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AMBIENTE CONSTRUÍDO E USUÁRIO: PERSPECTIVAS LATINO-AMERICANAS

Análise do Impacto de Estratégias Bioclimáticas no Desempenho e Conforto Térmico em Habitações Sociais em Clima Quente e Úmido

Análisis del Impacto de Estrategias Bioclimáticas en el Desempeño y Confort Térmico en Viviendas Sociales en Climas Cálidos y Húmedos

Analysis of the Impact of Bioclimatic Strategies on Thermal Performance and Comfort in Social Housing in Hot and Humid Climates

Conforto Térmico / *Confort Térmico* / *Thermal Comfort*

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Resumo

O conforto térmico em Habitações de Interesse Social (HIS) em climas quentes e úmidos é um desafio. Este artigo objetiva analisar o impacto de estratégias bioclimáticas no desempenho e conforto térmico de HIS em Belém-Pará, conforme NBR 15575. Utilizou-se simulações computacionais para comparar um modelo base com modelos incorporando ventilação natural, sombreamento, cores da envoltória, isolamento da cobertura e componentes de baixa capacidade térmica, avaliando PHFT e Tomáx (NBR 15575/16401-2). Os resultados indicaram melhoria substancial, como o aumento de 37% no PHFT da HU da cobertura. Conclui-se que estratégias bioclimáticas bem planejadas são cruciais para otimizar o conforto em HIS. O estudo contribui ao quantificar benefícios, subsidiando projetos mais sustentáveis e reforçando a aplicação integrada de normativas.

Palavras-chave: Conforto térmico. Eficiência Energética. Metamodelo.

Resumen

El confort térmico en Viviendas de Interés Social (VIS) ubicadas en climas cálidos y húmedos representa un desafío importante. Este artículo tiene como objetivo analizar el impacto de estrategias bioclimáticas en el desempeño y confort térmico de VIS en Belém, Pará, conforme a la norma NBR 15575. Se realizaron simulaciones computacionales para comparar un modelo base con otros que incorporan ventilación natural, sombreamiento, colores de la envolvente, aislamiento de la cubierta y componentes de baja capacidad térmica, evaluando PHFT y Tomáx (NBR 15575/16401-2). Los resultados indicaron mejoras significativas, como un aumento del 37% en el PHFT de la unidad habitacional ubicada en la cubierta. Se concluye que las estrategias bioclimáticas bien planificadas son fundamentales para optimizar el confort en las VIS. El estudio contribuye al cuantificar beneficios, apoyando proyectos más sostenibles y reforzando la aplicación integrada de las normativas.

Palabras clave: Confort Térmico. Eficiencia Energética. Metamodelo.

Abstract

Thermal comfort in Social Housing (SH) located in hot and humid climates presents a significant challenge. This article aims to analyze the impact of bioclimatic strategies on the thermal performance and comfort of SH in Belém, Pará, according to the NBR 15575 standard. Computational simulations were used to compare a base model with others incorporating natural ventilation, shading, envelope colors, roof insulation, and components with low thermal capacity, evaluating PHFT and Tomáx (NBR 15575/16401-2). The results indicated substantial improvements, such as a 37% increase in PHFT for the top-floor unit. It is concluded that well-planned bioclimatic strategies are crucial to optimizing comfort in SH. The study contributes by quantifying the benefits, supporting more sustainable designs, and reinforcing the integrated application of standards.

Keywords: Thermal Comfort. Energy Efficiency. Metamodel.

Introduction

Climate change and urban growth pose significant challenges to the housing sector, particularly in hot and humid regions such as Belém, Pará, located in Bioclimatic Zone 6A (NBR 15220, 2023). With annual average temperatures of 27°C and high humidity, social housing developments (*Habitações de Interesse Social – HIS*) often suffer from poor passive thermal performance, resulting in high energy consumption or thermal discomfort for low-income populations (KRELLING et al., 2023). Bioclimatic strategies such as cross ventilation, effective shading, and the use of low thermal conductivity materials are viable solutions for improving thermal performance (GIVONI, 1998; ROAF; FUENTES; THOMAS, 2003). Despite advancements in building regulations (ABNT NBR 15575, 2021; BRASIL, 2022), there remains a gap in the literature regarding the quantitative evaluation of such strategies in HIS under humid climates, particularly in relation to their cost-benefit ratio and compliance with current standards (DE VECCHI; CANDIDO; LAMBERTS, 2022).

This study aims to analyze the impact of bioclimatic strategies on the thermal performance and environmental comfort of HIS in Belém, Pará, by comparing a conventional model with an optimized one. The analysis will employ indicators such as the Percentage of Hours within the Operative Temperature Range (PHFT) and the Annual Maximum Operative Temperature (Tomáx), using tools such as the CBE Thermal Comfort Tool. The results will also be cross-referenced with the criteria of ABNT NBR 16401-2 (2021) and the INI-R (BRASIL, 2022) for energy efficiency, in order to identify synergies and contradictions between thermal comfort and energy performance. The methodology includes computational simulations using the PBE Edifica Metamodel and the analysis of actual climate data, applied to a case study of HIS in Belém. The results indicate that the combination of thermal insulation, natural ventilation, and low solar absorptance can reduce thermal discomfort hours by up to 59% (PHFT > 98%), even under extreme external temperatures of up to 33.76°C.

Methodology

This study adopts an integrated methodological approach, comprising digital modeling, computational simulation, and regulatory analysis, with the aim of evaluating the impact of bioclimatic strategies on the thermal performance of social housing (*Habitações de Interesse Social – HIS*) in the Amazonian context.

The initial stage involved defining design parameters based on the guidelines of NBR 15575 (ABNT, 2021) (thermal performance of residential buildings) and NBR 16401 (ABNT, 2021) (thermal comfort parameters for natural ventilation), as well as the criteria established by the INI-R (Residential Labeling Regulatory Instrument). Two representative models were developed: a reference model, based on conventional construction configurations, and an alternative model, incorporating bioclimatic strategies such as passive shading, cross ventilation, use of high thermal mass materials, and improvements to envelope components.

To assess thermal performance, the metamodel of the Brazilian Building Energy Labeling Program (PBE Edifica) was used, which allows the estimation of the Percentage of Hours within the Operative Temperature Range (PHFT), as well as the identification of high or low operative temperatures ($To_{máx/mín}$), under natural ventilation conditions. The data were then analyzed using the CBE Thermal Comfort Tool, enabling the validation of unit performance under different comfort limits. This approach aims to contribute to the consolidation of accessible and regulation-aligned methods for designing residential buildings in humid tropical regions.

Climate Overview of Belém, Pará – Bioclimatic Zone 6A

Belém do Pará is located in Bioclimatic Zone 6A, as defined by NBR 15220-3 (ABNT, 2024), and is characterized by an extremely hot and humid climate throughout the year. The annual mean dry-bulb temperature (TBSm) reaches or exceeds 27.0°C, while the relative humidity remains consistently high, with an annual average above 66.8%, allowing classification within Interval 3 (Table 1) of operative temperature range defined by NBR 15575 (ABNT, 2021).

Table 1 - Operative temperature ranges for determining PHFT and CgTR

Interval	Annual mean dry-bulb temperature from the climate file – TBS (°C)	Operative temperature range of interest (°C)	
		$PHFT_{APP}$	$CgTR_{APP}$
1	TBSm < 25,0°C	18,0 °C To_{APP} <26,0°C	To_{APP} ≥ 26,0°C

Source: Adapted from NBR 15575 (2021).

These climatic conditions pose significant challenges to thermal comfort in buildings, especially in social housing (HIS), where the capacity for passive adaptation to the climate is often limited.

Table 2 - Bioclimatic Strategies Recommended by NBR 15220-3:2024

Strategies	Recommendations
Natural Ventilation	Prioritize cross ventilation (opposite openings); maximize ventilation area + shading in Long-Term Occupancy Spaces; use height differences between openings (ventilated sill + upper exhaust).
Shading	Provide shading for all openings throughout the day.
Building Envelope Colors	Use light colors on the building envelope to reduce heat absorption.
Thermal Insulation	Recommended on the roof, combined with low solar absorptance (light colors).
Construction Components	Preference for components with low thermal capacity when thermal insulation is applied on external walls.

Source: Adapted from NBR 15220-3 (ABNT, 2024).

Case Study

The analyzed housing units (HUs) feature ceiling heights of 2.80m and 2.40m (reference model) and a total usable area of 47.70m², comprising two bedrooms (9.65m² each), one bathroom (3.39m²), a living room (15.10m²), and a kitchen integrated with the service area (8.85m²), as illustrated in the floor plan in Figure 1 and detailed in Table 3. For simulation purposes, three HUs located on different floors were selected, representing distinct thermal exposures: HU1 (ground floor), HU5 (intermediate floor), and HU9 (top floor/roof), all oriented northeast. Access to the housing units occurs through corridors located on the main facade and a staircase positioned on the building’s left side (Figure 1). The building envelope was designed with low thermal inertia solutions for walls and roofs, aligned with the recommendations of NBR 15220 (ABNT, 2023) for Bioclimatic Zone 6A. This strategy aims to reduce heat absorption and delay heat transfer to the indoor environment, thus promoting passive thermal comfort. Additionally, shading devices were incorporated on openings, and cross ventilation was prioritized.

Figure 1 - Case Study

Source: Author.

Construction Guidelines

The adopted construction guidelines followed the simplified method of INI-R and NBR 15575 (ABNT, 2021). Additionally, efficiency and cost-benefit recommendations from the EEDUS report (2021) were considered.

Table 3 - Construction Components of the Enhanced (Real) Model

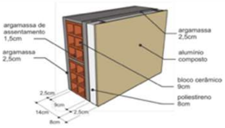
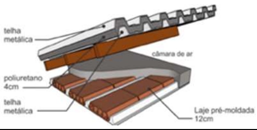
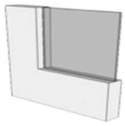
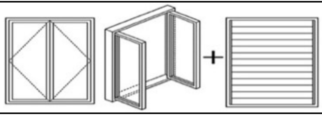
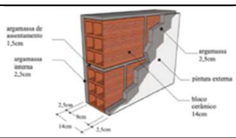
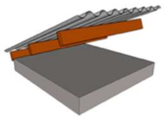
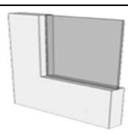
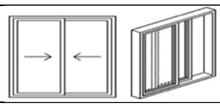
WALLS	ROOF SYSTEM	GLAZING
		
Internal plaster (2.5cm); Ceramic block (9.0 x 14.0 x 24.0cm); External plaster (2.5cm); Polystyrene (8cm); Composite aluminum panel; Matte acrylic exterior paint – White.	Precast slab 12cm (4cm concrete + 7cm EPS + 1cm mortar); Air chamber (> 5.0cm); Metal roofing sheet – 0.1cm; Polyurethane 4.0cm; Metal roofing sheet 0.1m.	Single clear glass (6 mm).
U (W/ m²K): 0,31; CT [kJ/ m²K]: 134, α: 0,158	U (W/ m²K): 0,53; CT [kJ/ m²K]: 176, α: 0,158	U-value (W/m²·K): 5.700; Solar Heat Gain Coefficient (SHGC): 0.87
SLAB	**WINDOWS**	
		
Ribbed slab with expanded polystyrene (EPS) infill (22.5cm); screed layer (2cm) – ceramic floor finish.	Ribbed slab with expanded polystyrene infill (22.5cm); screed (2cm) – ceramic flooring. Casement window with louvered shutters – 1.40×1.60/1.10m (bedrooms), 1.20×1.50/1.30 m (kitchen), 1.40×2.50/1.10m (living room) – shaded by brise-soleil/balcony.	
U (W/ m²K): 3,74; CT [kJ/ m²K]: 220	Ventilation Factor (VF): 90; Percentage of transparent elements: 23%	

Table 4 - Construction Components of the Reference Model

WALLS	ROOF SYSTEM	GLAZING
		
Internal plaster (2.5 cm); Ceramic block (9.0 × 14.0 × 24.0 cm); External plaster (2.5 cm); External finish: matte acrylic paint, color: Suede.	Wooden ceiling (1.0 cm); Air gap (> 5.0 cm); Ceramic roof tile; Finish: PVA latex paint, color: Sand.	Single clear glass (6 mm).
U (W/ m²K): 2,46; CT [kJ/ m²K]: 150; α: 55,8	U (W/ m²K): 2,06; CT [kJ/ m²K]: 233; α: 39	U-value (W/m²·K): 5.700; Solar Heat Gain Coefficient (SHGC): 0.87
SLAB	**WINDOWS**	

	
Solid concrete slab (10 cm)	Simple sliding windows – solar shading via brise-soleil/balcony: 1.20×1.40/1.10m (bedrooms) 1.00×1.50/1.30m (kitchen) 1.20×2.10/1.10m (living room)
U (W/ m²K): 3,74; CT [kJ/ m²K]: 220	Ventilation Factor (VF): 45; Percentage of transparent elements: 17%

Source: Projeteee (s.d)

Results

The metamodel was configured based on the limits established for the Reference Model (Table 2) and the construction components adopted in the Actual Model (Table 4). From this configuration, the output data were extracted as presented in Tables 6, 7, 8, and 9. These results form the basis for calculating the thermal comfort parameters in accordance with the criteria defined by NBR 15575 (ABNT, 2021).

Table 5 - Output Data for HU3 and HU6 (Reference Model)

APPs H6 e H3	Heating Load	Cooling Load	PHiFT	PHsFT	$To_{\text{máx}}$	$To_{\text{mín}}$
Bedroom 1	0,33	942	0,01	4,99	31,70	26,25
Bedroom 2	0,29	618,56	0,01	7,98	31,58	26,20
Living Room	0,62	2822,82	0,01	62,49	32,59	27,60

Table 6 - Output Data for HU3 e HU6 (Real Model)

APPs H6 e H3	Heating Load	Cooling Load	PHiFT	PHsFT	$To_{\text{máx}}$	$To_{\text{mín}}$
Bedroom 1	0,89	0,39	0,01	0	29,19	25,48
Bedroom 2	0,88	-1,94	0,01	0,02	29,37	25,47
Living Room	0,56	243,57	0,01	4,68	30,80	26,35

Table 7 - Output Data for HU9 (Reference Model)

APPs H6 e H3	Heating Load	Cooling Load	PHiFT	PHsFT	$To_{\text{máx}}$	$To_{\text{mín}}$
Bedroom 1	0,28	874,92	0,01	14,46	32.01	25,90
Bedroom 2	0,15	640,62	0,01	23,52	31,97	25,68
Living Room	0,63	2708,03	0,01	75,88	33,76	27,48

Table 8 - Output Data for HU9 (Real Model)

APPs H6 e H3	Heating Load	Cooling Load	PHiFT	PHsFT	$To_{\text{máx}}$	$To_{\text{mín}}$
Bedroom 1	0,68	0,15	0,01	0	29,56	25,07
Bedroom 2	0,52	-0,83	0,01	0	29,73	25,03
Living Room	0,67	245,96	0,01	4,12	31,20	26,18

Source: Author.

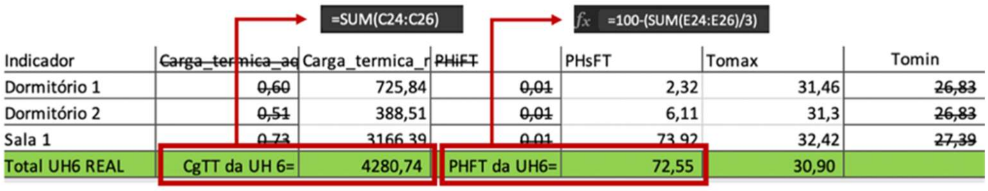
Based on these data, the building's thermal performance was analyzed using the normative indicators: Maximum and Minimum Operative Temperatures ($To_{\text{máx}}$ and $To_{\text{mín}}$), Percentage of

Hours within the Operative Temperature Range (PHFT), as well as the Annual Cooling Load (CgTR) and Heating Load (CgTA), whose sum results in the Annual Total Thermal Load (CgTT), employed for performance level classification. The obtained values were organized in a calculation spreadsheet developed to enable an automated, clear, and standards-compliant evaluation.

Percentage of Hours within the Operative Temperature Range

To perform the calculation of the percentage of occupied hours within an operative temperature range, it is necessary to calculate the PHFT for each Long-Term Occupancy Space (APP). From the arithmetic mean of all these percentages, it is possible to determine the value for the housing unit (HU), as illustrated in Figure 2:

Figure 2 - Procedure for Calculating PHFT and CgTT Using Excel Spreadsheets



Indicador	~~Carga_termica_aq~~	Carga_termica_r	~~PHIFT~~	PHsFT	Tomax	Tomin
Dormitório 1	~~0,60~~	725,84	~~0,01~~	2,32	31,46	~~26,83~~
Dormitório 2	~~0,51~~	388,51	~~0,01~~	6,11	31,3	~~26,83~~
Sala 1	~~0,73~~	3166,39	~~0,01~~	73,92	32,42	~~27,39~~
Total UH6 REAL	CgTT da UH 6=	4280,74	PHFT da UH6=	72,55	30,90	

Source: Author.

Table 9 - Thermal Performance Indicators for HU3 and HU6

Indicators	Reference Model	Real Model
PHFT (%)	62,05%	98,63%
CgTR (KWh)	4223,57	670,22
$To_{\text{máx}}$	33,76 °C	31,2 °C
$To_{\text{mín}}$	25,68 °C	25,03 °C

Table 10 - Thermal Performance Indicators for HU9 (Top Floor)

Indicators	Reference Model	Real Model
PHFT (%)	62,05%	98,63%
CgTR (KWh)	4223,57	670,22
$To_{\text{máx}}$	33,76 °C	31,2 °C
$To_{\text{mín}}$	25,68 °C	25,03 °C

Source: Author.

The results highlight the potential of bioclimatic strategies in mitigating thermal discomfort in social housing exposed to severe climates. A reduction of up to 59% in discomfort hours — with a Percentage of Hours within the Operative Temperature Range (PHFT) exceeding 98% — demonstrates that the synergy between efficient thermal insulation, natural ventilation, and low solar absorptance surfaces can largely offset the effects of high outdoor temperatures, which reach peaks of 33.76°C in the region. This performance suggests that, even without mechanical climate control systems, high levels of thermal comfort can be achieved, reinforcing the feasibility of passive solutions in the context of social housing in hot and humid zones.

Figure 3 - Comparison of PHFT and To$_{máx}$ for HU3 (Ground Floor on Pilotis): Real vs. Reference Model

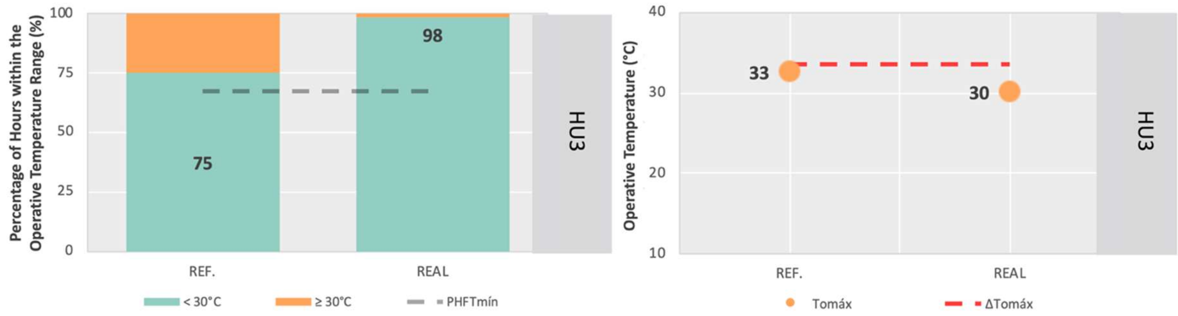


Figure 4 - Comparison of PHFT and To$_{máx}$ for HU9 (Top Floor): Real vs. Reference Model

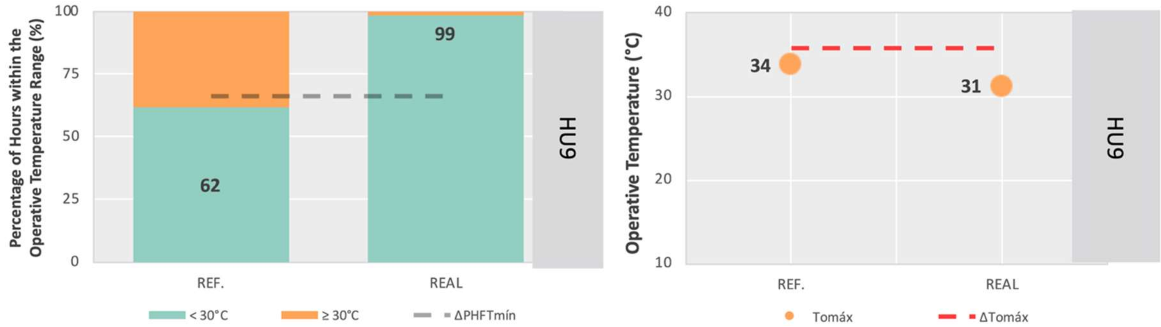
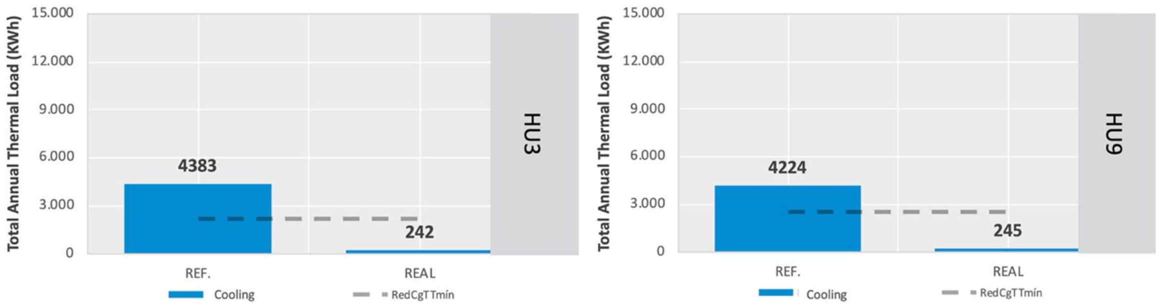


Figure 5 - Comparison of Annual Thermal Load Indicators for HU3 (Ground Floor) and UH9 (Top Floor): Real vs. Reference Model

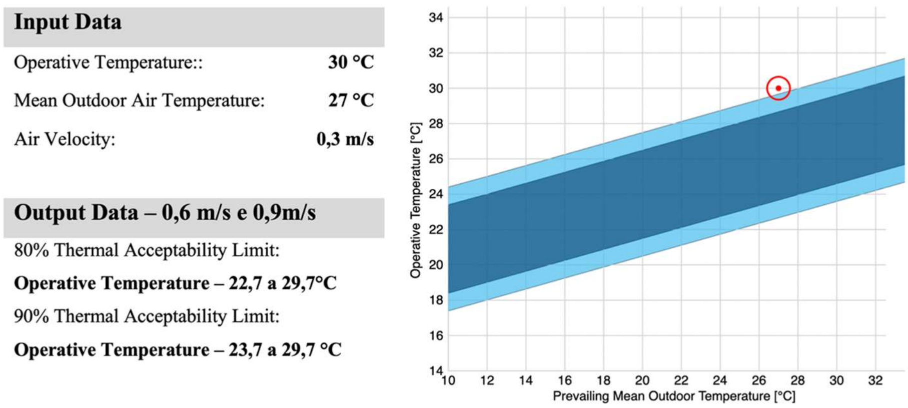


Source: Author.

Thermal Comfort Analysis

The first consideration is the operative temperature threshold of interest set at < 30°C, based on the annual average temperature of Belém city, which is 27.0°C. The objective is to verify whether the PHFT results comply with thermal comfort criteria. Additionally, the lowest air velocity value (0.3m/s) will be initially adopted. The output data and their corresponding graph were observed as follows:

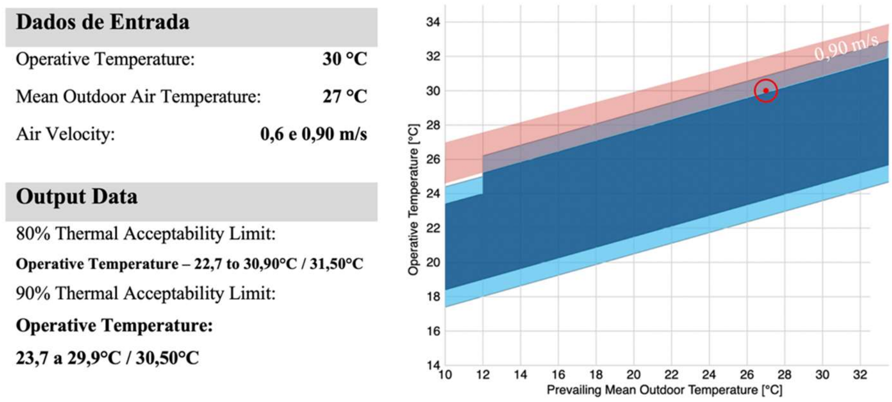
Figure 6 - Operative Temperature Comfort Zone (Target Range)



Source: Author.

The tool established an 80% thermal acceptability threshold, with an operative temperature range between 22.7°C and 29.7°C defining the comfort zone. It is observed that the estimated hours within this range align with the thermal comfort votes, considering the slight difference between the standards: TO<30°C (performance standard) and 29.7°C (comfort standard). NBR 16401:2021 allows for expanding the upper operative temperature limit for spaces above 25.5°C by considering increased air velocity (up to 0.8m/s).

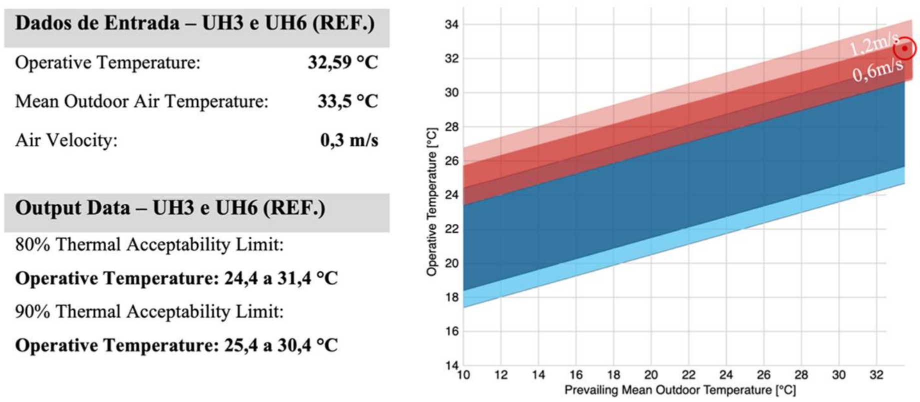
Figure 7 - Comfort Zone According to Air Velocity at 0.6 m/s



Source: Author.

Increasing the air velocity to 0.90 m/s raised the thermal acceptability to 90%, with operative temperatures ranging between 23.7°C and 30.5°C, highlighting the strategic role of cross ventilation in adverse climates. In the least efficient scenario (PHFT of 74.85%), the metamodel estimated a maximum operative temperature of 32.59°C, close to the external average temperature of 34.4°C recorded in the weather file. However, ASHRAE 55 (ANSI, 2020) imposes a limit of 33.5°C for the average external temperature, restricting the applicability of the analysis under more extreme conditions.

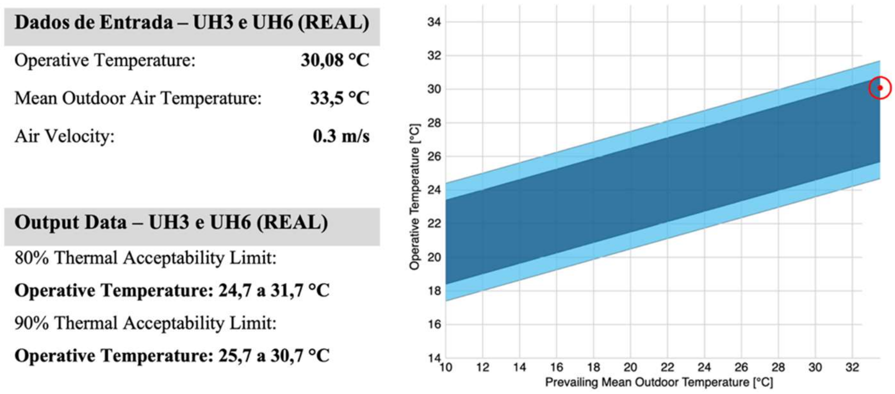
Figure 8 - Comfort Zone Graph for HU6: Reference Model



Source: Author.

It is observed that, without passive strategies, the environment exceeds the limits of thermal acceptability, especially when the average external temperature surpasses 31.4°C. However, with an air velocity of 0.6 m/s, thermal acceptability reaches 80%, highlighting the importance of cross ventilation. The analysis of the actual housing unit, featuring materials with higher thermal performance, confirmed this trend: a PHFT of 98.43% and a maximum operative temperature ($To_{máx}$) of 30.08°C kept the building within the 90% acceptability range, even under severe conditions.

Figura 9 - Comfort Zone Graph: Maximum Operative Temperature ($To_{máx}$) for HU6: Real Model



Source: Author.

In regions with high external temperatures, cold discomfort was observed despite elevated operative temperatures — 25.7°C for 90% and 24.7°C for 80% acceptability. These values are considered comfortable in other Brazilian climates. This behavior confirms the climate adaptation discussed by De Vecchi et al. (2014; 2021), who propose expanding the lower comfort limits by considering the influence of clothing insulation (clo). In the case of units HU9 (top floor), with an external temperature of 33.5°C, the reference model presented a PHFT of 62.05% and a $To_{máx}$ of 33.76°C, while the actual model reached a PHFT of 98.63% and a $To_{máx}$ of 31.2°C, reinforcing the effectiveness of the applied passive strategies.

Conclusion

This study aimed to analyze the impact of bioclimatic strategies on the thermal performance and comfort of Social Housing (HIS) in Belém, Pará, referencing the NBR 15575 standard. Computational simulations demonstrated that the application of strategies such as optimized natural ventilation, adequate shading, use of light colors on the building envelope, thermal insulation in the roof, and construction components with low thermal capacity can lead to significant improvements. Specifically, an increase of up to 37% was observed in the Percentage of Hours within the Operative Temperature Comfort Zone (PHFT) for the top-floor housing unit, along with reductions in maximum operative temperatures. It is concluded that the conscious and planned adoption of bioclimatic strategies is fundamental to optimizing thermal comfort and energy efficiency in social housing located in hot and humid climates. This work contributes by providing quantitative evidence of the positive impact of these strategies, offering support for more sustainable architectural designs and for the formulation of public policies aimed at improving the quality of life in social housing, aligning with normative guidelines and promoting a built environment more resilient to adverse climatic conditions.

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