ANALYSIS OF THERMO-ENERGY PERFORMANCE IN ARTIFICIALLY CONDITIONED BEDROOMS FROM SOCIAL HOUSING BUILDINGS IN BRAZIL

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ABSTRACT

Brazil, with a territorial extension of approximately 8.5 million km² and diverse climatic conditions, is distributed into eight bioclimatic zones. This study examined the impact of thermal insulation on the envelope of a single-family social housing unit located in bioclimatic zones 3 and 8 in Brazil. Various envelope solutions that incorporate thermal insulation were evaluated to assess the effect on the nighttime energy performance of artificially conditioned bedrooms. The analyses were conducted through computer simulations using EnergyPlus 8.1 software on a housing unit model with two bedrooms, comparing strategies for thermal insulation placement on walls and roofs across four Brazilian cities: Florianópolis, São Paulo, Rio de Janeiro and Natal. The parameters evaluated in the simulations were: types of walls; types of roofs; types of windows; orientation; use of insulation in the envelope; and with or without daytime natural ventilation. The findings indicated that optimal thermal-energy performance is achieved when thermal insulation was applied solely to the internal part of the envelope walls. Furthermore, the analysis conducted in the four cities demonstrated that the building's thermal performance was compromised in the absence of daytime ventilation, even with the presence of thermal insulation. This result emphasized the importance of implementing mechanisms that promote daytime ventilation, such as pivoting windows or ventilated shutters. This study presented important strategies to enhance energy efficiency in artificially conditioned bedrooms, which can be adopted during the design phase of new social housings.

Keywords: *computer simulation; thermal performance; thermal insulation, social housing buildings.*

I. INTRODUCTION

Architecture plays a fundamental role in constructing physical spaces, influencing both urban landscapes and enhancing users' quality of life. Achieving higher energy efficiency levels requires effective design strategies and collaboration among construction sector professionals. Recently, energy consumption has surged due to global population growth, economic advancement in developing countries, and an increased demand for improved environmental comfort. Lamberts, Dutra, and Pereira [1] point out that integrating energy efficiency and environmental comfort principles in engineering and architectural projects can significantly reduce energy consumption.

Brazil, predominantly powered by a clean energy matrix, derived 61.9% of its domestic electricity from hydroelectric sources in 2023 [2]. However, this scenario is shifting rapidly. The Ministry of Mines and Energy [3] estimate that by 2030, Brazil's electricity consumption will double from 2023 levels, indicating a growing reliance on non-renewable sources.

The energy crisis of 2001 marked a turning point, prompting Brazil to adopt a new attitude towards energy consumption and creating rationalization measures. Law 10.295 [4] - the "Energy Efficiency Law" - among other results, established minimum energy efficiency standards for buildings, leading to the publication of: Technical Quality Regulation for the Energy Efficiency Level of Residential Buildings, RTQ-R [5]. The aim of the regulations is to determine assessment and classification methods for buildings' energy efficiency.

According to the National Energy Balance [2], residential buildings account for 50.9% of Brazil's electricity consumption, with 26.6% attributed to the residential sector, 16.6% to commercial buildings, and 7.6% to public buildings. Increased ownership of air conditioning equipment in the residential sector rose 9.0% between 2005 and 2017. This increase was due to new equipment sales in the period from 2010 to 2015 [6].

Tubelo et al. [7] conducted energy performance simulations for social housing in cities across Brazil's South and Southeast, demonstrating the effectiveness of thermal insulation and reduced air infiltration, though high costs of implementation make the proposed strategies unfeasible. Mourão [8] studied air conditioning performance in a social housing development in Rio de Janeiro using computer simulation. The work highlights the best low-cost and low-intervention strategies, such as painting, shading, glass thickness and window shutter installation. Ozarisoy et al. [9] examined energy optimization in warm and temperate climates, proposing strategies that include thermal insulation in the seals, high thermal inertia, LED lighting and double glazing in the openings. These studies underscore the climate's influence and importance as well as how design definitions impact building performance and energy consumption.

This study aims to analyze the effect of thermal insulation on the night-time energy performance of artificially conditioned bedrooms in cities within bioclimatic zones 3 and 8 [10]. The focus is on envelope solutions for single-family social housing to enhance building component efficiency and create thermally suitable environments in air conditioned bedrooms.

This paper is structured into four sections. The Introduction provides context for the research problem and its significance, also delineates the research objectives. The Methodological Procedures section details the processes used to evaluate the impact of envelope design strategies on energy consumption in artificially conditioned residential units. The Results section presents the energy performance findings for each analyzed city under different insulation conditions, including graphs and detailed analyses. Finally, the Conclusions summarize the principal outcomes, practical implications, recommendations, and suggest directions for future research.

II. METHODOLOGICAL PROCEDURES

This section describes all methodological procedures and programs used to evaluate the impact on the energy consumption of an artificial air conditioning system when adopting envelope design strategies for a housing unit (HU). The analyses were carried out using parametric computer simulations on a base HU model with the following steps:

a) Define the study object (model) of a single-family dwelling and the reference thermal zone for a bedroom;

b) Identify the most representative construction characteristics of the envelope, reflecting typical Brazilian civil construction and determine the strategies to be implemented;

c) Carry out simulations with EnergyPlus 8.1 software [11] using the input data from the computer simulation method for evaluating the envelope according to RTQ-R;

d) Apply parameter variations to improve the building's energy performance and analyze the impact on the results.

2.1 Definition of the model

To mitigate the housing deficit problem in Brazil, the government implemented the "My House, My Life" program, offering standardized low-cost social housing, with similar typologies being built throughout different regions. The building typology (Figure 1) evaluated in this work represents a single-family unit from a standardized social housing project developed by Caixa Econômica Federal [12]. The building consists of a single floor in direct contact with the ground, featuring a ceiling height of 2.60m. The functional layout includes a kitchen, a bathroom and three long-term living spaces: a living room and two bedrooms. The opening of the bedroom is facing west.

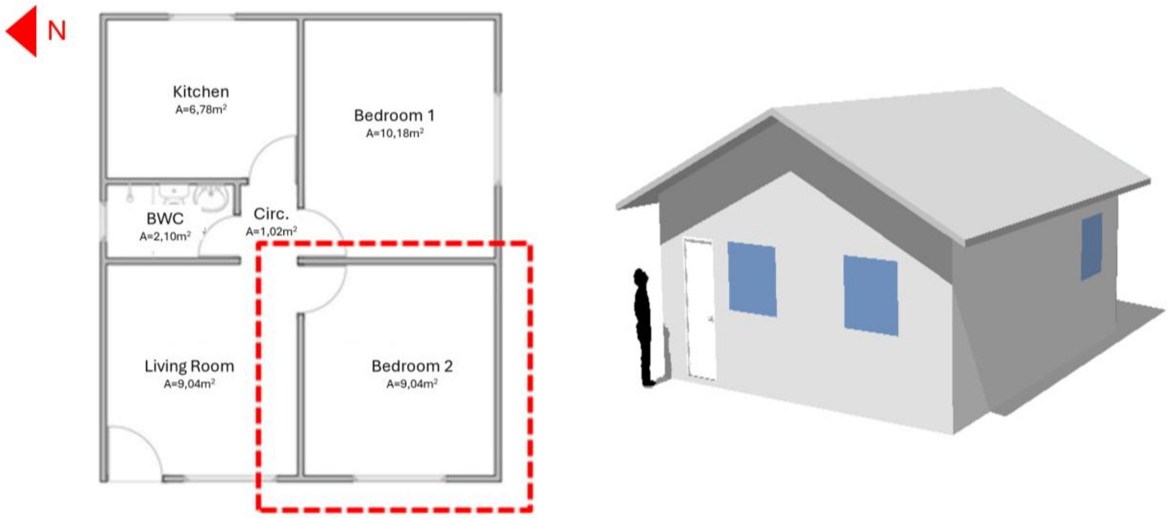

Figure 1. Floor plan and electronic model of the single-family building. Source: adapted [12].

2.2 Envelope properties

In Brazilian residential buildings, opaque enclosures such as masonry block walls, concrete block walls and solid concrete walls are commonly used. For this study, the construction consisted of concrete block walls and a roof with PVC lining, wooden structure, and ceramic tiles. The detailed configurations of the primary construction components, along with the thermal properties of the materials used in the walls, are presented in Table 1 and Table 2 below.

Table 1**.** Properties of building components - Wall and roof materials.

Construction component	**Material**	**Thickness [cm]**	**Heat transmittance [W/m²K]**	**Heat capacity [kJ/m²K]**
Concrete block wall	Plaster	2.50		
	Concrete block	19.00	2.69	272
	Plaster	2.50		
Ceramic tile roof with PVC lining	PVC lining	1.00	1.71	21
	Air chamber	> 5.00		
	Ceramic tile	.1.00		
	Air chamber	> 5.00		
	Ceramic tile	.1.00		

Table 2. Thermal insulation properties.

Property /Material	Expanded polystyrene
Conductivity [W/m.K]	0.04
Density[kg/m³]	25
Specific heat [J/kg.K]	1,420
Emittance	0.90
Solar absorptance	0.30

2.3 Analysis of the data obtained - Energy consumption

For each simulated case, a report containing the annual energy consumption of the air conditioning system (kWh and/or MWh) was requested, along with the total consumption for both heating and cooling loads. The consumption results for air conditioning served as the basis for the analysis of the influence of parameter variation on the model’s energy behavior.

2.4 Analysis of Social and Environmental Aspects

Social and environmental impacts are important aspects to consider when adopting thermal insulation strategies in housing projects. The assessment of social impacts consists of evaluating an action on the anthropic environment, such as people, the population, and the surrounding community. The central concern of social impact assessment is not just the identification or mitigation of negative effects, but the commitment to development and improving quality of life. Environmental impacts are generally related to the conservation of natural resources and the protection of the local environment.

III. Results

3.1 Energy performance – use of insulation

This section presents the energy performance results for each analyzed city, -under different conditions: (a) without insulation in walls and roofs, (b) with wall insulation, (c) with roof insulation, and (d) with insulation in both walls and roofs. The fixed and variable parameters used for the simulations are detailed in Table 3.

Table 3. Parameters used for simulation.

Fixed parameters		**Variable parameters**	
Fixed parameters	Concrete block	Use of insulation	Without insulation With wall insulation With roof insulation With insulation in walls and roof
Wall Type	Ceramic tile roof, wooden structure, and PVC lining	Location	Florianópolis São Paulo Natal Rio de Janeiro
Type of windows	Single glass without blinds	Daytime ventilation	Without daytime ventilation With daytime ventilation
Orientation	Orientation 1 West-facing bedroom window		Note: To analyze the thermal insulation positioning, the building with daytime ventilation was adopted

In the city of Florianópolis (Figure 2a), the improvement in energy performance occurred when insulation was used on the internal side of the walls, resulting in a reduction of 4.4% (0.72 kWh/m².year). However, when insulation was used on the internal side of the roof, a slight increase in consumption was detected. There is no significant difference when reversing the thermal insulation positions within the components. When the openings of the housing unit were kept closed during the day, energy performance was adversely affected. The most significant reduction in electricity consumption occurred when daytime ventilation was allowed, and no insulation was used—a reduction of 13.6% (2.61 kWh/m².year). The reduction was 11.2% with wall insulation, 12.6% with roof insulation, and 12.0% when insulation was applied to both the walls and roof.

In Florianópolis (Figure 2a), the use of wall insulation on the internal side results in a 4.4% improvement in energy performance (0.72 kWh/m².year). Using roof insulation on the internal side slightly increased energy consumption. The insulation position within the components did not significantly alter the outcomes. When the housing unit's openings were kept closed during the day, energy performance was negatively impacted. The most substantial reduction in electricity consumption—13.6% (2.61 kWh/m².year)—occurred when daytime ventilation was allowed, with no insulation applied. When wall insulation was used, the reduction was 11.2%, for roof insulation, it was 12.6%, and with both wall and roof insulation, the reduction was 12.0%.

In São Paulo (Figure 2b), there was an improvement in energy performance when insulation was used on the internal side of the walls, with a reduction of 4.6% (0.38 kWh/m².year). When insulation was used on the internal side of the roof, a slight increase in consumption was observed. There was no significant difference when reversing the insulation positions within the components. When the openings of the housing unit were kept closed during the day, energy performance was adversely affected. The most significant reduction in electricity consumption occurred when daytime ventilation was allowed, and insulation was used on both the walls and roof—a reduction of 23.3% (2.63 kWh/m².year). The reduction was 21.4% with wall insulation, 20.1% with roof insulation, and 18% when no thermal insulation was applied to the walls and roof.

In Natal (Figure 3a), the improvement in energy performance occurred when insulation was used on the internal side of the walls, resulting in a reduction of 6.0% (0.38 kWh/m².year), followed by a reduction of 5.9% when insulation was applied to both the walls and roof on the internal side of the components. There was no significant difference when reversing the thermal insulation positions within the roof component. When the openings of the housing unit were kept closed during the day, energy performance was adversely affected. The most significant reduction in electricity consumption occurred when daytime ventilation was allowed and insulation was applied to the roof, with a reduction of 6.1% (4.69 kWh/m².year). When thermal insulation was applied to the walls, the reduction was 1.7%. With insulation applied to both the walls and roof, the reduction was 1.9%, and 3.4% when no insulation was used.

In Rio de Janeiro (Figure 3b), there was an improvement in energy performance when thermal insulation was used on the internal side of the walls, with a reduction of 6.0% (2.92 kWh/m².year), followed by a reduction of 5.4% when thermal insulation was applied to both the walls and roof on the internal side of the components. When insulation was used in the internal side of the roof, a slight increase in consumption was observed. When the openings of the housing unit were kept closed during the day, energy performance was also adversely affected. The most significant reduction in electricity consumption occurred when daytime ventilation was allowed and thermal roof insulation was implemented, with a reduction of 9.5% (5.11 kWh/m².year). The reduction was 6.1% with wall insulation, 5.3% with both wall and roof insulation, and 7.6% when no insulation was used.

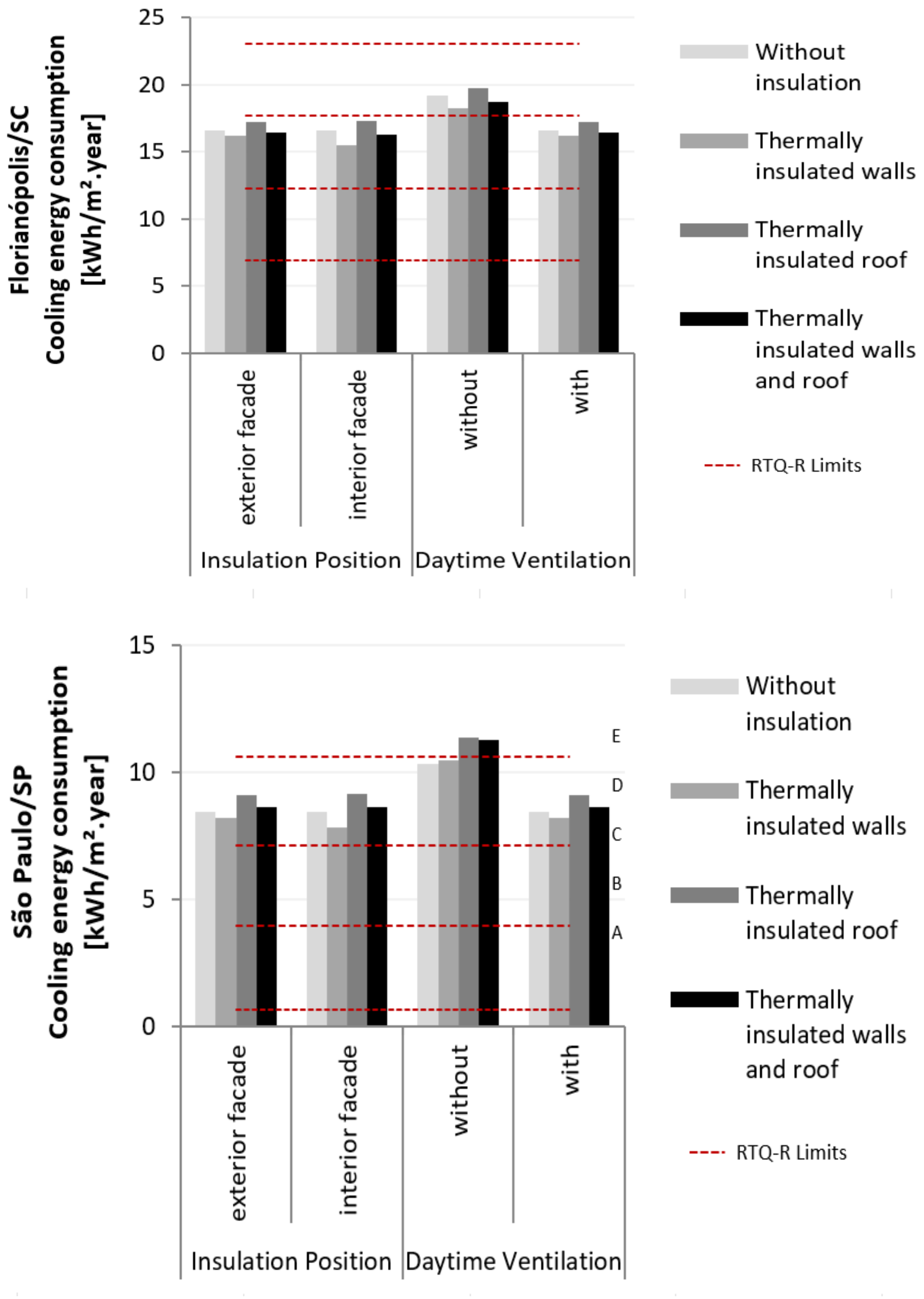

Figure 2. Consumption for cooling - (a) Florianópolis/SC and (b) São Paulo, bioclimatic zone 3.

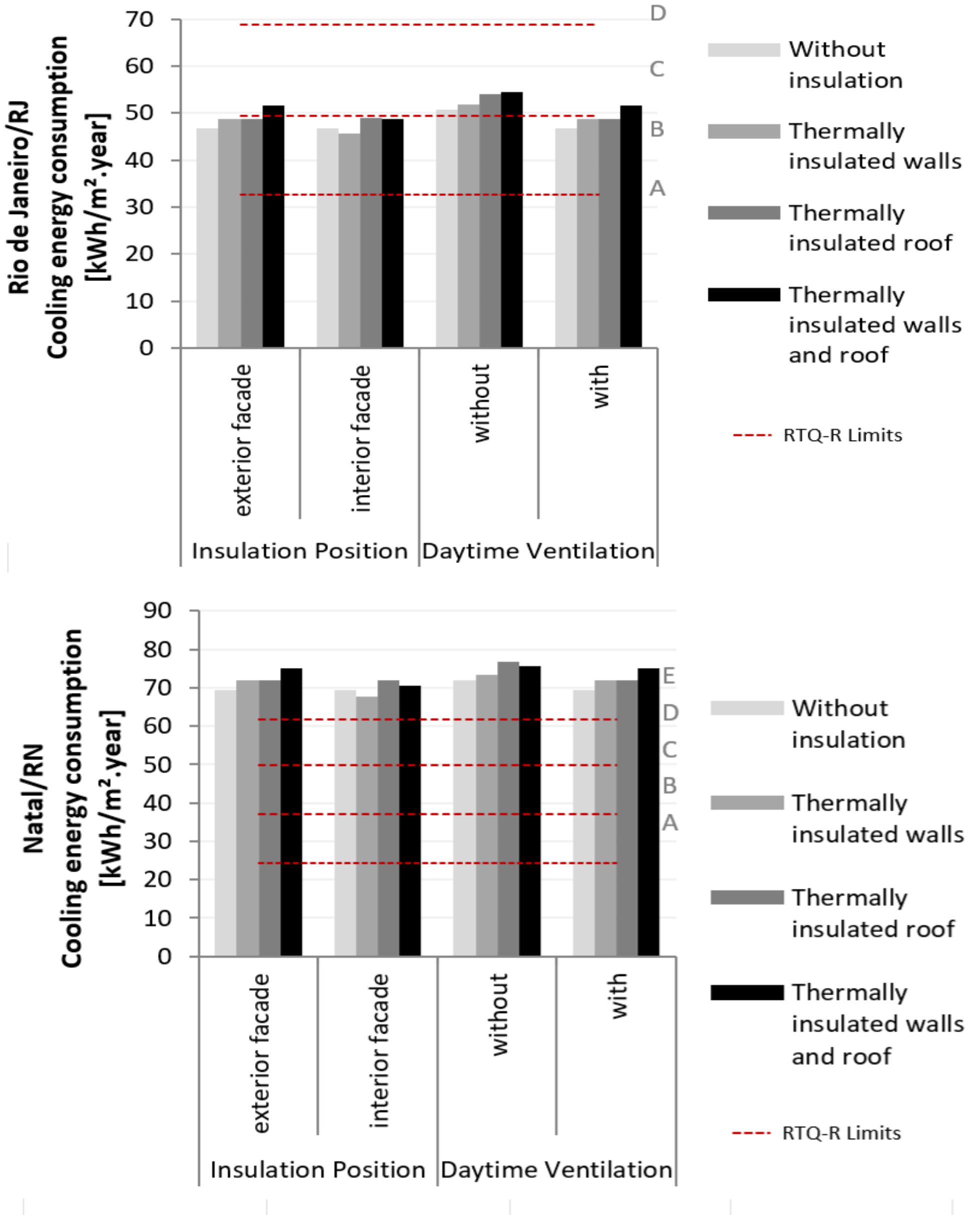

Figure 3. Consumption for cooling - (a) Natal/RN and (b) Rio de Janeiro/RJ, bioclimatic zone 8.

The analysis conducted in the four cities demonstrated that, even with the presence of thermal insulation, the building's thermal performance was compromised in the absence of daytime ventilation. This result emphasizes the importance of implementing mechanisms that promote daytime ventilation, such as pivoting windows or ventilated shutters. The adoption of these strategies allows for air circulation even when residential spaces are unoccupied.

3.2. Social and Environmental Aspects

One of the main social impacts identified in this study is the enhancement of thermal comfort as perceived by the occupants, which directly relates to their quality of life and well-being. Additionally, there was a notable decrease in electricity consumption, leading to lower utility bills, thus providing financial benefits that also qualify as social impacts. From an environmental standpoint, the improvements in energy efficiency contribute to reducing carbon emissions associated with electricity generation, thereby mitigating climate change, and preventing energy crises (blackouts), which result in significant financial losses.

IV. Conclusions

This paper analyzed the effect of thermal insulation on night-time energy performance in artificially conditioned bedrooms in cities located in bioclimatic zones 3 and 8. Based on the results, the best thermal-energy performance, due to the use of thermal insulation, occurred when it was applied only to the internal side of the walls. When insulation was used on the roof within the proposed construction system, there was an increase in cooling consumption, as it did not allow the dissipation of internal heat accumulated throughout the night.

The study presented the impact of using thermal insulation in walls and roofs on the building's thermal performance. Through computational simulation of building envelope strategies for residential structures, the optimal typology that minimized heat gain within spaces was identified. This led to improved thermal comfort for users and reduced electricity consumption in artificially conditioned bedrooms.

Another factor to consider is the environmental comfort indicators associated with the design strategies of this study, such as the relationship between the use of thermal insulation and external noise levels, in addition to ensuring that constant daytime ventilation provides better air quality within the residence. It is evident that understanding the social and environmental impacts of adopting strategies for energy performance in housing needs to be expanded. Further research is needed to promote thermal insulation in residential buildings, investigating how socio-environmental aspects can influence the design, development, and operation of projects.

For future work, it is suggested to study other design strategies, such as different usage patterns, with higher internal loads, a greater number of occupants, and more equipment. It is also recommended to analyze the impact of different thermal insulation materials, applying these studies in other climates, and conducting a long-term analysis of the building's performance after the implementation of the measures. Based on these studies, improved strategies can be developed for the design phase of new social housing projects to enhance energy efficiency.

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