# EVALUATION OF MATERIALS IN POPULAR APARTMENTS BY THERMOENERGY MODELING

# AVALIAÇÃO DE MATERIAIS EM APARTAMENTOS POPULARES POR MODELAGEM TERMOENERGÉTICA

# EVALUACIÓN DE MATERIALES EN VIVIENDAS POPULARES MEDIANTE MODELACIÓN TERMOENERGÉTICA

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**ABSTRACT**

The Minha Casa Minha Vida (MCMV) program, promoted by the Federal Government, seeks to reduce Brazil's housing deficit by providing housing to low-income populations. This study uses numerical simulations to evaluate the thermal performance of a typical housing unit in the Viver Melhor Residential complex in Marituba, Pará, focusing on indoor thermal comfort, a key factor for the health, well-being, and quality of life of its occupants. The analysis compares the results with the criteria established by NBR 16401-2:2008. Thermoenergetic modeling was performed using SketchUp®, OpenStudio®, and EnergyPlus® software, simulating the building's thermal behavior over the course of a year. Five thermal zones were defined: bathroom, living room/service area, bedroom 1, bedroom 2, and living room, to analyze temperature and relative humidity parameters in each room. The results indicate that the most thermally comfortable room was the living room, meeting the requirements of NBR 16401-2:2008 for approximately 7.53% of the year. The other rooms—kitchen/service area, bedroom 2, bedroom 1, and bathroom—represented thermal comfort levels of approximately 6.73%, 6.51%, 6.39%, and 5.82% of the year, respectively. The study highlights the importance of computer simulations in the evaluation and design of social housing, allowing the identification of thermal inefficiencies even at the design stage.

**Keywords:** Thermoenergetic Efficiency. Environmental Comfort. Social Housing.

**RESUMO**

O programa Minha Casa Minha Vida (MCMV), promovido pelo Governo Federal, busca reduzir o déficit habitacional brasileiro por meio da oferta de moradias à população de baixa renda. Este estudo avalia, por meio de simulações numéricas, o desempenho térmico de uma unidade habitacional típica do Residencial Viver Melhor, em Marituba-PA, com foco nas

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condições de conforto térmico interno, fator essencial para saúde, bem-estar e qualidade de vida dos ocupantes. A análise compara os resultados obtidos com os critérios da NBR 16401-2:2008. A modelagem termoenergética foi realizada com os softwares SketchUp®, OpenStudio® e EnergyPlus®, simulando o comportamento térmico do edifício ao longo de um ano. Foram definidas cinco zonas térmicas: banheiro, sala/serviço, quarto 01, quarto 02 e sala, com intuito de analisar parâmetros de temperatura e umidade relativa em cada cômodo. Os resultados apontam que o cômodo mais confortável termicamente foi a sala, atendendo às exigências da NBR 16401-2:2008 em aproximadamente 7,53% do ano. Os demais cômodos – cozinha/serviço, quarto 02, quarto 01 e banheiro – apresentaram, respectivamente, índices de conforto térmico em cerca de 6,73%, 6,51%, 6,39% e 5,82% do período anual. O estudo destaca a importância das simulações computacionais na avaliação e no projeto de habitações sociais, permitindo identificar ineficiências térmicas ainda na fase de concepção.

**Palavras-chave:** Eficiência Termoenergética. Conforto Ambiental. Habitação Social.

**RESUMEN**

El programa Minha Casa Minha Vida (MCMV), impulsado por el Gobierno Federal, busca reducir el déficit habitacional de Brasil mediante la provisión de viviendas a poblaciones de bajos ingresos. Este estudio utiliza simulaciones numéricas para evaluar el desempeño térmico de una vivienda típica en el complejo residencial Viver Melhor en Marituba, Pará, centrándose en el confort térmico interior, un factor clave para la salud, el bienestar y la calidad de vida de sus ocupantes. El análisis compara los resultados con los criterios establecidos por la norma NBR 16401-2:2008. Se realizó un modelado termoenergético con los software SketchUp®, OpenStudio® y EnergyPlus®, simulando el comportamiento térmico del edificio a lo largo de un año. Se definieron cinco zonas térmicas: baño, sala de estar/área de servicio, dormitorio 1, dormitorio 2 y sala de estar, para analizar los parámetros de temperatura y humedad relativa en cada habitación. Los resultados indican que la estancia con mayor confort térmico fue la sala de estar, cumpliendo con los requisitos de la norma NBR 16401-2:2008 durante aproximadamente el 7,53 % del año. Las demás estancias (cocina/área de servicio, dormitorio 2, dormitorio 1 y baño) presentaron niveles de confort térmico de aproximadamente el 6,73 %, el 6,51 %, el 6,39 % y el 5,82 % del año, respectivamente. El estudio destaca la importancia de las simulaciones por computadora en la evaluación y el diseño de viviendas sociales, ya que permiten identificar ineficiencias térmicas incluso en la fase de diseño.

**Palabras clave:** Eficiencia termoenergética. Confort ambiental. Vivienda social.

## 1 INTRODUCTION

Studies on environmental thermal comfort began in the 1970s, with emphasis on the contributions of Povl Ole Fanger, who investigated human reactions to the thermal conditions of built environments (Gouveia, 2021). Since then, it has been understood that thermal comfort results from the interaction between physical, physiological and sociopsychological factors. The human body, acting as a thermoregulatory system, seeks to maintain thermal equilibrium with the environment, being compared to a "heat engine" by Prek (2004) and described by Fernandes (2019) as a system that continuously regulates heat exchanges through metabolism and circulation. Heat transfer by conduction, convection, and radiation also exerts a direct influence on this process (Holanda, 2021; Duarte, 2020; Paula *et al*., 2019), being essential to understand the role of the building envelope in the comfort of occupants.

In this context, the thermophysical properties of the materials that make up the building envelope are fundamental, as they determine the thermal insulation capacity of the construction elements and directly influence the thermoenergetic behavior of the internal environments (Araujo, 2021; Peach *et al*., 2023; Char *et al*., 2024). Controlling this heat transfer is essential to ensure occupant comfort, as the envelope acts as a barrier against solar gains and thermal losses.

In practice, achieving thermal comfort depends on numerous variables, as each situation requires a specific approach, taking into account factors such as the local climate and the characteristics of the building (Borges *et al*., 2023a). Therefore, it is essential to consider strategies such as good thermal insulation, control of solar gains, use of thermal inertia of materials, sealing against infiltrations, and adequate ventilation (Borges *et al*., 2023b). These measures help to reduce the need for artificial HVAC systems, promoting more comfortable and energy-efficient environments.

Among the external factors that can influence the perception of thermal comfort, solar radiation stands out for promoting the increase in the internal temperature of buildings, especially in regions with hot and humid climates, such as the North region of Brazil. The incidence of sunlight on external surfaces, including roofs and facades, generates heat gain that, if not adequately controlled through appropriate construction techniques and materials, tends to raise the temperature of the internal environments, directly impacting the thermal sensation of the occupants (Silva *et al*., 2015). With regard to internal factors, the temperature of the ambient air directly influences the thermal balance of the human body, affecting the comfort and well-being of users (Lucas *et al*., 2019). In addition, the relative humidity of the air exerts a significant influence, especially in hot and humid climates, where high levels of humidity can reduce the efficiency of sweat evaporation, a natural mechanism of thermoregulation of the body, aggravating the sensation of stuffiness (Tavares, 2014; Brook *et al*., 2024). On the other hand, very low humidity levels can also cause discomfort and health problems, which makes it essential to consider them in studies and evaluations of thermal comfort in built environments (Oliveira *et al*., 2023).

Recent studies demonstrate, through numerical simulations, that improvements in the envelope materials can increase the annual hours within the range of thermal comfort in housing of the Minha Casa, Minha Vida (MCMV) program, as observed in Belém-PA (Dantas *et al*., 2024) and Campinas-SP (Vieira *et al*., 2023), reinforcing the importance of thermoenergetic evaluation in the planning of these dwellings. The purpose of this study is to evaluate the thermoenergetic performance of popular apartments delivered by the MCMV program, located in Marituba-PA, northern region of Brazil, through numerical simulations carried out with the tools *SketchUp®, OpenStudio®* and *EnergyPlus®.* The investigation focused on the analysis of the impact of the variables solar radiation, air temperature and relative humidity and their influence on the thermal comfort of indoor environments, considering the climatic conditions of the region studied.

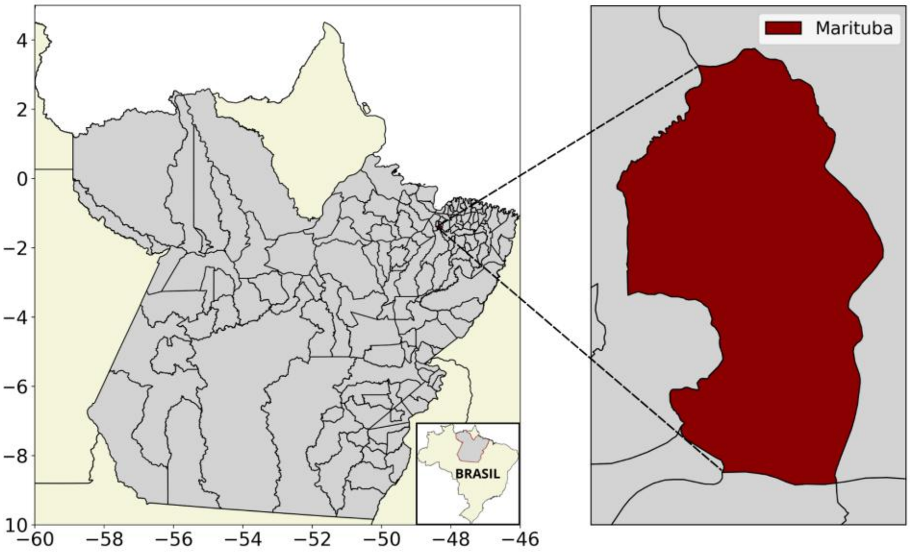
## 2 METHODOLOGY

To evaluate the thermoenergetic performance of low-income housing linked to the Minha Casa Minha Vida (MCMV) program, an approach based on computer simulations of the internal thermal conditions of the buildings throughout the year was adopted. The focus of the research was a typical housing unit of the Residencial Viver Melhor, located in the municipality of Marituba, in the state of Pará, in the northern region of Brazil. The research was divided into three main stages: (i) geometric modeling of the building; (ii) insertion of construction materials, accompanied by the attribution of relevant thermophysical properties (thermal conductivity, specific heat and specific mass), physical and climatic parameters; and (iii) execution of thermoenergetic simulations for subsequent analysis of the results based on criteria of the NBR 16401-2:2008 standard.

The local climatic conditions, especially the hourly data of air temperature, relative humidity and solar radiation, were incorporated into the simulations by means of a representative climatic file of the region, in order to represent the thermoenvironmental reality of the site under study. Figure 1 shows the geographic location of the municipality, where the apartments studied are located.

**Figure 1**

*Geographical location of the municipality of Marituba-PA*




2.1 MODELING AND PARAMETERIZATION

Figure 2 presents the floor plan of a typical MCMV apartment, located in Marituba-PA, which supported the creation of the three-dimensional model of the physical spaces in the *SketchUp® software* (Figure 3). The geometry was later exported to the *OpenStudio®*, in which the thermal zones, internal loads and other elements necessary for the simulation were defined. The simulation engine used was the *EnergyPlus®*, responsible for the calculations of heat transfer and dynamic thermal performance over the period of 1 (one) year. The climatic conditions used in the simulations were obtained from annual meteorological files (. EPW and . DDY) representative of the local climate, available in the TMY database (*Typical Meteorological Year*), which gathered climate information over 14 years (2007-2021).

**Figure 2**

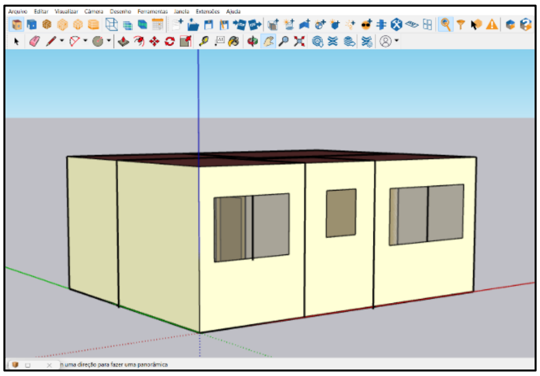
*Floor plan of a typical MCMV family housing apartment in Marituba-PA*


Source: Adapted from COHAB/PA (2017).

**Figure 3**

*Popular MCMV apartments in Marituba-PA: a) Real building1; b) Three-dimensional model in the SketchUp® interface*

a)



b)

Source: [1]PA Agency (2017).

Table 1 lists the thermophysical properties of the materials popularly used in the apartments delivered by MCMV.

**Table 1**

*Thermophysical properties of the traditional materials used in the MCMV apartments*

| Material | *h* (m) | λ (W/mK) | ρ (kg/m³) | c (J/kgK) |
|---|---|---|---|---|
| Mortar | 0,020 | 1,150 | 2000 | 1000 |
| Concrete Slab | 0,200 | 1,750 | 2400 | 1000 |
| Plaster | 0,010 | 0,700 | 1200 | 840 |
| Ordinary glass | 0,003 | 0,900 | - | - |
| Wood | 0,035 | 0,290 | 1000 | 1340 |
| Ceramic Tile | 0,020 | 0,700 | 1000 | 920 |
| Ceramic brick | 0,090 | 0,900 | 1764 | 920 |
| Acrylic texture | 0,010 | 0,400 | 1300 | 1000 |

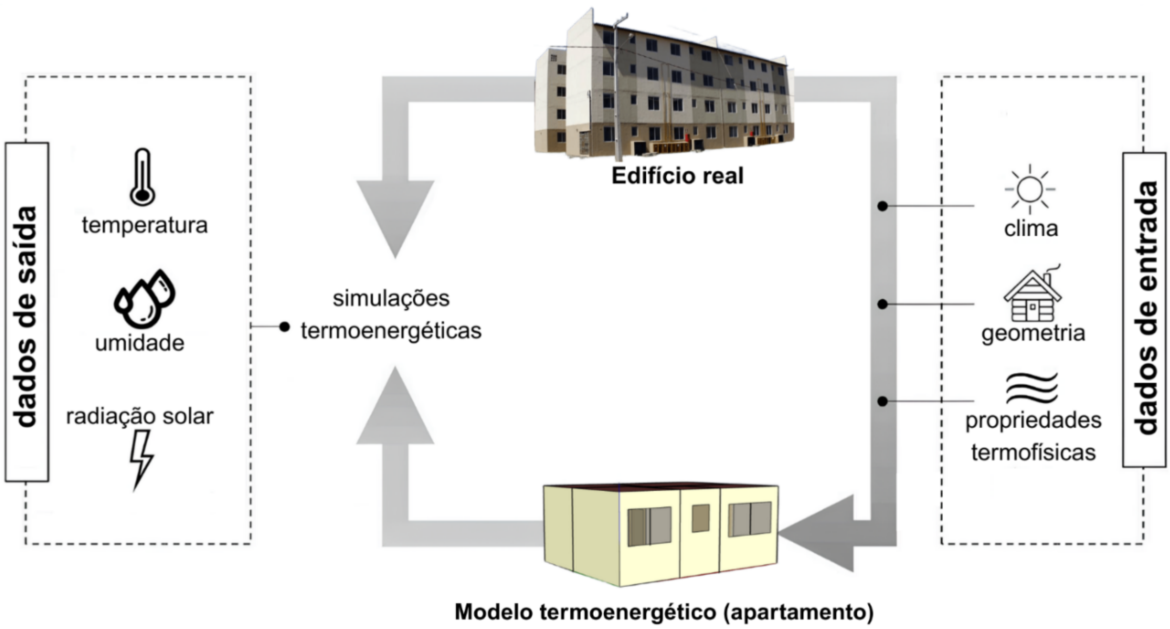
Source: ABNT (2003)

## 2.2 THERMOENERGETIC SIMULATIONS

Figure 4 shows the feeding system of the simulations carried out to obtain the selected variables (solar radiation rate, temperature, relative humidity). The results of the simulations were analyzed based on the NBR 16401-2:2008 standard, which establishes an internal temperature range considered ideal for thermal comfort: between 22.5 °C and 25.5 °C. Based on the simulated operating temperature data throughout the year, the duration of the periods in which the rooms – bathroom, kitchen/service, bedrooms and living room – remained within the limits recommended by the standard was evaluated.

**Figure 4**

*Data input and output flow in OpenStudio®*

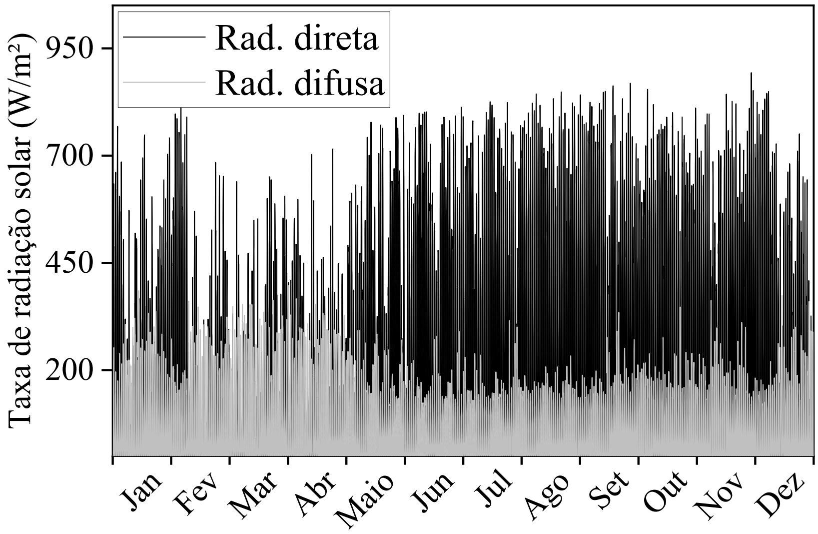


## 3 RESULTS AND DISCUSSIONS

Understanding the thermal behavior of social housing is essential when it comes to comfort and well-being, especially in regions with a hot and humid climate, such as Marituba-PA. Based on the thermoenergetic modeling of the typical housing unit of Residencial Viver Melhor, the data obtained over the course of a year demonstrate how external conditions influence the internal environment of the houses of the Minha Casa Minha Vida (MCMV) program. Figure 5 shows the variation in incident solar radiation throughout the year. It is possible to observe that, throughout the year, the levels of direct radiation exceed 700 W/m², while the diffuse radiation also remains significant. These data reflect the expressive solar thermal load present in the region, which requires greater attention to the performance of the housing envelopes.

**Figure 5**

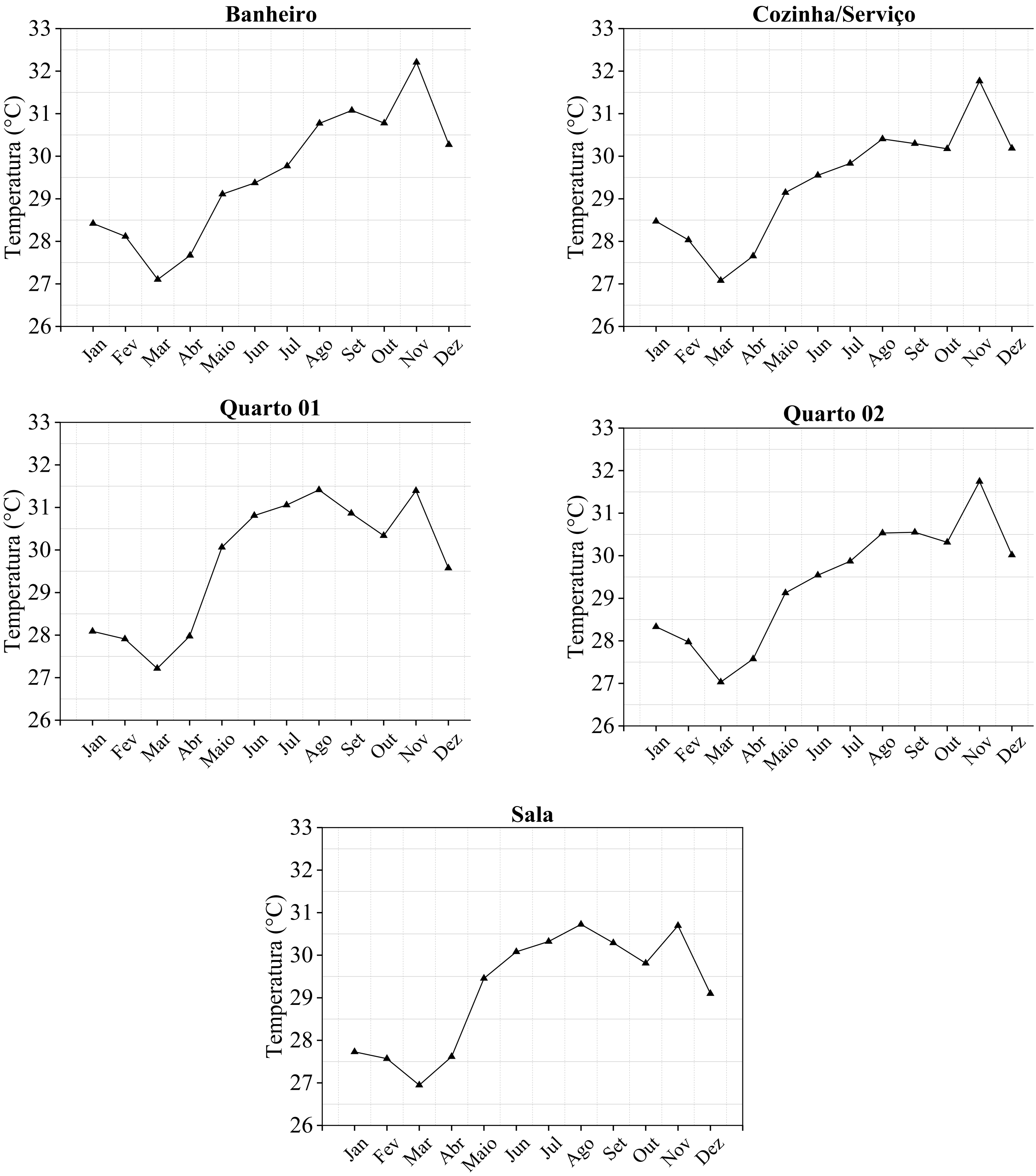
*Rate of solar radiation outside the thermal zones*




The rate of solar radiation, especially direct radiation, has an impact on the internal temperatures of the rooms, as illustrated in Figure 6. Throughout the year, the five defined thermal zones had average monthly temperatures above 26 °C, even exceeding 30 °C in the hottest periods, such as the months of August to November. The bathroom and room 01 recorded the highest peaks, which is attributed to less ventilation or greater sun exposure. Despite having presented the best relative thermal performance among the rooms evaluated, the room did not meet, for most of the year, the thermal comfort requirements established by NBR 16401-2:2008. The month of March consistently recorded the lowest temperature in the rooms, while November recorded the highest index.

**Figure 6**

*Average monthly temperature inside the thermal zones*




The relative humidity of the air varies among the different environments of the residence (Figure 7). The living room has high humidity levels, while the bathroom had the lowest levels.

**Figure 7**

*Average monthly relative humidity inside the thermal zones*

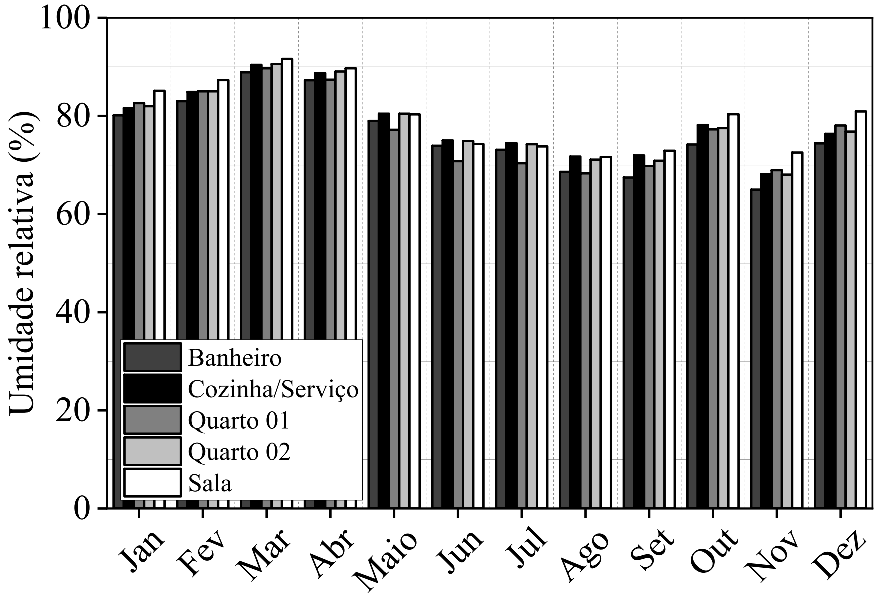
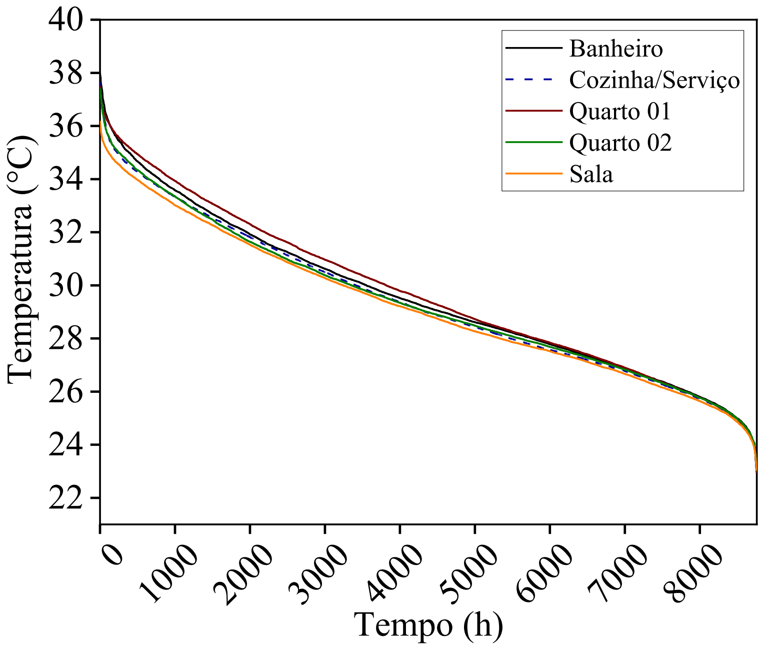



Figure 8 offers a more dynamic analysis by presenting the curves for the duration of the internal temperature in the rooms. In it, it is possible to see how environments respond to external and internal influences throughout the annual hours. The internal temperatures remain high for several consecutive hours, with little thermal dissipation, which suggests an unsatisfactory performance of the materials used in the project.

**Figure 8**

*Internal temperature duration curves in the rooms of the apartment*



Considering the criteria of the NBR 16401-2:2008 standard, which defines temperatures between 22.5 and 25.5 as ideal $^{Oc}$ The results obtained show that none of the rooms reaches significant comfort indexes. The living room was the space with the highest percentage of compliance with comfort limits (7.53% of the year), followed by the kitchen/service (6.73%), room 02 (6.51%), room 01 (6.39%) and bathroom (5.82%). These numbers reinforce the thermal limitation of the simulated building and highlight the need to review the design criteria adopted, seeking more efficient solutions.

These results confirm limitations already pointed out by previous studies conducted in single-storey houses of the same housing program, such as the one in Dantas *et al*. (2024), which proposed the replacement of traditional envelope materials, due to the high thermal discomfort and Vieira's *et al*. (2023), which demonstrated the negative influence of the increase in occupancy on the thermal performance of the units.

## 4 CONCLUSION

This research investigated the thermoenergetic performance of low-income apartments of the Brazilian Federal Government's Minha Casa, Minha Vida (MCMV) program. The analysis compared the results obtained with the parameters of the NBR 16401-2:2008 standard. It was demonstrated that the housing unit studied presents unsatisfactory thermal performance throughout the year. The use of simulation tools proved to be essential to identify problems in the design phase, opening space for interventions aimed at improving environmental comfort in future low-income housing constructions. None of the simulated indoor environments reached acceptable levels of thermal comfort during a significant fraction of the year, with emphasis on persistently high indoor temperatures and humidity variations that compromise the habitability of the dwellings in hot and humid climates.

Thus, the study contributes to direct applications in the improvement of public policies for social housing, especially in the northern region of Brazil, where climatic conditions impose greater challenges to the promotion of thermal comfort in buildings. The adoption of regional bioclimatic criteria and passive air conditioning solutions, such as effective shading, and cross ventilation emerges as a fundamental strategy to improve the performance of housing units. In addition, considering the high levels of solar radiation characteristic of the region, it is also proposed to take advantage of this resource through the installation of photovoltaic solar panels, in order to reduce the internal thermal load and promote greater energy autonomy and environmental comfort.

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