Evaluation of the thermal performance of a Social Interest Housing (SIH) with ecological brick masonry produced with urban solid waste stabilized in a tropical climate to replace the use of traditional building materials

M P Dunel 1, C F Teixeira Barbosa 2

1 Pauladunel@hotmail.com, Federal University Of Sergipe, São Cristovão, Brazil.
2 cafbt@yahoo.com.br, Federal University Of Sergipe, São Cristovão, Brazil.

Abstract. The increasing urbanization and industrialization of modern societies has led to a large-scale production of solid waste, and its proliferation is therefore a global problem with immediate consequences for public health and the environment. Urban solid waste must be managed and controlled so as to reduce its volume and hazard, minimizing the damage of environmental pollution and the impacts in the population health. Currently, the most common waste control techniques are recycling and composting. Such techniques are known as tools that allow waste reuse. In this context, the use of recyclable materials in civil construction has been increasing day by day. However, in Brazil, no approach was found regarding material for the civil construction that is based on domiciliary solid residues, as the ecological brick. In this work, the thermal comfort of the ecological brick was analyzed, a brick of low environmental impact and of easy applicability that can be used to improve the thermal comfort of the Brazilian constructions in general, including the housing for the low-income population. The main objective of the study was to verify the effectiveness of the ecological brick regarding the thermal comfort. The methodology consists of measuring the thermal comfort in a reference model of low-income residence with ecological bricks masonry produced with waste from urban solid waste. Changes in the envelope were soon made, such as the addition of coating mortar and white paint and the replacement of the ecological brick masonry with the ceramic brick masonry with and without coating in order to compare the values of the residence internal temperature. The measurement was performed by computational simulation with the EnergyPlus® software using the real-scale prototype of the popular standard Brazilian house, on the typical summer day. In the results, it was noticed that the residence of ecological bricks obtained a sensitive difference in temperature in comparison to the residence of solid ceramic bricks. The prototype built with ecological brick contributed to better conditions of thermal comfort, as it provided lower internal temperatures, and, consequently, lower heat gain. Therefore, it was verified a change in the values of thermal transmittance and delay related to the behavior of masonry in the different environments of the building. As for the influence of the addition of the coating mortar and the external paint with a light color, it was observed that there was a significant improvement in the thermal performance of the masonry. Therefore, for a better thermal comfort of the users of the buildings in the bioclimatic zone-8, it is indicated that the seal composed by ecological bricks is towed and its facade painted with light colors.

1. Introduction
Currently, much has been discussed about the environmental impacts in the world. Governments, corporations and society are seeking new ways to reverse or minimize environmental damage. According to data from the United Nations - UN Brazil (2016), half the world population lives in cities,
and the estimate for 2030 is that 60% will live in urban areas. In addition, the global population is expected to reach 9.6 billion by 2050, requiring three planets to generate natural resources capable of sustaining the current lifestyle [1].

As the population grows, consumption also grows, mainly from disposable products or with disposable packaging, such as plastic, aluminium, paper, among others. This condition causes an increase in the generation of Urban Solid Waste (USW), especially in large centers, thus reducing the useful life of landfills and causing greater environmental impacts [2].

The Ecological Brick Project is an initiative of the Coordinación Ecológica Área Metropolitana Sociedad del Estado (CEAMSE), designed to take advantage of the thin and organic fraction of USW tailings for the production of bricks. These are produced from mixing and combining such tailings with other materials used in construction (lime, cement and sand). Once the solid waste arrives at the treatment plant, the organic wastes are separated mechanically and then degraded and stabilized by applying a biological treatment for three weeks, until the bacteria have consumed all the organic and stopped generating liquids (picture 01). Thus, the tailings are used to construct landfills soil cover and to manufacture ecological bricks.

The stabilized organic waste is received in the organic brick factory, and a new process is carried out, which consists of fine crushing and then sifted to the appropriate size for later use in the manufacture of bricks (picture 02). All dry materials (organic waste, lime, cement and sand) are mixed and water is added to knead and homogenize. Once the proper consistency is achieved, the brick is formed by mechanical filling of moulds. Finally, the elaborated bricks dry for about 20 days, when the material acquires hardness and strength (picture 02).

Thus, the ecological brick produced by CEAMSE in Argentina has sustainable attributes, since the waste that would go to the landfill is part of the raw material of the material, generating a reduction in the "greenhouse gases" of landfills and, in turn, a reduction in the environmental impact. The bricks are qualified in Argentina for social purposes.

The use of recyclable materials in civil construction has increased day by day, and has the potential for greater growth in the coming years [3]. For this reason, the industry needs new products and solutions. Many researches and studies have been developed with excellent results, such as the work of the researchers [4] which demonstrates the success of Reject-Cement Brick (RCB) with a very similar manufacture, but with different raw material, mining tailings. However, in Brazil, we did not find an approach regarding material for the civil construction that is based on solid domiciliary residues, as it is the case of the material under study.
The research interests are in the thermal performance of the material applied in Brazil, specifically in the Brazilian bioclimatic zone 8, since it has a lot of sustainability compared to a material with physical characteristics similar to the one in the study, such as solid brick. In Brazil, when there is a very large population growth in a region, it is common to have, in parallel, the need to expand the production system that provides the most diverse items used in civil construction and urbanization [5]. Thus, the demand of products from the ceramic sector arises to supply the need of the market.

[5] states that within the ceramics sector the segment of red ceramics is what causes the most negative impacts on the environment. The environmental problems generated relate, in particular, to the extraction and consumption of raw materials: clay, water, firewood, etc, as well as, production tailings, mainly of defective products, and gaseous emissions (particulate material) from the burning in the manufacture.

In view of the flagrant environmental impacts caused by the massive ceramic brick production process and the increase in the production of this material in the face of the civil construction growth, it is relevant the use of environmentally friendly alternatives, such as ecological brick, in order to reduce the aggression to the environment.

Evaluating the performance of the construction systems is an advance for the construction industry and constitutes the path to the evolution of all components of the chain [6]. In the last decades, besides the rationalization, the civil construction sector has been trying to improve the construction systems under the logic of energy efficiency, through the universe of architectural and technological solutions, in order to guarantee better performance to the buildings and provide greater comfort to their users. The envelope of the building is the most important parameter in the passive conditioning, besides being the main factor for the definition of the internal climate, responsible for the heat flows in its interior. Therefore, determinant for the thermal performance [7].

In the research of [8] this idea is confirmed by affirming that, amongst all the parameters that affect the thermal comfort and the energy conservation in the buildings, among them the orientation of the building, the distance between buildings, the shape of the building and the thermophysical properties of the envelope of the building, the latter is the most important. This is because the envelope is responsible for separating the external environment from the internal one. With the addition of coating mortar to the seal, the thermal barrier increases due to the increase in the thermal mass of the opaque closure of the building, which causes the inner enclosures to receive the thermal energy transmitted through the envelope more slowly. This behavior can be explained by means of two phenomena: the damping and thermal delay, which, together, make up the thermal inertia.

According to [9], a wall presents greater or lesser inertia according to its weight and thickness, and therefore coatings play an important role, since the insulating coatings reduce the heat exchanges with the wall, as well as its inertia.

According to [10], using a more reflective color in the envelope of the building is the most effective climate control architectural feature and the most feasible way of minimizing the thermal loads of buildings, especially in the summer.

For this reason, considering the need to protect the degraded environment, the current search for sustainable materials for insertion in the construction industry, and the need to reduce the disposal of waste in landfills, the present research is relevant, in order to evaluate the adaptation of the ecological brick produced with USW tailings in Brazil, from the analysis of its suitability to the rules related to thermal performance in the bioclimatic zone 8.

The objective of this article is to evaluate the thermal performance of a Housing of Social Interest (HSI) with ecological brick masonry produced with USW tailings, in a city of the Bioclimatic Zone 8, through computational simulation.

2. Method
The thermal performance evaluation can be done in a simplified way, based on thermal properties of the facades and roofs, or by computer simulation, where all the elements and all the intervening phenomena are simultaneously collated. [11] recommends that the computational simulation is performed using the
EnergyPlus® software and determines that the housing construction should put together characteristics that meet the thermal performance requirements, considering the bioclimatic zone defined in the standard. In this research, the computational simulation was carried out using the EnergyPlus® software, in order to obtain the thermal comfort evaluation of the organic bricks produced by USW tailings in the city of Aracaju / SE, located in the Bioclimatic Zone 8.

For the thermal comfort study, a reference model of an HSI was created in the EnergyPlus® software, and from this model, variations related to the materials used in the envelope of the building were performed. Variations in the envelope construction elements may result in different thermal performance of the building. A comparative analysis was carried out between the thermal comfort offered by the ecological brick produced with waste from the USWs and by the solid brick. The manufacture of the latter material has a negative impact on the environment and within the physical characteristics it is similar to the ecological brick studied.

The procedure was divided into two steps:
1. Definition of the reference model of a HSI.
2. Variations in the envelope of the building.

2.1 Definition of the reference model of a HSI
A single-family residential building, in the patterns of Caixa Econômica Federal (CEF) for Housing of Social Interest (HSI) was chosen for the reference model, still in the design phase, and located in the city of Aracaju / SE. The building has a built area of 48 m², with dimensions of 6.00m x 8.00m x 2.80m.

Its composed of three bedrooms, a living room, a toilet and a kitchen. Based on the information provided by CEF, the floor plan of the building (picture 3) was reproduced in the AutoCad 2015 software, as well as the thermal zones modeling in the SketchUp software. These graphic pieces served as basis for the data required concerning the building geometry for computational simulation in the EnergyPlus® software.

![Picture 3 – Building ground floor](image)

2.1.1 Building Geometry
The building was modeled in the EnergyPlus® program with six thermal zones: room 1 zone, room 2 zone, room 3 zone, kitchen zone, toilet zone and living room zone (pictures 4 and 5). The simulation occurs in all enclosures of the housing unit, but the results are evaluated only for bedrooms and living room.
2.1.2 External Temperature

In this research, the prototype was simulated using the INMET climatic archive of the city of Aracaju (bioclimatic zone 8), during the month of December 2015, made available by LabEEE / UFSC and analyzed the typical summer day, December 21, as stipulated in the standard [11]. With this, it was possible to compare the internal temperatures of the building in relation to the external temperature.

2.1.3 Thermal Resistance of Materials

The thermal properties of most of the materials used, such as thermal conductivity, density, specific heat and absorptivity for solar radiation, were obtained in the standard [11]. Only the characteristics used for the ecological brick were obtained from the results of the laboratory of the National Institute of Technology (INTI) of Argentina, whose brick samples were sent by the Coordinación Ecológica Área Metropolitana Sociedad del Estado (CEAMSE) in 2015 to analyze the physical characteristics, mechanical and thermal properties of the material. These data are presented in Table 1.

Table 1 – Thermal Properties of the Materials.

| Material           | Thermal Conductivity [W/m.K] | Density [kg/m³] | Specific Heat [J/kg.K] | Absorptivity |
|--------------------|-----------------------------|-----------------|------------------------|--------------|
| Ecological brick   | 0,43                        | 1408            | 1000                   | 0,70         |
| Solid concrete     | 1,75                        | 2200            | 1000                   | 0,70         |
| Ceramic roof tile  | 1,05                        | 2000            | 920                    | 0,70         |
| Under floor        | 1,15                        | 2000            | 1000                   | 0,70         |
| Common mortar      | 1,15                        | 2000            | 1000                   | 0,70         |
| Ceramic floor      | 0,90                        | 1600            | 920                    | 0,60         |
| Door wood          | 0,16                        | 600             | 2300                   | 0,70         |

According to [12], the calculation method for determining the thermal performance used by the EnergyPlus® program provides the materials in the wall in layers in series, thus skipping important information about the geometry of the component that is necessary for its correct energy quantification. Therefore, this study was modeled with an equivalent wall system (picture 6).
The equivalent constructive element, shown in Picture 4, was composed by an ecological brick module measuring 12 cm x 05 cm x 25 cm with 1 cm of mortar laying in the upper and posterior face. The procedures for calculations of total heat transfer \( UT \), total thermal resistance \( TR \) and total thermal capacity \( TC \) were the same as those considered by [11] (table 2).

| Property               | Ecological Brick |
|------------------------|------------------|
| Height m               | 0.06             |
| Width m                | 0.12             |
| Length m               | 0.26             |
| Area m²                | 0.0186           |
| Mortar Percentage %    | 33               |
| Density kg/m³          | 1602.2           |
| Conductivity W/(m K)   | 0.91             |
| Specific Heat cp kJ/(kg K) | 1.00         |
| Resistance m²K/W       | 0.13             |
| Transmittance W/(m² K) | 7.62             |

According to standard [11], the aperture of the window frames for ventilation and illumination is 40% relative to the ambient area, with 4mm common glass. The roof is composed of ceramic tile without slab or lining under the roof. This type of cover is very common in the northeast area of Brazil [13]. The internal and external doors are made of wood. The building is in contact with the ground and is composed of concrete base, waterproof underlayment, regularization, common mortar and ceramic floor with grout. In order to consider the influence of the soil, a preliminary simulation was carried out, adopting the average monthly values of soil temperature, provided by the climatic reference file of the city in question. Next, the Slab preprocessor integrated with the EnergyPlus® was used to obtain the average monthly temperatures of the soil underlying the building. For this, it was necessary to inform the following parameters (objects): concrete base of 10 cm, waterproofing subfloor of 5 cm, regularization with 3 cm of common mortar and ceramic floor with grout. Slab was built by Site: GroundDomain: Slab.

In the reference model, the values of absorption of the materials were defined by the observation of the colors in the studied building (table 1).

### 2.1.4 Equipments internal heat gain

For the computational simulation, one of the parameters to be defined is the thermal load present in the building, determined by the occupancy and lighting patterns. In order to the simulation approach the maximum of the use in reality, some procedures proposed by [14] were adopted.

For each dormitory of the building must be adopted the pattern of occupation of two people, between 9 p.m. and 7 a.m. The living room of the building should be simulated with an occupancy pattern of 50% between 2:00 p.m. and 6:00 p.m. and 100% between 6 p.m. and 9 p.m.

The metabolic rate for each activity is determined according to the type of activity performed in each environment. For activities in the dorm (sleeping or resting), the dissipated heat value of 81 W / person. For activities in the living room (sitting or watching television), the value considered is 108 W / person. Users are expected to use artificial lighting in the dormitory in the early hours of the morning, between 6 and 7 a.m. and in the evening between 9 and 11pm, and in the living room from 5 to 9 p.m.
The power of lighting use stipulated for the bedrooms was of 9.86, 13.45 watts for the kitchen, 7.0 watts for the toilet and 10.07 watts for the living room. For the living room, it was considered the use of the TV with a power of use of 80 watts, at 6h, 7h, 12h, 13h and 18h to 22h. For the kitchen, it was considered the use of refrigerator with 33.19 watts of power and stove use with 60 watts at the times: 6h, 7h, 12h, 13h, 18h, 19h and 21h.

With regard to air infiltration, considering that the residence studied has a good seal, a rate of 5 air changes per hour was adopted for all areas.

2.2 Variations in the building envelope

From the reference model, variations related to the materials used in the building envelope were executed. Variations in the envelope construction elements may result in different thermal performance of the building.

2.2.1 Addition of coating mortar and paint.

In the present research, it was tried to improve the thermal performance of the material with the addition of coating mortar and white paint. In order to enter the input data into the EnergyPlus® software, it was necessary to create a new equivalent wall system and perform the calculations manually to insert in the software (Resistance = 0.35 m²K / W and Transmittance = 2.90 W / (m² K. The total thickness of the lightweight wall is 17 cm (picture 7), and the white paint absorptive value (α = 0.20) was inserted directly into the software.)

![Picture 7](composition-of-the-wall-system-of-ecological-brick-with-cladding.png)

**Picture 7** – Composition of the wall system of ecological brick with cladding

2.2.2 Replacement of ecological brick by solid ceramic brick

Another variation in the envelope of the reference model was the replacement of the ecological brick by the solid ceramic brick. This was conducted in order to compare the thermal performance of the materials. The solid ceramic brick has similar physical characteristics to the ecological one (see picture 8).

For the replacement, an equivalent wall system was created with the solid ceramic brick set with mortar in the smallest direction (picture 8). The data of the brick and mortar were collected from the standard [11] and then the calculations of the thermal properties of the equivalent wall system, given by the combination of the materials (table 3), were performed.

![Picture 8](equivalent-wall-system-with-solid-brick-and-mortar-with-and-without-coating.png)

**Table 3** - Thermophysical properties and dimensions of the equivalent wall system

| Property                     | Solid Brick |
|------------------------------|-------------|
| Area m²                      | 0.0203      |
| Mortar Percentage %          | 35          |
| Density kg/m³                | 1739.9      |
| Conductivity W/(m K)         | 0.99        |
| Specific Heat cp kJ/(kg K)   | 0.95        |
| Resistance m²K/W             | 0.10        |
| Transmittance W/(m² K)       | 9.87        |
3. Analysis of results

December 2015, at 1h, 3h, 6h, 9h, 12h, 15h, 18h, 21h and 24h; the first two graphs show the values of external average air temperature for each typical daylight saving time of the day and the values of internal average air temperature simulated in the building with ecological brick masonry and masonry of solid ceramic bricks without coating and painting. In the last graph, the values of internal temperature in the living room with the ecological brick with coating and painting are presented. In picture 9, the values for the living room environment are shown and in picture 10, the values refer to the bedrooms.

This simulation adopted the external temperature value of 26.27 °C at 1h, 25.83 °C at 3h, 25.57 °C at 6h, 27.55 °C at 9h, 30.00 °C at 12h, 30.90 °C at 15h, 29.81 °C at 18h, 27.90 °C at 21h and 26.61 °C at 24h, which are listed in the TRY climatic archives.

![Graph showing temperature values](image)

**Picture 9** – Living room results: building with ecological brick and solid ceramic brick without coating and painting.

**Picture 10** – Bedroom results: building with ecological brick and solid ceramic brick without coating and painting.
Through these graphs, it is possible to verify that the time of greatest radiation and solar incidence is usually by noon, but inside the prototypes the highest temperature was obtained between 14.00 and 15.00. This is because in opaque materials such as bricks, it is necessary to consider the storage of heat during transmission, in which the mass is heating up, track by track, causing the thermal delay. The time when the temperatures are lower is at 6 o’clock, an expected result, as the sun rises on the east side and the windows of the prototypes are positioned on the north facade. The biggest difference in temperature is from 12.00 to 3.00 p.m., when the temperature increases notably in relation to the others. The time at which the prototype of ecological brick compared to that of solid ceramic brick obtained similar temperatures values, almost null, was between 01h to 09h. It can be said that there is not much difference in the internal temperature of the environments during sunrise.

It is important to note that there is an internal temperature difference between the prototype of ecological brick compared to the ceramic mass, from 0.12ºC for the living room, from 0.13ºC for bedrooms 01 and 03 and 0.09ºC for bedroom 02. This happened at 15.00, at the most critical time of the building, benefiting the ecological brick.

Comparing the simulated building with uncoated organic brick masonry with the simulation of ecological brick masonry with coating and color of low absorbance, it is verified that the brick with coating and paint has a better thermal performance, reaching a difference of 1.28 ºC in the living room, 1.85 ºC in bedroom 01, 1.06 ºC in bedroom 02 and 1.40 ºC in bedroom 03, at 3:00 p.m. (picture 11).

The results of this research therefore indicate that in hot climates, such as ZB-8, it is recommended that the masonry in ecological bricks is coated and its exterior surface painted in light colors in order to guarantee better thermal comfort conditions.

Comparing the simulated building with uncoated organic masonry with the simulation of ecological brick masonry with coating and color of low absorbance, it is verified that the brick with coating and paint has a better thermal performance, arriving in the room at a difference from 1.02 ºC to 3:00 p.m.

4. Conclusions
With the results presented, it can be concluded that, despite being a sensitive difference, the prototype constructed with ecological brick contributed to better conditions of thermal comfort, as it provided lower internal temperatures, and, consequently, lower heat gain. In addition, this type of brick is produced without burning, that is, with less emission of greenhouse gases, and it proves to be a more economical alternative, being therefore more accessible to the population of low income and used more easily in the self-construction joint efforts.
Consequently, the ecological brick is shown as a viable alternative to the solid ceramic brick, considering not only its environmental characteristic, but also, according to the obtained results, by the inexistence of loss for the purpose of thermal comfort.

As for the influence of the addition of the coating mortar to the masonry, it was observed that there was a significant improvement in the thermal performance when compared to the non-plastered masonry, due to the increase of the thermal mass, reflecting on the optimization of the thermal properties, thermal resistance, resulting in less heat gain by the seal, in order to provide better conditions of thermal comfort. The same can be noted when the masonry has its white painted exterior surface which causes a reduction of the solar heat factor by 70% when compared to the value of non-towed masonry, and approximately 65% in relation to the not painted masonry, which reflects in the reduction of heat gains for the interior of the building. Therefore, the painting has significant and positive impacts on the masonry thermal performance.

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