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AMBIENTE CONSTRUÍDO E USUÁRIO: PERSPECTIVAS LATINO-AMERICANAS

Desempenho térmico em edifícios institucionais na Amazônia: um estudo de caso no Amapá e na Guiana Francesa

Desempeño térmico en edificios institucionales en la Amazonia: um estudio de caso em Amapá y Guayana Francesa

Thermal performance in institutional buildings in the Amazon: a case study in Amapá and French Guiana

Desempenho térmico do ambiente construído / *Rendimiento térmico del entorno construído / Thermal performance of the built environment*

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Resumo

O trabalho analisa o desempenho térmico de dois edifícios universitários na região do Platô das Guianas, comparando estratégias bioclimáticas e índices de conforto térmico passivo. A pesquisa utiliza simulações computacionais com o software EnergyPlus para avaliar a relação entre clima, materiais de construção e desempenho térmico. Ambos estão localizados em Macapá e Caiena, ambos em clima equatorial, e foram analisados em outubro (período mais seco e com altas temperaturas) e em fevereiro (período mais úmido e com temperaturas amenas). Os resultados indicam altos níveis de desconforto térmico, especialmente no período seco, mesmo com o uso de estratégias bioclimáticas. Em Macapá, a taxa de conforto variou de 84% em fevereiro para 11% em outubro, enquanto o edifício em Caiena apresentou desconforto na maior parte do tempo. A pesquisa destaca a necessidade de soluções passivas, como ventilação aprimorada e isolamento térmico eficiente, para melhorar o conforto térmico em edifícios educacionais na Amazônia.

Palavras-chave: Desempenho térmico. Simulação computacional. Modelo adaptativo. Clima equatorial amazônico.

Resumen

Este estudio analiza el rendimiento térmico de dos edificios universitarios en la región de la meseta guayanesa y compara estrategias bioclimáticas e índices de confort térmico pasivo. La investigación utiliza simulaciones por ordenador con EnergyPlus para evaluar la relación entre el clima, los materiales de construcción y el rendimiento térmico. Ambos edificios se encuentran en Macapá y Cayena, ambos en un clima ecuatorial, y se analizaron en octubre (más seco y con mayores temperaturas) y febrero (más húmedo y con temperaturas suaves). Los resultados indican altos niveles de incomodidad térmica, especialmente en la estación seca, incluso con las estrategias bioclimáticas. En Macapá, el índice de confort varió del 84% en febrero al 11% en octubre, mientras que el edificio de Cayena resultó incómodo la mayor parte del tiempo. La investigación señala la necesidad de soluciones pasivas, como una mejor ventilación y un aislamiento térmico eficiente, para mejorar el confort térmico en los edificios educativos de la Amazonia.

Palabras clave: Rendimiento térmico. Simulación por ordenador. Modelo adaptativo. Clima ecuatorial amazónico.

Abstract

This study analyzes the thermal performance of two university buildings in the Guiana Highlands region by comparing bioclimatic strategies and passive thermal comfort indices. Using computer simulations with EnergyPlus software, the research evaluates the relationship between climate, building materials, and thermal performance. The buildings, which are located in Macapá and Cayenne, were analyzed in October (the driest period with high temperatures) and February (the wettest period with mild temperatures). Both cities have an equatorial climate. The results indicate high levels of thermal discomfort, particularly during the dry season, despite the use of bioclimatic strategies. In Macapá, the comfort rate ranged from 84% in February to 11% in October; meanwhile, the building in Cayenne was mostly uncomfortable. This study underscores the necessity of passive solutions, such as enhanced ventilation and efficient thermal insulation, to enhance thermal comfort in educational facilities in the Amazon region.

Keywords: Thermal performance. Computer simulation. Adaptive model. Amazon equatorial climate.

Introduction

The energy crisis of the 1970s sparked a significant global debate about finite natural resources and climate change, emphasizing the need for unified and coordinated action. This dialogue gained momentum during the Earth Summit in Rio de Janeiro in June 1992, where the UN Framework Convention on Climate Change was established, ultimately leading to the signing of the Kyoto Protocol in 1997. This agreement addressed critical issues such as reforming energy and transportation sectors, increasing the use of renewable energy sources, limiting methane emissions, and protecting forests and other carbon sinks (la Cruz-Lovera, de *et al.*, 2017). In the decades since, increasing electricity demand—driven by economic development, population growth, and the intensification of extreme climate events—has reinforced the central role of energy efficiency in sustainable development strategies. In Brazil, for instance, residential and commercial buildings accounted for 50.4% of all electricity consumed in the country in 2023 (Brazil. Ministry of Mines and Energy, 2024).

In this context, the Amazon region presents climate challenges that have direct implications for energy consumption. Projections indicate an increase in average air temperatures exceeding 4°C and a reduction in rainfall of up to 40% by the end of the 21st century (Marengo and Souza Jr., 2018). These changes contribute to greater thermal discomfort in buildings, which can lead to a higher demand for mechanical cooling systems and, consequently, increased electricity consumption. The situation underscores the need to evaluate and promote passive design strategies, especially in the built environment of institutional buildings. The vulnerability of ecosystems, exacerbated by extreme weather events such as droughts and wildfires, further reinforces the urgency for sustainable adaptation strategies. Understanding how these climatic shifts impact the thermal performance of buildings is essential for improving energy efficiency in this sensitive region.

The Amazon context presents diverse realities across its vast territory in South America, like the Guiana Plateau, which encompasses parts of Venezuela, Brazil, and the entirety of Guyana, French Guiana, and Suriname. Situated in the northeast of South America, French Guiana (a French overseas department) and Amapá (a state in Brazil) share unique characteristics, including extensive Amazon rainforest coverage, significant hydrographic networks, and a narrow coastal strip where most population and economic activities are concentrated. The Plateau's hydrographic system, which flows from south to north, contributes to the preservation of one of the best-preserved forests in Brazil. Additionally, the region's equatorial climate, characterized by a distinct wet and dry season due to the intertropical convergence zone, further unites these territories (Leplat et al., 2010).

These similarities motivated a research study to evaluate energy efficiency in buildings located in the region. Regarding the construction sector, the industry is undergoing a transformative shift, challenging traditional practices by adopting standards, labels, and approaches that promote energy efficiency in buildings, guided by global energy transition objectives. France and French Guiana, for example, have implemented energy efficiency certifications such as HPE (High Energy Performance), BBC (Bâtiment Basse Consommation énergétique rénovation), HQE (High Quality Environmental Standard), and QEA (Qualité Environnementale Amazonienne). In Brazil, similar certifications include AQUA (High Environmental Quality), and INI-C (INMETRO Normative Instruction for the Energy Efficiency of Commercial, Service, and Public Buildings).

Objective

As part of ongoing research, this paper aims to compare the thermal performance of two university buildings in the Guiana Plateau region, establishing a relationship between passive bioclimatic strategies and passive thermal comfort indices.

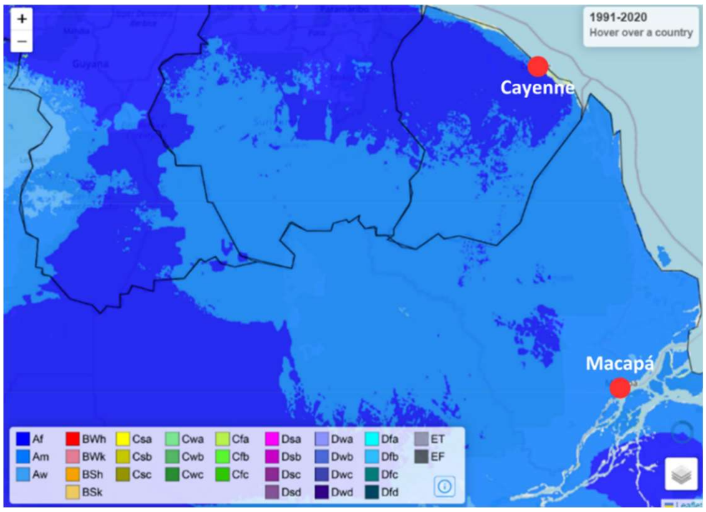
Methodology

This study follows an experimental approach, which includes building performance simulation using EnergyPlus software and the adaptive thermal comfort index to assess the relationship between climate, building materials, bioclimatic strategies and building thermal performance.

Analyzed cities

Two university buildings were selected for the study, one located in the Federal University of Amapá (UNIFAP) Campus, in the south region of Macapá, and the other in the University of French Guyana (UG) Campus, in the central north region of Cayenne, henceforth named building B-AP and B-FG, respectively. First, the climatic characteristics of the cities are presented. Macapá is the Capital of the state of Amapá, in the North region of Brazil, with 0° latitude, 51.07° south longitude, and 15m altitude. According to the Köppen-Geiger classification, Macapá is classified as tropical monsoon (Am). The city presents 29% discomfort throughout the year, mostly due to heat, considering the comfort adaptive model for 80% acceptability. Cayenne is the capital of French Guiana, a French overseas department in northern South America, with 4.82° north latitude, 52.36° south longitude, and 7m altitude. It is also classified as tropical monsoon (Am) climate (Peel; Finlayson; McMahon, 2007). The city presents 20% discomfort all year, the comfort adaptive model for 80% acceptability (Figure 1).

Figure 1: Köppen-Geiger classification for Amapá and French Guiana, with the location of Macapá and Cayenne

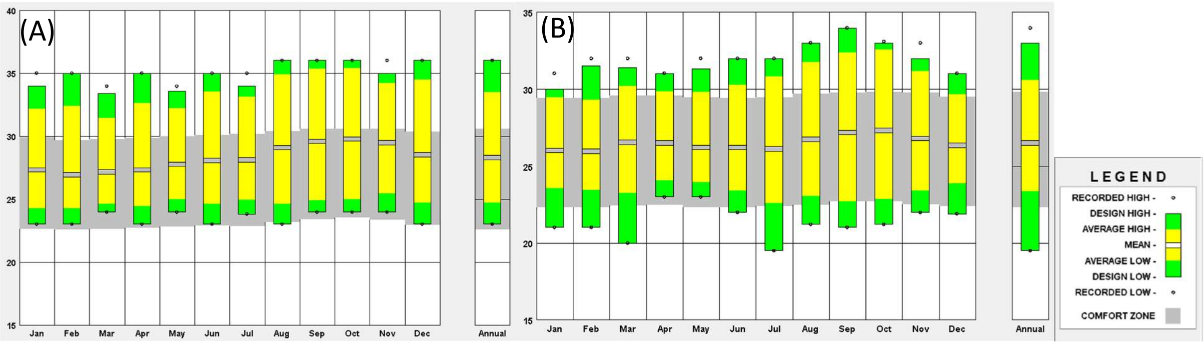


Source: https://koppen.earth/

The average temperature of Macapá is 25.77°C and relative humidity equivalent to 83.07% (Figure 2). The average incidence of solar radiation is highest in the months of April, August, September and October, the latter with the highest values reaching 23,068 Wh/m². Regarding winds, Macapá has a predominance of incidences from the Northeast and East directions, with speeds between 0 and 3.77 m/s, with an annual average of 1.25 m/s. The average temperature of Cayenne is 26,50°C and relative humidity of 84.30% (Figure 2). The average incidence of solar radiation is highest in the months of August, September and October and November. September with the highest values reaching 15,068 Wh/m². Regarding winds, Cayenne, as well as Macapá, has a predominance of incidences from the Northeast and East directions, with speeds between 0 and 10 m/s, with an annual average of 2.30 m/s.

Because the Guiana Plateau is in the equatorial zone, a four-season pattern is not ideal for thermal comfort studies in the region. Macapá and Cayenne mainly have two seasons: a rainy season with mild temperatures (from January to June) and a dry season with high temperatures (from July to December). These seasons are commonly described as winter and summer, respectively. This nomenclature was used in the analysis of this study.

Figure 2: Average temperature and adaptive comfort range for Macapá (A) and Cayenne (B)



Source: Climate Consultant 6 software, and EPW climate file for Macapá and Cayenne from TMY: 2009-2023.

Buildings' description and simulation parameters

B-AP consists of a two-story, rectangular-shaped building, with 4,674.8 m² of total floor area and 3 m floor to ceiling height, with 16% average window-to-wall ratio (WWR). The main facades are North and South (Figure 3). The space is divided into living areas, administrative rooms, teachers' rooms, classrooms, an auditorium on the first floor, technical laboratories and classrooms on the second floor. The building structure is of reinforced concrete, with concrete block walls, polished concrete floors and gypsum bords ceilings. The roof is composed of a metallic tile with PU insulation and precast concrete slab. Windows are of simple glazing, with no shading on the North facade, but protected by metallic shutters on the South side.

Figure 3: Building B-AP (Macapá)

Source: authors

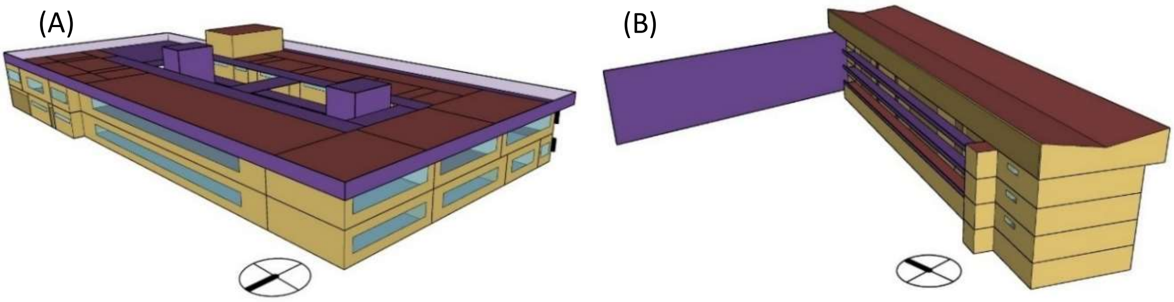
B-FG is a three-story plus basement, thin rectangular-shaped building, with 2,853.6 m² of total area, and 2.6 m floor to ceiling height, with 6,0% WWR. The main facades are Northwest and Southeast. The space consists mainly of classrooms and laboratories. It is an annex of a main concrete block building. B-FG has a concrete main structure, however, differently from B-AP, the envelope is composed of operable modules of wooden plates with wool insulation. Ceilings are also made of wood boards. Like B-AP, the roof in B-FG is composed of a metallic tile with PU insulation but detached from the top floor. Windows on the Southeast side are made of pivoting adjustable vertical vents of double panel glass (Figure 4).

Figure 4: Building B-FG (Cayenne)

Source: www.jagarchi.fr

The buildings were modelled in SketchUp, using the Euclid plugin (Figure 5). An IDF file was then configured in EnergyPlus, version 9.3. Equivalent layer models were used to maintain the properties of the construction elements (Weber *et al.*, 2017), as shown in Table 1.

Figure 5: Building models in SketchUp: (A) Building B-AP and (B) Building B-FG



Source: authors

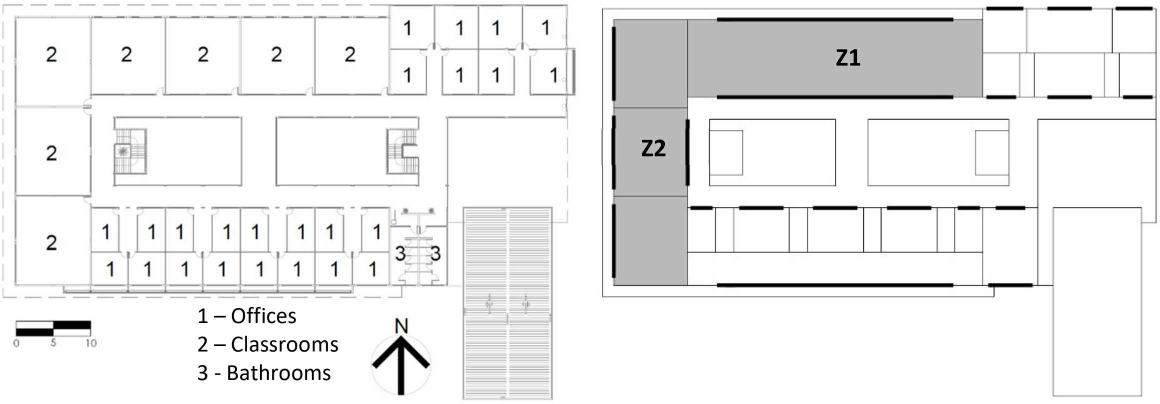
Table 1: Construction components

Parameter	Building 1	Building 2
External Walls	Concrete block with plaster on both sides (14cm)	Wooden plate with insulation (10cm)
U-value: thermal transmittance (W/m²K)	2,76	0,95
α: solar absorptance	0,7	0,5
Roof	Metallic tile with insulation	
U-value: thermal transmittance (W/m²K)	0,65	
α: solar absorptance	0,4	
Windows	Single glazing	Double glazing
U-value: thermal transmittance (W/m²K)	3,70	3,10
SHGC: solar heat gain coefficient	0,72	0,46

Source: authors

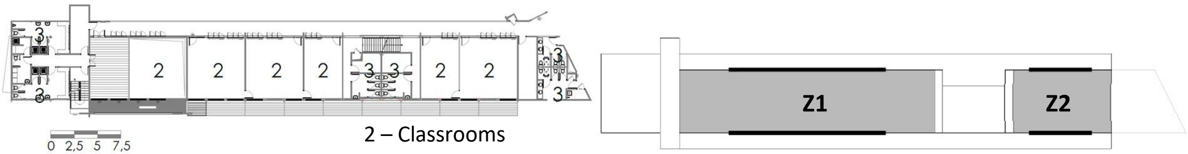
The rooms with the same activities and materials were grouped in thermal zones for a more efficient simulation process. The zones are divides into workspaces (classrooms and offices) – permanent stay areas, and transitory spaces (bathrooms, storage rooms, corridors). Figure 6 and Figure 7 shows the schematics of the buildings' floor plan and thermal zones, with the classrooms highlighted in grey. Two zones in each building were selected for this analysis. In B-AP, Zone 1 (Z1) is located on the first floor facing North, and Zone 2 (Z2) is located on the second floor, facing west. In B-FG, Zone 1 (Z1) is located on the first floor, and Zone 2 (Z2) is located on the third floor, both facing Southeast and Northwest.

Figure 6: Floor plan and Thermal Zones (Building B-AP)



Source: authors

Figure 7: Floor plan and Thermal Zones (Building B-FG)



Source: authors

For the simulation, the schedules for use of the buildings were kept the same, as well as the internal loads, based on the tables of the Brazilian INI-C regulation, even though B-FG is in French Guyana. This methodology approach keeps both buildings with similar activities. For natural ventilation, the multizone Airflow Network module was used in EnergyPlus. In this model, wind paths are calculated by pressure difference, but it does not simulate air speed or inertia (Rackes, Melo e Lamberts, 2016). The simulation parameters are shown in Table 2.

Table 2: Internal gains and natural ventilation parameters

Parameter	Building B-AP	Building B-FG
Internal gains		
Occupancy (m²/person)	2,0	
Clothing (clo)	0,50	
LPD: lighting power density (W/m²)	8,0	
Equipment density (W/m²)	5,0	
Natural ventilation (Airflow Network)		
Wind pressure coefficient	Surface average	
Ventilation type	Multizone	

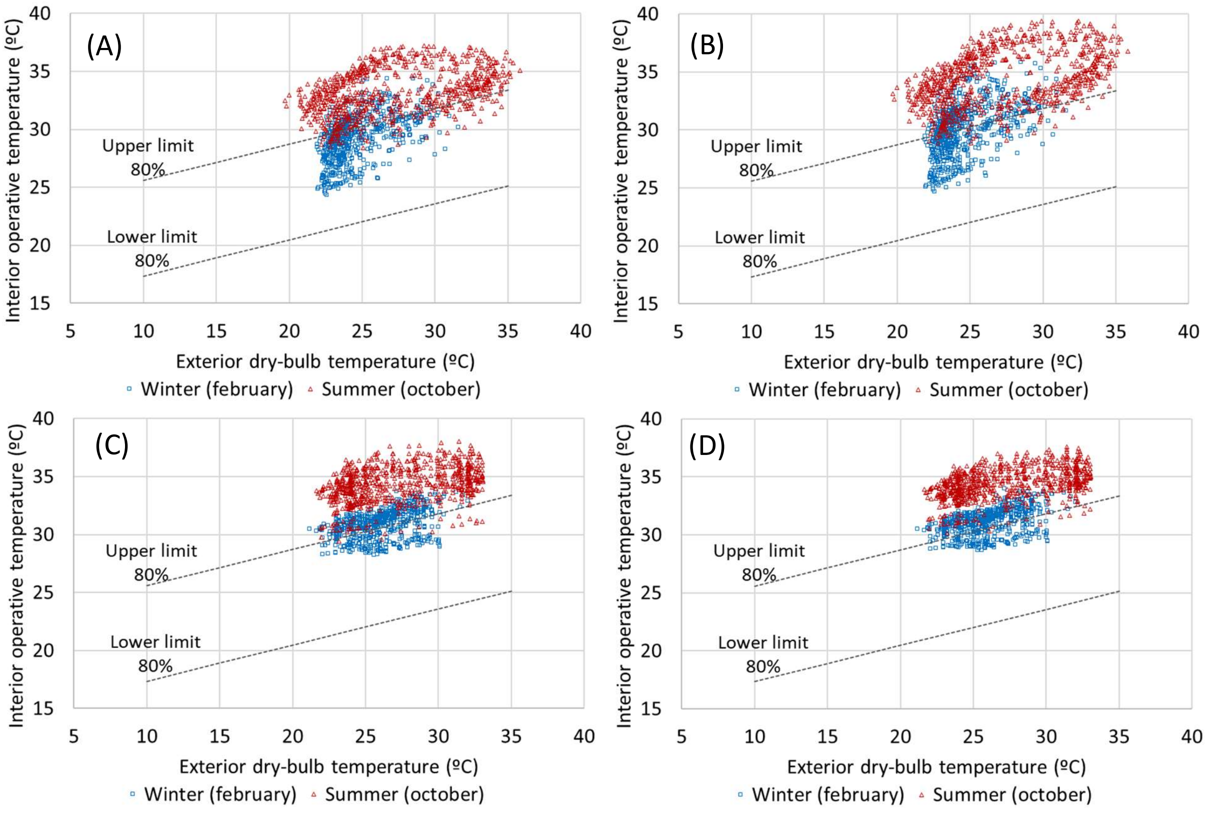
Source: authors

For thermal comfort analysis, the adaptive model of Standard 55 (ASHRAE, 2017) was used. The model is applicable when the monthly average temperatures are ≥ 10°C and ≤ 33.5°C. The predominant average temperature of the external air, Ta_{ext}, was then calculated using a period of 30 days. From the ideal Ta_{ext}, operating temperature that defines the center of the comfort range was calculated. Comfort limits with 80% acceptability were used, calculated with 3.5ºC lower and upper than To_{conf}. With the simulation in EnergyPlus, results are then presented.

Results

The results of the simulations were tabulated in Excel spreadsheets to obtain more objective data. The values analyzed for thermal comfort for users are presented below. Figure 8 shows the adaptive comfort model for the 4 zones analyzed in the two buildings. The results demonstrate a clear correlation between the Amazonian climate and thermal discomfort in all zones, especially in the summer period (October).

Figure 8: Adaptive comfort model. A: Building B-AP Zone 1 (B-AP.Z1), B: Building B-AP, Zone 2 (B-AP.Z2), C: Building B-FG, Zone 1 (B-FG.Z1), D: Building B-FG, Zone 2 (B-FG.Z2)

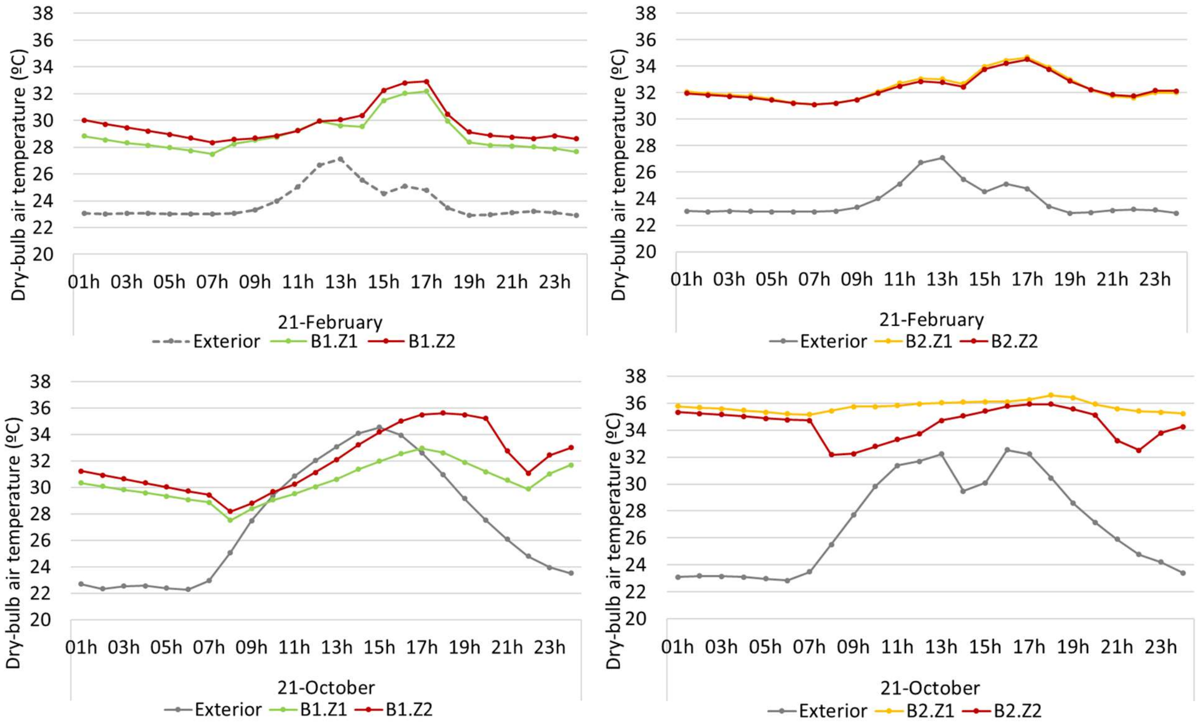


Source: authors

In Macapá, for B-AP.Z1, 84% of the time in the winter period (February), the users feel comfortable in the room, even without the use of air-conditioning, while in October, the outcome is the opposite, for 89% of the time, people would feel discomfort in the room. The results are similar in B-AP.Z2, with only 68% of comfortable hours in February, but 92% of discomfort in October. For the building in Cayenne, B-FG.Z1 and B-FG.Z2 show very similar behavior regarding the thermal performance of the building. Even with more suitable bioclimatic strategies, most of the time in the winter (February) and summer (October), people would not feel very comfortable in the rooms. The percentage of discomfort hours was 95% for B-FG.Z1 and 97% for B-FG.Z2.

A second part of the study consisted of analyzing the dry-bulb temperature in the zones for representative days chosen for each season, February 21st for the winter, and October 21st for the summer, based on the climatic file used for simulations. Figure 9 brings the data for the zones.

Figure 9: Dry-bulb Temperature. A: Building B-AP Zone 1 (B-AP.Z1), B: Building B-AP, Zone 2 (B-AP.Z2), C: Building B-FG, Zone 1 (B-FG.Z1), D: Building B-FG, Zone 2 (B-FG.Z2)



Source: authors

The outdoor temperature in both cities is very similar, representing the average Amazonian climate. In February the temperature ranges between 22ºC and 27ºC, while in October it ranges between 22ºC and 34ºC. The performance of the buildings is also similar. The indoor dry-bulb temperature in B-AP.Z1 (first floor North) is slightly colder than B-AP.Z2 (second floor West), while the temperature in B-FG.Z1 (first floor Southeast) is a little higher than B-FG.Z2 (third floor Southeast). This can be explained by the detached roof in B-FG, which enhances the natural ventilation effects in the building.

This paper focuses on the first stage of an ongoing research cooperation to assess, analyze and propose bioclimatic solutions applied to Amazonian public institutions, particularly in university buildings. Recent studies in related areas demonstrate the importance of this subject. In tropical climates there is a seasonal variation between two well-defined seasons that divide periods throughout the year, the dry and rainy seasons (Sánchez-Montes *et al.*, 2025). The results of this study align with information found in the literature. It has been shown that passive strategies alone are insufficient to guarantee thermal comfort for users. Architecture can help select design solutions that are suitable for different seasons. Cen *et al.* (2024) point out that reducing the temperature and increasing air speed are important factors for better cognitive performance. These parameters can be developed in the next stage of the research.

Conclusion

This study highlights the thermal performance of two university buildings in the Guiana Plateau, emphasizing the impact of climate, building materials, and bioclimatic strategies on occupant comfort. Despite similar climatic conditions in Macapá and Cayenne, architectural design and construction materials significantly influence indoor thermal conditions, leading to varying levels of discomfort.

Findings indicate that both buildings experience high thermal discomfort, particularly in October. Building B-AP in Macapá showed seasonal variations, with comfort levels dropping from 84% in February to 11% in October for Zone 1. Similarly, Building B-FG in Cayenne exhibited discomfort year-round, despite incorporating bioclimatic strategies, suggesting the need for additional passive solutions or hybrid cooling systems to enhance comfort conditions.

A key observation is the role of natural ventilation and construction materials in regulating indoor temperatures. The detached roof in B-FG improved air circulation, mitigating heat buildup in upper floors. However, the limited effectiveness of passive strategies reinforces the need for further optimization, including enhanced shading, improved ventilation, and better thermal insulation. Future studies should incorporate occupant feedback and real-time monitoring to refine strategies for energy-efficient and thermally comfortable educational spaces in the Amazonian context. It is crucial to state that this study is the first step of a research that will later compare the INI-C with the Guyanese QEA regulation and different bioclimatic solutions. Understanding educational spaces in equatorial climates is challenging, as it represents a climate with high temperatures most of the time, which can affect students' cognitive processes.

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