal and vertical arrangement avoiding the thermal bridge.



(a) **(b)**

Figure 2. Construction Unit Design: (a) Plan (b) Isometry.

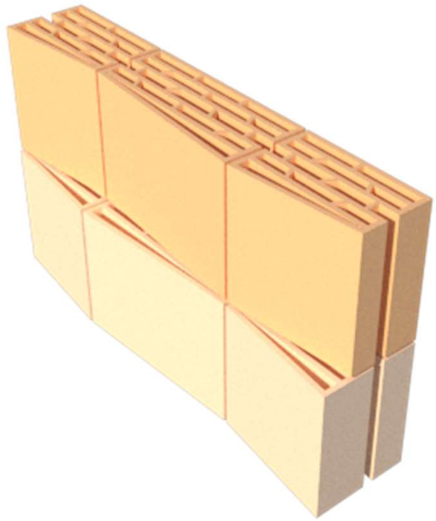


Figure 3. Construction system.

4. 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 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:

$$\text{Re} = \rho * \text{V} * \text{Lc } \mu\text{Re} = \rho * \text{V} * \text{Lc } \mu \text{ Equation (3)}$$

ρ: Air density.
V: Wind speed.
μ: Dynamic viscosity of air.

The properties of the air for a temperature of 33°C are described below.

ρ = 1.1526 Kg / m^3
k = 0,026102 $W / m. °C$
μ = 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/ 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/ m^2 °C and a heat flux of 796.8 W/m^2. For surfaces that are not enclosed as internal air chambers, a heat transfer coefficient by natural convection of h = 5 W/ m^2 is assumed $°C$.

A mesh density of 1,085,812 nodes was used to carry out the computational simulation, as shown in Figure 4.

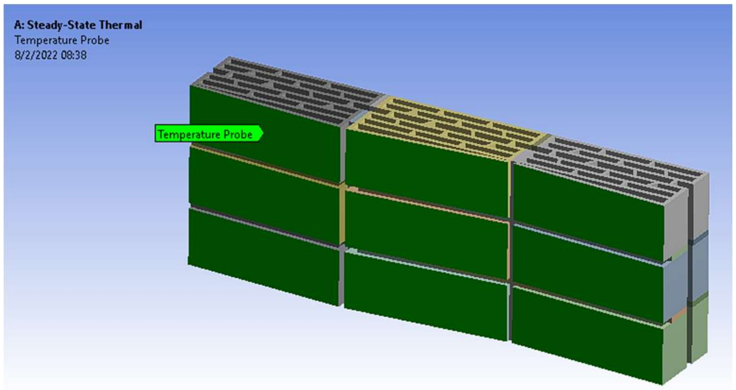


Figure 4. Mesh.

5. Results

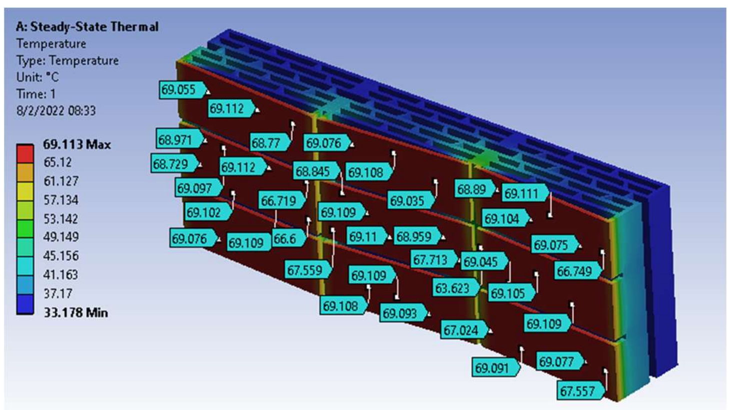


Figure 5. Results of exterior surface temperature distribution.

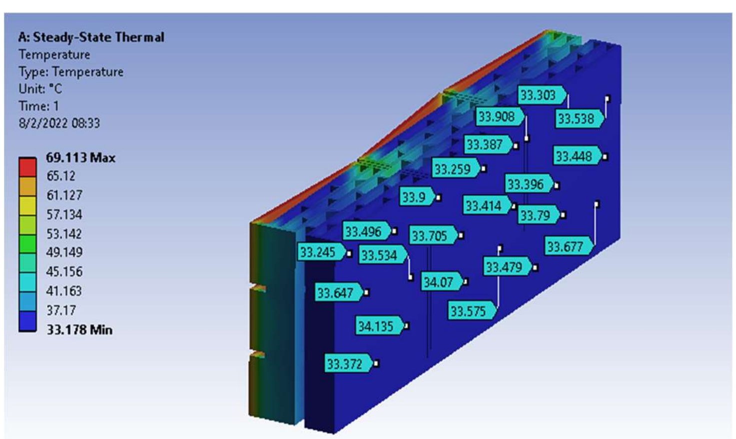


Figure 6. Inner surface temperature distribution results.

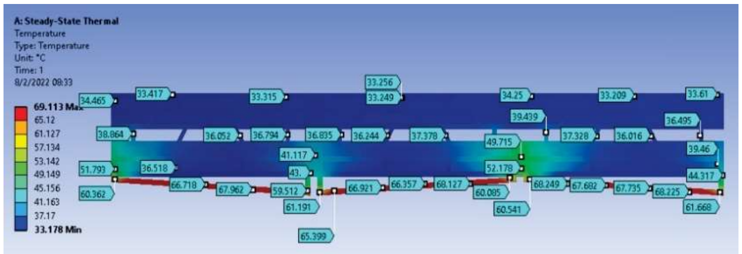


Figure 7. Results of temperature distribution in top view.

Product	Initial Temperature maximum	Final Temperature minimum
Block H13	69,1°C	33,1°C

Table 3. Thermal behavior of the proposed ceramic part.

Figures 5 and 6 show the three-dimensional distribution of the temperature on the front and back surfaces, where the average temperatures on the front surface are 64.7°C, and on the back surface, 33.6°C on average. In thermal bridges formed by partition walls, the initial temperature is 60.3°C and the final temperature is 34.4°C; in mortar joints, the initial temperature is 52.1°C and the final temperature on the internal surface is 34.2°C.

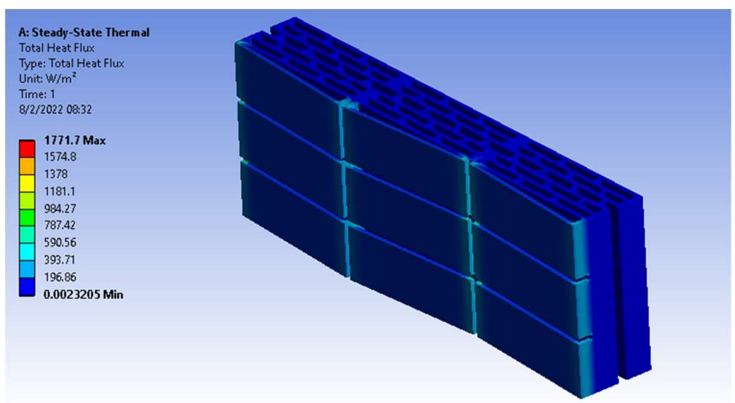


Figure 8. Results of external surface heat flow.

Heat fluxes are concentrated in the thermal bridges formed by the side walls, registering heat concentrations of 491W/m^2.

6. Conclusions

The results show that the proposed product presents a temperature reduction of 10.53°C compared to a multiperforated brick type product, 6.74°C to an H10 block and 3.78°C to an H15 block because its geometric configuration or conceptual design has a large area where air circulates. These air chambers ideally could behave as an insulating "layer" due to the low conductivity of the air being stagnant between the front face and the rest of the brick or block. The data obtained show a temperature reduction of 20.6%, 12.6% and 5.1%, respectively, for bricks, H10 and H15 blocks, significantly improving ceramic products' thermal performance for building envelopes.

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