Improving Thermal Comfort in Brazilian Residence

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Abstract. Brazil has a predominantly tropical climate, with temperatures typically ranging between 24 and 25°C. However, the thermal performance standards for buildings in the country establish an ideal comfort temperature range of approximately 22°C to 24°C. To meet this standard, the use of air conditioning systems in Brazilian residences is common. There are various construction techniques that can be applied to improve the thermal performance of buildings, aiming to enhance energy efficiency. These techniques include modifications to building facades to promote better natural ventilation. Additionally, these strategies can be optimized with the use of high thermal efficiency materials, such as Phase Change Materials (PCM), which have the ability to absorb and release heat, maintaining stable temperatures.
This study aims, first and foremost, to explain the importance of architectural modifications to building facades in Brazilian constructions. Subsequently, the article proposes an evaluation of the thermal performance of a five-story residential model with the incorporation of PCM. The main objective is to identify construction strategies that provide greater thermal comfort without the need for artificial cooling systems. This is of utmost importance in creating more comfortable and sustainable indoor environments in regions with hot climates, significantly contributing to energy efficiency and the well-being of people.

Keywords. Phase Change Materials, Residential Buildings, Thermal Performance, Subtropical Climate.

1. Introduction

According to ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers), thermal comfort is defined as people's satisfaction with the temperature conditions in an environment, assessed subjectively by the user. It is estimated that human beings spend approximately 70 to 80% of their lives in enclosed spaces. Therefore, environmental comfort in these spaces can generally be controlled in two distinct ways: the first involves the use of equipment such as air conditioning systems, while the second method of control is related to the architectural strategies employed in the built environment.

One effective way to reduce the dependence on artificial cooling systems is the application of Phase Change Materials (PCMs). Due to their high latent heat, these materials can store or release large amounts of heat during temperature variations, helping to regulate indoor air temperature passively and sustainably. As temperatures rise, these materials absorb heat as they change from a solid to a liquid state, keeping the environment cooler. When temperatures drop, heat is released during solidification, contributing to maintaining a stable and comfortable indoor temperature.

Thus, the incorporation of Phase Change Materials represents an intelligent and eco-friendly strategy for improving thermal comfort in buildings, reducing the demand for artificial cooling systems, and promoting a more sustainable approach to thermal management in enclosed spaces.

2. Thermal Comfort in Architecture: Main Strategies

2.1 Benefits Generated by Thermal Comfort

Thermal comfort is essential for people's well-being and productivity, influencing various aspects of their lives. Reducing heat in an environment is crucial and is achieved through a balance between indoor and outdoor temperatures, taking into account the local climate during construction. During intense heat, productivity decreases, leading to stress and fatigue, affecting performance at work, especially in corporate environments.Maintaining emotional balance is fundamental for psychological well-being.

Performing tasks that require concentration in excessively hot or cold environments can negatively impact one's emotional state.In summary, thermal comfort is critical for productivity and emotional well-being. Investing in solutions to improve thermal comfort is essential to create more pleasant and functional spaces.

2.2 Solar impact on home comfort

The NBR 15520, known as "Thermal Performance of Buildings," plays an essential role in the quest to improve thermal comfort in our constructions. One of the fundamental aspects to consider is solar orientation and solar gain.

Correct solar orientation plays a vital role in energy efficiency and the thermal comfort of buildings. During certain times of the year, especially in regions of the southern hemisphere, north-facing facades tend to receive more direct sunlight, absorbing heat. On the other hand, south-facing facades receive less direct sunlight and, therefore, absorb less heat. This consideration is crucial in architectural planning as it influences the choice of cladding materials, the use of glass, and the creation of shaded areas.

Furthermore, the strategic adoption of openings in facades or roofs plays a fundamental role in the thermal comfort of buildings. These openings not only capture sunlight to provide natural lighting, saving electrical energy but also facilitate natural ventilation, allowing air circulation. This further contributes to maintaining a comfortable indoor environment, reducing the need for air conditioning systems.

3. NBR 15575-2021 - Thermal Performance

The ABNT NBR 15575 standard describes criteria for assessing the efficiency of PCM applicability.

1st: The thermal performance should be assessed to meet the minimum level; both the real and reference models should be simulated considering only natural ventilation.

2nd: The considered operative temperature range varies with the local climate, with three possible intervals: from 18°C to 26°C, up to 28°C, and up to 30°C. The article considered interval 1.

3rd: The values of PHFTAPP, TomáxAPP, and TomínAPP for each room area should be considered, and PHFTUH, TomáxUH, and TomínUH of the UH determined.

The computational simulation procedure allows for the evaluation of three levels of thermal performance: minimum (M), intermediate (I), and superior (S). Minimum, which assesses the PHFTUH and the maximum annual operative temperature (TomáxUH) of the real model in relation to the reference model.

- Intermediate, which evaluates the real model in meeting the minimum level criteria as well as the increase in PHFTUH and the reduction in the total thermal load (CgTTUH) of the real model compared to the reference model.

- Superior, which evaluates the real model in meeting the minimum level criteria as well as the increase in PHFTUH and the reduction in the total thermal load (CgTTUH) of the real model compared to the reference model. Compared to the intermediate level, meeting the superior level stands out in achieving higher reductions in the total thermal load (CgTTUH).

For all performance levels (minimum, intermediate, or superior), in all bioclimatic zones, the maximum annual operative temperature of the real model must be less than or equal to the one obtained for the reference model, after adding a tolerance value (ΔTomáx), as per the equation:

$$Tomáxreal \leq Tomáx + \Delta Tomáx$$

Where:

Tomáx UH,real is the maximum annual operative temperature of the UH in the real model, expressed in degrees Celsius (°C).

TomáxUH,ref is the maximum annual operative temperature of the UH in the reference model, expressed in degrees Celsius (°C).

ΔTomáx is the tolerance value for the maximum annual operative temperature, expressed in degrees Celsius (°C).

Abbreviations:

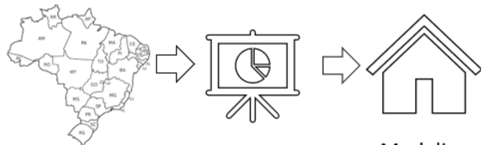
PHTAPP(%) - Percentage of Hours of Temperature

ΔTomáx - Maximum annual operative temperature tolerance value.

ΔTomín - Minimum annual operative temperature tolerance value.

4. Methodology

Fig. 1 - Methodology flow



The Figure 1 illustrates the flowchart that describes the sequence of the methodology used to evaluate the efficiency of PCM in the construction of a 5-story building with 4 apartments on each floor. Initially, the article addresses the geographical description of the city of Curitiba, in the state of Paraná. Next, it details the methodology employed to assess the PCM's performance. Finally, the methodology also provides a brief description of the architectural modeling carried out using the SketchUp software and the thermal simulator EnergyPlus.

4.1 City Climate Classification

The city chosen for this study is Curitiba, located in the state of Paraná. This choice is due to the fact that the region has a typically subtropical climate. One of the most distinctive characteristics of this type of climate is the regular distribution of rainfall throughout the year and temperature stability between seasons.

4.2 Methodology

The methodology included the following:

Literature Review: Mendeley and Microsoft Excel were used to manage references and select relevant literature.

Project Preparation: In AutoCAD, the dimensions of the original project were adjusted for energy modeling, as the initial dimensions were not available.

Energy Modeling: SketchUp Make, OpenStudio, and AutoCAD were used to create energy models.

Initial Simulations: Simulations were performed in EnergyPlus without the presence of PCM using the defined models and climate data from INMET.

Preliminary Analysis: The results were processed in Microsoft Excel to evaluate thermal performance.

Simulations with PCM: Simulations were repeated considering the presence of PCM in the models.

Comfort Temperature Range Calculation: The comfort temperature range was calculated in Microsoft Excel.

Statistical Analysis: Comparison of results with and without PCM using statistical tools in Rstudio.

4.3 Architectural modeling

Fig 2 – Architectural modeling in SketchUp

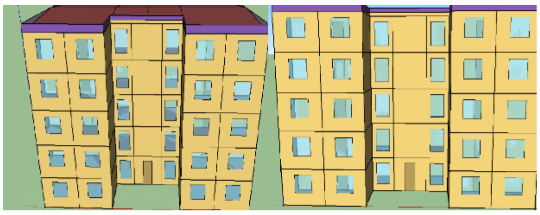


Figure 2 depicts the architectural modeling of a 5-story building with 4 apartments on each floor, created using the SketchUp software. Subsequently, the EnergyPlus software was employed to simulate this project, generating a thermal data report that analyzes temperature variations over the course of hours throughout the year. This simulation was conducted in accordance with the guidelines of the NBR 15575-1 standard - Residential Buildings — Performance. Interval 1 was selected in accordance with this standard, as the temperature in this range varies from 18°C to 26°C, while the average temperature in Curitiba was 23°C.

5. Project description

The thermal performance of dwellings depends on factors such as wall and roof components, window and ventilation area, internal loads, and the local climate. ABNT NBR 15575 standard addresses the thermal performance of residential buildings, whether they have artificial conditioning systems or not, setting minimum requirements. The assessment involves comparing geometric characteristics and thermal properties with reference values. It includes laboratory measurements and simulations using representative climatic data. The models consider various spaces, including permanent and transient ones. Natural ventilation is modeled based on temperature criteria, while models without it use efficient thermal load systems. Solar radiation absorptance degradation is assessed in various ways, including product evaluations and aging tests.

5.1 Results

In the simulation, an analysis was conducted on which rooms, according to the time range, comply with the temperature variations during occupancy. From this analysis, a comparison table was created for ToAPPa (the number of hours the APP is occupied throughout the year, equivalent to 2,920 hours for living rooms and 3,650 hours for bedrooms) in relation to NhFT (the number of hours the APP is occupied and within the operative temperature range).

Table 1 – Presentation of the result

Reference model			Real Model	
UH A			UH A	
Criteria /APP	Room 1	Room 2	Room 1	Room 2
PHTAPP(%)	79.0	81.0	32.5	80.0
T0máxAPP(ºC)	26.1	26.3	16.8	13.9
T0minAPP(º C)	13.9	14.2	37.7	29.3
Reference model			Real Model	
UH B			UH B	
Criteria /APP	Room 1	Room 2	Room 1	Room 2
PHTAPP(%)	74.0	78.2	37.5	76.0
T0máxAPP(ºC)	26.1	26.3	16.2	13.7
T0minAPP(º C)	13.7	14.1	37.7	29.4
Reference model			Real Model	
UH C			UH C	
Criteria /APP	Room 1	Room 2	Room 1	Room 2
PHTAPP(%)	74.4	78.3	36.6	76.2
T0máxAPP(ºC)	26.2	26.4	16.3	13.8
T0minAPP(º C)	13.8	14.2	36.5	29.3
Reference model			Real Model	
D			UH C	
Criteria /APP	Room 1	Room 2	Room 1	Room 2
PHTAPP(%)	79.2	81.4	31.8	80.2
T0máxAPP(ºC)	26.2	26.5	16.8	14.0
T0minAPP(º C)	14.0	14.5	38.0	29.2

Table 1 presents the thermal performance analysis of the habitable area of the apartments distributed across 5 floors, with 4 rooms per floor. The evaluation was conducted according to the criteria established by ABNT NBR 15575, considering spaces with and without the application of PCM. The assessed criteria include PHTAPP(%), TomáxAPP(ºC), and TominAPP(ºC). Most rooms showed a reduction in internal temperature when compared to the thermal model without the application of PCM.

Most of the rooms in the architectural modeling met the minimum thermal performance criteria proposed by the Brazilian performance standard when evaluating the criteria for long-term occupancy areas (APP) and transient occupancy areas (APT).

6. Conclusion

The use of PCM has proven to be effective in reducing the temperature in most of the apartment rooms in Curitiba, Paraná, contributing to a decrease in indoor temperature throughout all seasons of the year. Additionally, architectural techniques such as proper solar orientation, natural ventilation, thermal insulation, high thermal inertia materials, green roofs, shading, high-performance windows, and bioclimatic architecture adapted to the local climate also play significant roles in improving the thermal comfort of buildings. The choice between these techniques depends on climatic conditions, budget, and project objectives. Collectively, these approaches offer significant potential for creating more comfortable and sustainable indoor environments, improving energy efficiency, and enhancing the quality of life for residents. However, it is important to note that, despite the substantial benefits demonstrated by PCMs, Brazil has not fully embraced their use in residential properties. This is partly due to the lack of awareness among consumers about these materials and the limited availability of options in the market. Therefore, this article aims to encourage further in-depth studies on PCMs and promote their adoption in residential projects, highlighting their benefits and positive impacts on thermal comfort and energy efficiency in buildings.

7. References

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