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Simulation of the Influence of Vegetation on Thermal Comfort Conditions in the Surroundings of the Medical Emergency Unit in the Municipality of São José dos Quatro Marcos - MT


Simulação da Influência da Vegetação para as Condições de Conforto Térmico no Entorno do Pronto Atendimento Médico do Município de São José dos Quatro Marcos, MT


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Abstract

In order to contribute to the understanding of the dynamics of the urban microclimate, this work aimed to simulate microclimatic scenarios and develop chromatic maps around the medical emergency room in the city of São José dos Quatro Marcos, MT, aiming to reduce the thermal discomfort of users of the local health unit. Data on temperature and relative humidity were collected at six different points around the unit, between the spring (December/2023) and autumn (March/2024) seasons. ENVI-met Microclimate Simulation System Version 5 was used to simulate the microclimate before and after the insertion of vegetation in the locations, evaluating thermal comfort with the Predicted Mean Vote (PMV) index for different times (8 am, 2 pm and 8 pm) using the BIO-met module. The Mann-Whitney test was applied to compare the mean hourly air temperature and humidity levels between the seasons, revealing a statistically significant difference between the groups ($W = 74$, $p < 0.005$ for temperature and $W = 495.5$, $p < 0.005$ for humidity). The implementation of tree cover in the simulation resulted in a reduction in the temperature around the São José dos Quatro Marcos Medical Emergency Room; however, it proved to be inadequate in relation to the PMV thermal comfort index, not meeting its minimum requirements for the established comfort rate. This study provided a valuable basis for the development of urban planning strategies aimed at optimizing thermal comfort.

Keywords: Thermal Discomfort. Urban Microclimate. Air Temperature. Relative Humidity. Predicted Mean Vote.

Resumo

De modo a contribuir com o entendimento da dinâmica do microclima urbano, este trabalho teve como objetivo simular cenários microclimáticos e o desenvolvimento de mapas cromáticos no entorno do pronto atendimento médico na cidade de São José dos Quatro Marcos, MT, visando reduzir o desconforto térmico dos usuários da unidade de saúde local. Foram coletados dados de temperatura e umidade relativa do ar, em seis pontos distintos no entorno da unidade, entre as estações de primavera (dezembro/2023) e outono (março/2024). O ENVI-met Microclimate Simulation System Version 5 foi utilizado para simulações do microclima antes e após a inserção de vegetação nos locais, avaliando o conforto térmico com o índice Voto Médio Predito (PMV) para diferentes horários (8h, 14h e 20h) utilizando o módulo BIO-met. O teste de Mann-Whitney foi aplicado para comparar os níveis médios horários de temperatura e umidade do ar entre as estações, revelando uma diferença estatisticamente significativa entre os grupos ($W = 74$, $p < 0,005$ para a temperatura e $W = 495,5$, $p < 0,005$ para a umidade). A implementação de coberturas arbóreas na simulação realizada resultou em uma redução da temperatura no entorno do Pronto Atendimento Médico de São José dos Quatro Marcos, entretanto, se mostrou inadequado em relação ao índice de conforto térmico PMV, não atendendo aos seus requisitos mínimos para taxa de conforto estabelecida. Este estudo forneceu uma base valiosa para o desenvolvimento de estratégias de planejamento urbano voltadas para otimizar o conforto térmico.

Palavras-chave: Desconforto Térmico. Microclima Urbano. Temperatura e Umidade Relativa do Ar. Voto Médio Predito.

1 Introduction

Climate change is progressing more rapidly than scientists predicted less than a decade ago. According to the Intergovernmental Panel on Climate Change (ONU, 2023), the AR6 report highlights that the urban population will reach approximately 70% in 2025, which will result in a greater conversion of natural environments into anthropized landscapes. In Brazil, according to the Brazilian Institute of Geography and Statistics (IBGE, 2022), the urban population currently represents 61% of the total population.

The urbanization process in the state of Mato Grosso accelerated in the 1970s with industrialization, also known as the "emancipatory race." However, in recent decades, the growth of the urban population in Brazilian cities has undergone transformations, with an inversion in urbanization rates between 2010 and 2020 (Abreu, 2023).

The removal of native vegetation, the increase in the number of buildings, and the expansion of impermeable surfaces to meet the physical and social demands of the population—such as infrastructure needs generated by urbanization—modify the urban landscape and increase the rate of environmental degradation (Maciel; Nogueira; Santos, 2014).

For Oke (2005), heat variations recorded within cities are driving factors in the formation of heat islands, consequently altering the local climate.

Thermal comfort in urban spaces should be prioritized from the planning stage, as the composition and microclimate of these spaces affect the quality of life of their users and the surrounding population (Feitosa *et al.*, 2021). The study of thermal comfort assesses the influence of atmospheric variables in relation to the functioning of the human body. In this context, the Predicted

Mean Vote (PMV) thermal balance index conceptualizes the individual as a passive receptor of thermal stimuli and is based on the principle that the effects of a given environment are mediated by the physical forces of heat exchange between the body and its surroundings (Fanger, 1970).

One possible approach to the dilemma between the need for infrastructure expansion and environmental comfort for the population is urban planning and design that incorporates tree planting throughout the territory. This is one of the strategies used to mitigate thermal discomfort problems resulting from unplanned urbanization (Novais *et al.*, 2020). The vegetated areas enhance the value of urban areas and the surrounding buildings, play an important role in urban thermal comfort, act as temperature regulators, and increase relative humidity through plant transpiration (Souza *et al.*, 2020).

According to Oke (1987), the urban climate can be defined as the result of modifications caused by the urbanization of the Earth's surface and the interference of this process with the atmospheric characteristics of a given location.

The city of São José dos Quatro Marcos, in the state of Mato Grosso, the site of this research, is known for its hot climate, classified as Aw according to Köppen, with dry and rainy months and high temperatures, reaching or exceeding 40 °C in some months. This makes it particularly vulnerable to the impacts of rising temperatures (Alvares *et al.*, 2013).

The Emergency Care Unit (PAM) of São José dos Quatro Marcos is a facility providing urgent and emergency care to approximately 4,000 people per month. It offers laboratory and imaging exams uninterruptedly, seven days a week (Prefeitura de São José dos Quatro Marcos, 2023). The unit is also surrounded by a large open area, commonly used by the local population for physical activities and walking. With an extension of approximately 800 m², the area is characterized by scarce tree cover, lack of pavement, and reduced vegetation. Due to its size and importance in the lives of residents, it is relevant to discuss the thermal comfort parameters it provides to users and the general population.

A significant issue identified is the removal of vegetation in the urbanized surroundings of PAM, which alters the local microclimate by increasing temperature and generating thermal discomfort for users seeking healthcare services.

Thus, considering the needs of PAM users, this study is justified as an example of how climatic characteristics influence the population's well-being and as a contribution to the incorporation of environmental thermal comfort guidelines into the municipality's urban planning.

The objective of this study was to analyze the influence of vegetation on thermal comfort conditions by simulating afforestation scenarios in the surroundings of the Emergency Care Unit in São José dos Quatro Marcos, Mato Grosso. To achieve this objective, the study specified: collecting air temperature and local humidity data during two seasons (spring and autumn) for statistical

treatment of microclimatic variables; elaborating modeling maps using ENVI-met to analyze the interaction between the Emergency Care Unit (PAM) and the microclimate, verifying the resulting thermal conditions in the study area caused by heat exchanges among air, buildings, soil, and vegetation; and analyzing thermal comfort using the PMV index and microclimatic variables to evaluate the current situation around the healthcare facility and how afforestation scenarios may influence this thermal comfort index.

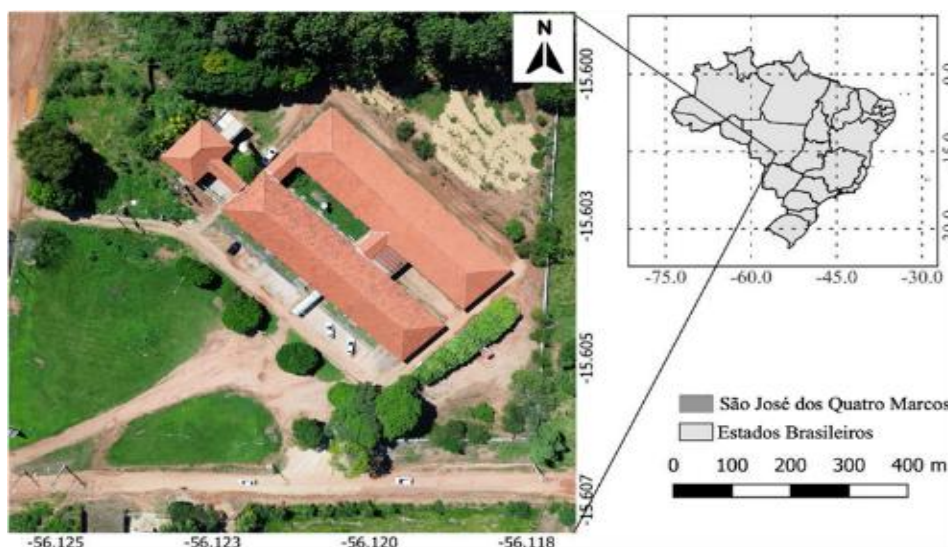
2 Material and Methods

2.1 Study Area

The research was conducted in the surroundings of the Emergency Care Unit (Figure 1), located in the municipality of São José dos Quatro Marcos, which has approximately 17,849 inhabitants (IBGE, 2022), in the southwest of the state of Mato Grosso (56° 15' N; 16° 60' W, 238 m altitude), during the years 2023 and 2024. The healthcare facility provides urgent care exclusively, serving an average of 4,000 people per month. Its surroundings have little tree cover, being dominated by forage grasses of the genus *Brachiaria* sp., trees of the genus *Tectona* (*Tectona grandis*), and *Tabebuia* (*Tabebuia aurea*), as well as sidewalks and unpaved areas.

The climate of the region is classified, according to Alvares *et al.* (2013), as Aw, corresponding to dry winters and rainy summers, with a pronounced rainy season (from November to March) and a dry season (from April to October). The mean annual temperature is approximately 26.2 °C, and average annual rainfall is 1,261 mm (Souza *et al.*, 2020).

Figure 1 – Surroundings of the Emergency Care Unit, located in the municipality of São José dos Quatro Marcos, MT

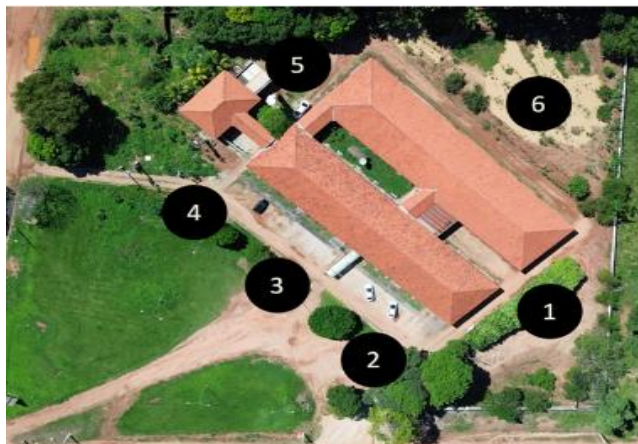


Source: the author.

2.2 Data Collection Period, Instrumentation, and Measurements

The study focused on a one-year period (Figure 2), with data collected during two seasons (spring and autumn) in December 2023 and March 2024.

Figure 2 – Representation of the six data collection points for air temperature and relative humidity over a 24-hour period in both seasons



Source: the authors.

Air temperature and relative humidity data were collected over a 24-hour period at six (6) points in the surroundings of the healthcare facility (Figure 3).

Figure 3 – Data collection points for air temperature and relative humidity: Point 1 (parking lot), Point 2 (emergency entrance), Point 3 (reception), Point 4 (laboratory entrance), Point 5 (staff parking lot), Point 6 (hospital garden)



Source: the authors

After collection, the data were tabulated in spreadsheets, statistically analyzed, and presented

in the form of figures. Point 1 was located in the ambulance parking lot and emergency entrance. Point 2 corresponded to the main emergency entrance. Point 3 was located at the hospital reception. Point 4 referred to the laboratory entrance. Point 5 was the staff parking lot, and Point 6, the hospital garden.

To measure the environmental variables—air temperature ($^{\circ}\text{C}$), relative humidity (%RH), wind speed and direction (m/s)—a portable microclimatic weather station, the Kestrel 4500 (Kestrel 4500 Weather Tracker, NK Company, USA), was used (Figure 4). The model is a portable datalogger with Bluetooth technology. Readings were taken at 30-second intervals, with a 15-minute stabilization period for the device. Following the recommendations established by the INT – National Institute of Technology, the instrument was positioned at a height of 1.20 m above the ground during meteorological data collection.

Figure 4 – Instrument
(Kestrel 5200 Meter and
Anemometer)



Source: the authors.

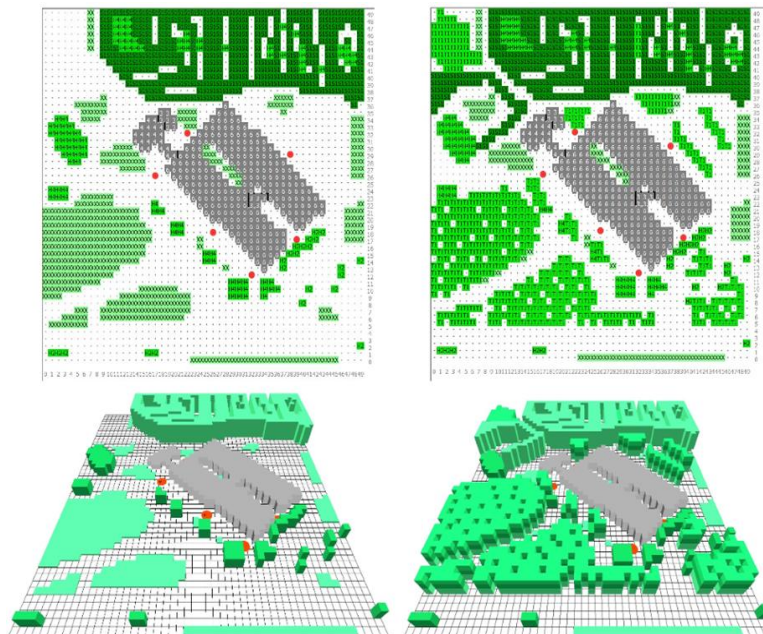
2.3 Simulation of Scenarios with Vegetation Insertion

Microclimate simulations were carried out for the real situation and with the addition of trees up to 10 meters high in the access areas to the Emergency Care Unit (PAM), where there is a greater concentration of people (parking lot, reception, and laboratory).

The trees were configured by combining the characteristics of the existing vegetation with the ENVI-met database, seeking to approximate height, canopy, leaf density, and seasonality. The original model trees were selected based on their characteristics, using the 3D-Plants database of the

software. For the trees used in the vegetated model variation, configurations were based on the *Simple Plant, Tree 20m dense, distinct crown layer* model, without modifications to the software's default settings (Figure 5).

Figure 5 – Simulation of the real and afforested microclimate in ENVI-met version 5 and their respective data collection points

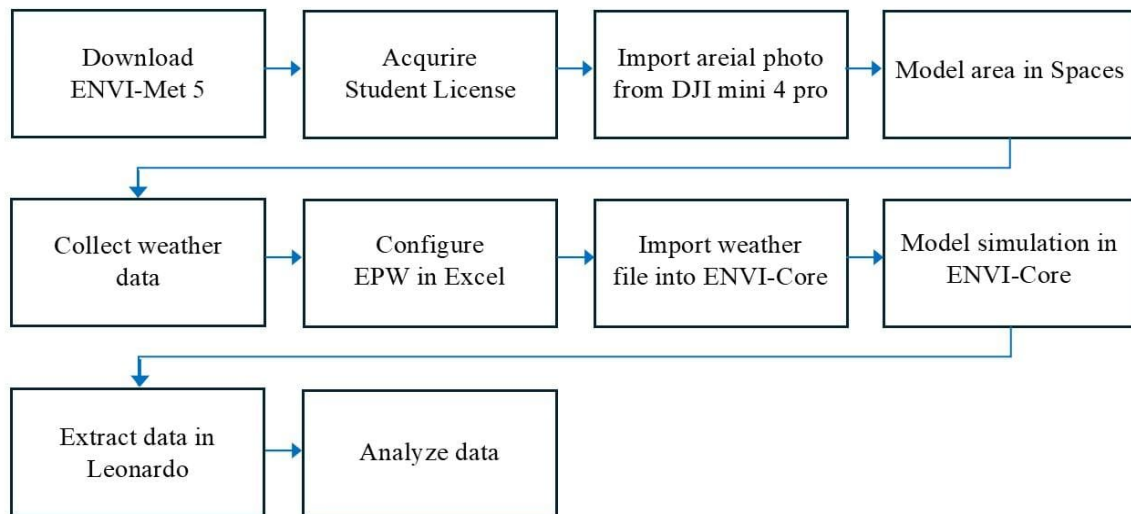


Source: the authors.

The software used for modeling was the ENVI-met Microclimate Simulation System Version 5, a three-dimensional microclimate model that simulates hypothetical scenarios and thermal comfort indices, involving interactions among surfaces, soil, vegetation, and the urban atmosphere. It has a spatial resolution from 0.5 to 10 m and a temporal resolution of 10 seconds, taking into account wind, pollutant dispersion, radiative fluxes, and soil temperature (Morakinyo; Lam, 2016). In the ENVI-met model, plants are described as a porous medium that interacts with the environment through transpiration, evapotranspiration, and photosynthesis, considering the leaf area density (LAD) as an important parameter for modeling turbulence and heat exchange between vegetation and its surroundings (Zhang; Zham; Lan, 2018).

For a better understanding of the software, a flowchart is presented below to illustrate how the simulation was carried out in ENVI-met and to allow reproduction in other academic studies, based on Silva *et al.* (2015) (Figure 6).

Figure 6 – Flowchart illustrating the simulation process in the ENVI-met software



Source: based on Silva *et al.* (2015).

After the microclimate simulation, the Predicted Mean Vote (PMV) thermal comfort index was calculated using the BIO-met 5.5.1 module. The Predicted Mean Vote is a thermal comfort index proposed by Fanger (1970), who used climate-controlled chambers to define comfort parameters, suggesting a 7-point scale in which the PMV range varies from -3, very cold, to +3, very hot, and -0.5 to 0.5 corresponds to the comfort zone. The model was extended to outdoor conditions and is more suitable for evaluating human thermal responses (cold and heat sensations) (Hoppe, 2002).

As input parameters for the model, a 35-year-old male individual, weighing 75 kg, walking at a speed of 0.55 m/s, wearing shorts, a t-shirt, socks, and sneakers, with a total clothing thermal resistance of 0.32 clo and a metabolic energy exchange of 68.56 W/m² (equivalent to 1.18 met) was considered, generating results for the hours of 08:00 am, 02:00 pm and 08:00 pm (Liu *et al.*, 2021).

After modeling the real scenarios at 08:00 am, 02 pm, and 08:00 pm, these results were compared with the collected data for validation purposes.

The selection of these hours was based on data compiled in a .idf file, *design_days_Brasil_2.5%*, developed by LABEE/UFSC using the same climatic .TRY file, and based on the studies of Goulart and Lamberts (2000), grounded in the American and Canadian (ASHRAE) method. Air temperature, humidity, wind speed, and wind direction data were statistically analyzed with occurrence levels and frequencies compatible with the presence of people on site.

The non-parametric Mann-Whitney test was used to compare the hourly mean temperature and relative humidity levels between the two seasons, spring (December 2023) and autumn (March 2024) (Table 1), to determine whether there is a difference in the dependent variable between the two groups.

Table 1 – Modeled dates for the Emergency Care Unit.

	Emergency Care Unit
Spring	December 18th, 2023
Autumm	March 20th, 2024

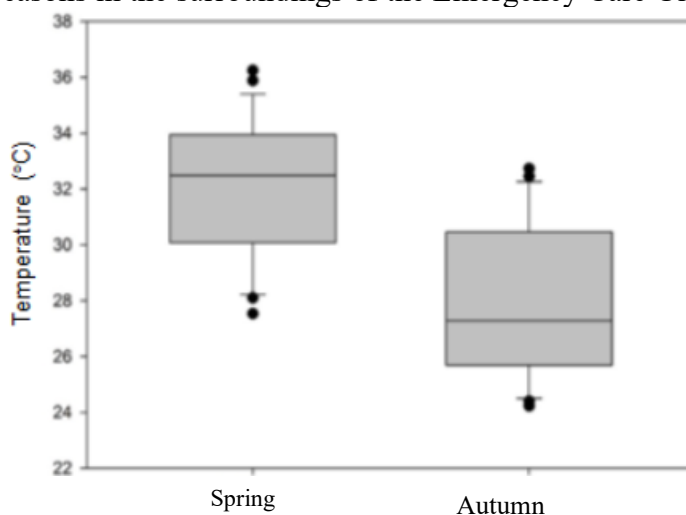
Source: research data.

3 Results and Discussion

3.1 Microclimatic Characterization and Input Data for Each Scenario

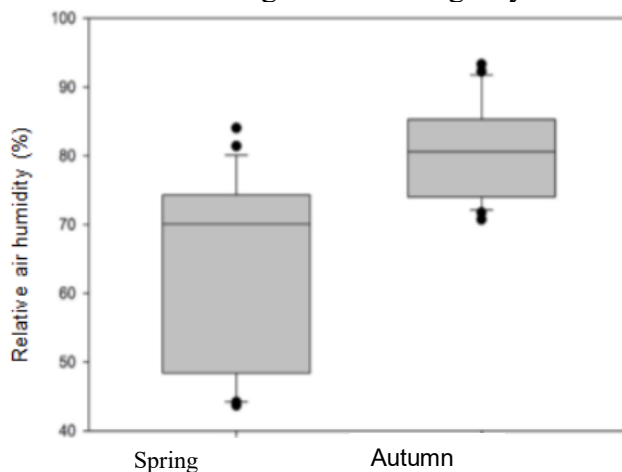
Based on the data collected in December 2023 and March 2024, Figures 7 and 8 exhibit the mean values of air temperature and relative humidity over a 24-hour period in the two seasons, spring (December) and autumn (March).

Figure 7 – Comparison of air temperature for the two seasons in the surroundings of the Emergency Care Unit



Source: research data.

Figure 8 – Comparison of relative humidity for the two seasons in the surroundings of the Emergency Care Unit



Source: research data.

In spring, the maximum air temperature reached 37.7 °C at 12:00, while the minimum recorded was 27.3 °C at 04:00. For relative humidity, the highest value observed was 84% at sunrise, around 07:00. In March, the maximum temperature was 32.7 °C at 16:00, and the minimum was 24.2 °C at 07:00. For relative humidity, the highest value observed was 93% in the early morning at 02:00.

Comparing the average values for the two seasons, higher temperatures were observed in spring (37.7 °C) than in autumn (32.7 °C). The date chosen for the first data collection (December 18) was notably less rainy than in previous years (Embrapa, 2023). In a comparative analysis, the highest air temperatures occurred during the afternoon, similar to the findings of Hillesheim (2021) at Parque das Águas in Cuiabá. During this period, the average air temperatures were 29.86 °C in grassy areas, 35.73 °C in paved areas, and 36.9 °C in asphalted areas, such as the parking lot.

Temperature variations between spring and autumn showed a significantly higher median in spring, around 32 °C, while in autumn it was around 27 °C, possibly influenced by external factors such as higher solar incidence and lower precipitation in spring, which affect the microclimate of the Emergency Care Unit (Figure 7). These variations suggest that in the spring, the environment can become uncomfortable, especially in areas with high human flow and heat-generating equipment, such as emergency and observation rooms. In autumn, although the temperature is lower, comfort may still be compromised if proper air conditioning is not provided.

The chart presents the variation in relative humidity (RH), which is higher in autumn, with a median of 80%, compared to spring (around 60%), which may be associated with inadequate ventilation, creating a feeling of stuffiness indoors. In the spring, reduced RH, while potentially mitigating the sense of stuffiness, combined with high temperatures, can result in a dry environment, causing respiratory discomfort and complications in susceptible patients—a frequent concern in hospital environments.

Temperature and relative humidity variations directly impact thermal comfort, especially in urbanized areas with impermeable surfaces such as asphalt and concrete, which register higher temperatures and lower humidity, particularly in the afternoon. In the spring, maximum temperatures were higher than in the autumn, ranging from 26 °C to 36 °C, while in the autumn they ranged between 24 °C and 34 °C, exacerbating discomfort in environments such as the emergency care unit, where vulnerable patients are affected by heat and low humidity. Regarding relative humidity, in the spring the mean values ranged from 70% to 85%, while in the autumn they ranged from 50% to 80%, reinforcing that vegetated areas presented better thermal comfort conditions, with milder temperatures and higher humidity. This highlights the importance of interventions such as shading and vegetation to mitigate the effects of urban heat islands.

Furthermore, higher air temperatures were observed in areas where the ground surface is

covered by artificial materials such as concrete and asphalt, which have high thermal capacity. In these areas, afternoon air temperatures were 20% higher compared to grassy areas. Surface temperatures were also higher in impermeable, asphalted, and paved areas compared to permeable and grassy areas. The asphalted parking lot showed the largest surface temperature variation throughout the day, reaching 58.23 °C in the afternoon and 29.60 °C at night, resulting in a thermal variation of 28.63 °C. It can be concluded that asphalt tends to register the highest temperatures, especially in the afternoon, while surfaces under trees show the lowest surface temperatures.

In grassy areas, the air temperatures were lower, relative humidity higher, and surface temperatures lower. Conversely, areas with impermeable surfaces such as concrete sidewalks showed the worst values for the collected variables, with high air temperatures, low relative humidity, and high surface temperatures. Relative humidity reached its highest values in the morning and the lowest in the afternoon, recording 81.5% and 41%, respectively. This decrease is directly related to the rise in air temperature, as observed by Novais *et al.* (2017) in Várzea Grande, MT. Fully paved areas without vegetation showed the lowest relative humidity values at the three collection times.

Thermal comfort for patients at the Emergency Care Unit depends on this complex interaction between temperature and relative humidity. In environments where ground cover consists mainly of impermeable materials such as asphalt and concrete, temperature elevation can be significant, leading to pronounced thermal discomfort. Moreover, low relative humidity, especially in areas without vegetation, can exacerbate the sensation of heat and contribute to a less healthy environment, which is particularly concerning for vulnerable patients.

Analysis of air temperature averages showed that the nighttime period had the lowest mean, while the afternoon had the highest, 30.2 °C and 37.7 °C, respectively. The highest mean air temperatures were observed in asphalted areas at all three daily measurement times, with a difference of 7.5 °C higher at night compared to grassy surfaces. Surface temperatures of paved areas were higher than those of grassy and asphalted areas at all three times, with the highest mean at 02:00 pm (57.31 °C) and the lowest at 08:00 pm (36.2 °C). The lowest mean surface temperatures were recorded at night: 28.00 °C in grassy areas, 34.8 °C in paved areas, and 30.3 °C in asphalted areas.

Regarding morning relative humidity, the average was 71.4%, with grassy areas showing higher values compared to areas covered by artificial materials such as concrete and asphalt. Joaquim *et al.* (2018), in a study conducted in Cuiabá, observed a 16.59% variation in relative humidity between vegetated and paved areas.

Souza (2016), in his study on the relationship between solar radiation and the formation of heat islands in Cuiabá, found that air temperatures during the hot and dry period are higher between 08:00 am and 06:00 pm, while in other periods, the hot and humid period presents higher values, with

differences of up to 2 °C between the two periods.

A detailed inspection of the chart on mean air temperature and relative humidity values throughout autumn reveals the same dynamics as in the spring, with daytime gaps. Radiation peaks reach approximately 32 °C around 02:00 pm, while the trough occurs in the early morning and night, with lower temperatures at midday. Modeling and simulation with ENVI-met, as well as PMV calculation, are crucial for planning different interventions.

According to Sorano (2009), microclimatic modeling with ENVI-met and PMV analysis are essential tools to identify critical points of thermal discomfort and implement compensatory strategies, particularly regarding shaded areas and vegetation that help reduce thermal sensation and increase humidity. This is especially important during periods of the day when high temperatures and low relative humidity cause higher thermal stress.

3.2 Comparison between Hourly Mean Temperature and Relative Humidity Levels

The Mann-Whitney test was performed to compare hourly mean temperature levels between the spring (December) and the autumn (March) seasons. The test showed a statistically significant difference between the two groups ($W = 74$, $p < 0.005$), indicating that the mean temperatures during spring and autumn differ significantly.

For the analysis of relative humidity by season, the Mann-Whitney test was also used to compare the mean relative humidity between the spring (December) and the autumn (March). The test revealed a statistically significant difference between the two groups ($W = 495.5$, $p < 0.005$), indicating that relative humidity differs significantly between the spring and the autumn.

3.3 Spatial Distribution of PMV in Simulated Scenarios for the Two Seasons

Each simulation covered a total of 24 hours; however, three time periods are presented that best illustrate daily microclimatic variability and coincide with the presence of people in the health unit: morning at 08:00 am, afternoon at 02:00 pm, and evening at 08:00 pm, for both spring and autumn. In the PMV (Predicted Mean Vote) index classification, a space is considered comfortable when the PMV is between -0.5 and +0.5, indicating that the user perceives a neutral thermal sensation, represented through chromatic maps.

For comparison purposes, the maps were simulated in ENVI-met software considering two scenarios: the first, the existing scenario without trees; and the second, a vegetated scenario in which trees were proposed for the existing grassy areas and the access areas to the health unit, including the parking lot and circulation paths, aiming to understand how vegetation insertion could influence PMV.

Medium-sized, evergreen species were considered for the simulation. The species Oiti (*Licania tomentosa*) fits these characteristics and has been widely used in similar studies in Mato Grosso. Hillesheim (2021), in a study for thermal comfort adaptation at Parque das Águas, noted that Oiti is a common option for urban planting in the region, with thick leaves and a wide canopy providing ample shade.

Oiti, being native to the Pantanal, is extensively used in urban greening projects due to its characteristics that promote thermal comfort in urban areas. This medium-to-large tree has a dense, wide canopy that provides excellent shade, reducing direct solar radiation on urban surfaces and contributing to mitigating the urban heat island effect. Additionally, *Licania tomentosa* has evergreen leaves, ensuring continuous shading throughout the year, providing protection against excessive heat even during the hottest months. Its non-invasive roots make it suitable for planting near sidewalks and urban infrastructure, minimizing the risk of pavement or pipeline damage. Furthermore, the species is resistant to adverse conditions such as air pollution and water scarcity, common in the winter months of the studied ecotone, facilitating maintenance and longevity in urban environments (Hillesheim, 2021).

Other Pantanal species suitable for urban greening include:

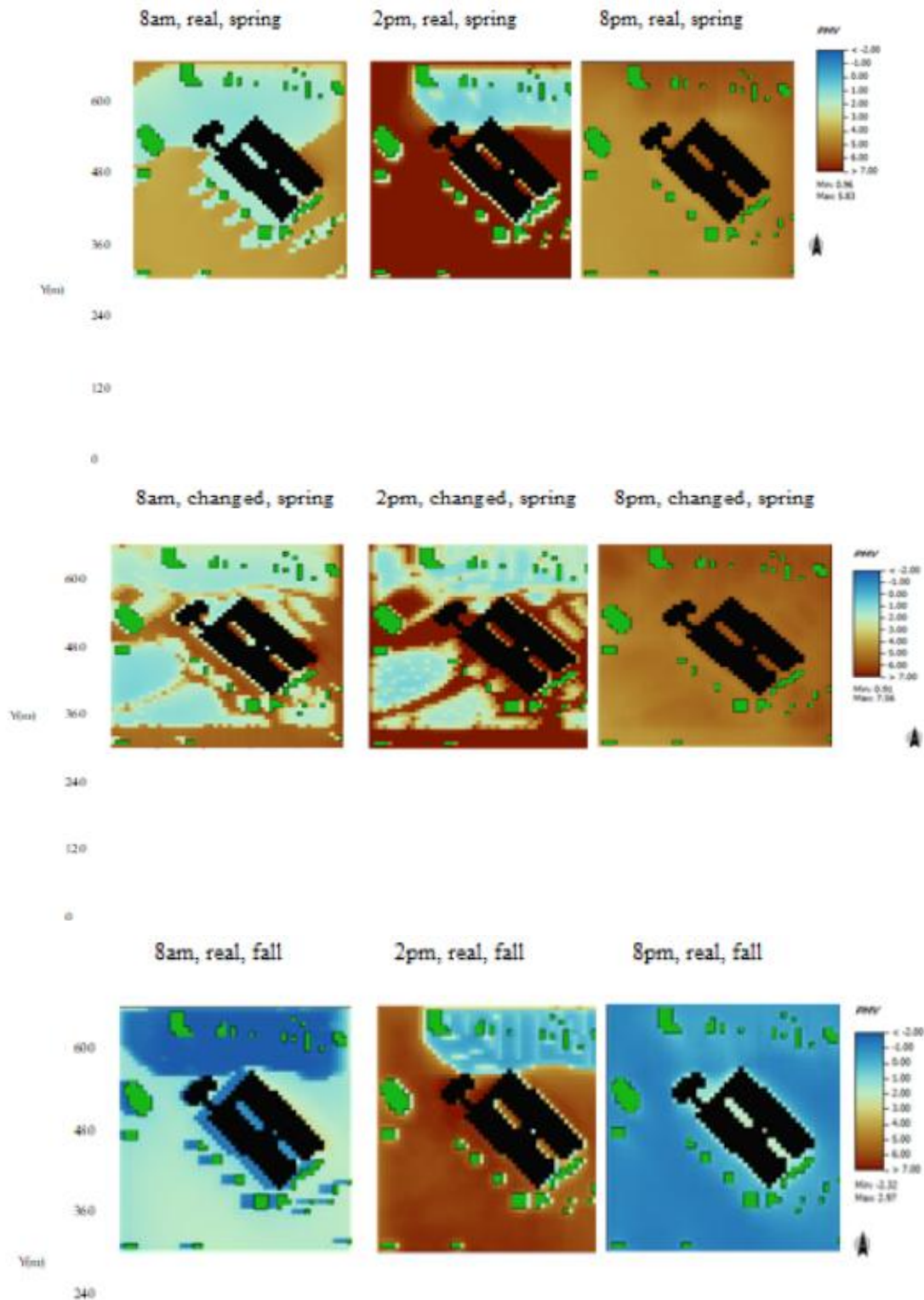
- Aroeira (*Schinus terebinthifolia*): Medium-sized, heat- and drought-resistant, with a dense canopy providing significant shade, suitable for sidewalks and public squares.
- Purple Ipê (*Handroanthus impetiginosus*): Large-sized, showy flowering, highly resistant to adverse conditions, providing shade during the summer and periods of high solar radiation.
- Cambará (*Vochysia divergens* Pool): Common in Pantanal flood areas, with a wide canopy offering shade, useful in urban areas near water bodies or infiltration zones, helping with thermal regulation and stormwater management.
- Guapuruvu (*Schizolobium parahyba*): Fast-growing, large-sized, with a broad canopy providing significant shade, ideal for high-traffic areas and open spaces, helping reduce ambient temperature (Embrapa, 2002; Rabello, 2023).

During the morning period (Figure 9) at 08:00, when solar radiation had not reached high levels yet, but some thermal energy had already been absorbed by surrounding materials, the PMV index for the real scenario in the spring ranged from comfortable to slightly warm, mainly around the health unit, in a numerical range from 0 to +2. This is explained by lower morning temperatures, higher relative humidity (average 70%), and the presence of vegetated areas, mainly behind the health unit.

For the same real scenario in the spring at 02:00 pm, during peak solar radiation, the PMV index rose to +3, indicating completely uncomfortable conditions, even in the vegetated scenario. In the evening at 08:00 pm, there were no significant changes in the chromatic map in either scenario (real

or altered), with PMV values ranging from 0.9 to +2.

Figure 9 – Spatial distribution of PMV around the Emergency Care Unit in the spring and the autumn for the studied period



Source: the authors.

For the vegetated scenario, the chromatic maps at 08:00 am in March (autumn) show an increase in areas around the Emergency Care Unit where the PMV index was mitigated. Locations benefiting from the shading of individual trees shifted from the warm scale to comfortable. The same effect was observed at 02:00 pm in the vegetated scenario for both periods, but exclusively under the tree canopy, not directly affecting the surrounding area of the unit.

The chromatic maps indicate that temperatures are lower near areas dominated by green spaces. According to Monteiro (2010), vegetation acts as a filter of radiation absorbed by the soil and built surfaces, cooling nearby environments, as tree foliage functions as protective barriers for surfaces immediately below and adjacent.

The inclusion of trees in the altered simulation demonstrates a clear improvement in thermal comfort conditions, especially during the critical period of the day at 02:00 pm. The presence of trees provided shade, reducing air and surface temperatures exposed to sunlight, resulting in a more comfortable environment (Ribeiro, 2021).

Moreover, the simulation shows a more homogeneous distribution of PMV values, indicating a more thermally balanced environment throughout the day. For an Emergency Care Unit, these improvements in thermal comfort are particularly important, as they contribute to the well-being of both patients and healthcare professionals. During the afternoon, PMV variations remained similar for both scenarios—real and vegetated—ranging from slightly warm in vegetated areas to very hot in paved areas. The addition of vegetation, while mitigating PMV values at some points within the unit, was insufficient to achieve overall comfort for the users, with key access areas such as the emergency entrance and laboratory maintaining PMV values above +3.

Ferreira *et al.* (2018), in their study on thermal comfort at Praça das Nações in Lisbon, found through ENVI-met simulation that PMV indices improved only during the morning and afternoon periods following urban redevelopment with the addition of trees and hedges.

Regarding seasonal comparison, in the autumn simulation, the chromatic maps reveal significant differences in thermal comfort throughout the day. At 08:00 am, both the real and altered scenarios show predominantly blue tones, suggesting cool conditions. In the altered simulation, this cool sensation is slightly intensified, likely due to additional tree shading reducing direct solar radiation early in the day, potentially causing greater thermal discomfort for Emergency Care Unit users during the morning, especially in a cooler season like the autumn.

At 02:00 pm, the peak solar radiation period, the real scenario shows significant thermal discomfort due to heat, with extensive areas around the building displaying red and brown tones. In this context, tree planting proved effective in moderating temperatures and reducing heat intensity. The altered simulation exhibits a more favorable color distribution for thermal comfort, with fewer

areas of intense heat. This improvement is critical for providing a more comfortable outdoor environment in the afternoon, benefiting both patients and healthcare staff.

At 08:00 pm, after the absence of solar radiation, the temperatures decrease, again reflected in blue tones on the chromatic maps. Approximately two hours after sunset, the albedo of materials such as concrete and asphalt has lost most of its energy, allowing measurements to reflect air temperature and humidity. The altered simulation continues to show a slight intensification of coolness, although to a lesser degree than in the morning. This pattern suggests that tree shading may have a less favorable effect during the night when ground radiation is lower, and temperatures tend to be cooler.

It is important to understand that relative humidity and air temperature are interdependent variables crucial in urban microclimate dynamics, directly affecting thermal comfort and habitability. As air temperature increases, the air capacity to retain water vapor also rises, reducing relative humidity if the absolute water vapor content remains constant. This interaction is key to understanding perceived thermal sensations: on hot and humid days, sweat evaporation is inhibited, amplifying the sensation of heat, a phenomenon described by the heat index. Conversely, under low relative humidity and high temperatures, sweat evaporation is more efficient, providing a milder perceived temperature despite high air temperatures (Pompei *et al.*, 2023).

In the context of growing urbanization, where rising outdoor temperatures in built environments compromise habitability and thermal comfort, it is crucial to understand the interdependence of relative humidity and air temperature, which play central roles in urban microclimate dynamics.

To address these challenges, this study proposes a simple yet accurate combined prediction model capable of evaluating outdoor thermal comfort around a theoretical isolated building, considering wind speed, relative humidity, solar radiation, and building height to quantify its effect on urban comfort at a fixed air temperature (Pompei *et al.*, 2023).

As demonstrated by Ferreira, Estevam, and Maia (2022) in their study on re-greening thermally stressed areas, this delicate balance between relative humidity and air temperature must be carefully considered in urban planning, particularly when selecting tree species for planting and designing public spaces to create more comfortable and climate-resilient environments. Beyond environmental and ecological benefits, urban vegetation provides physical, psychological, social, and economic advantages. Through shading and ventilation capture, vegetation can improve thermal comfort in hot climates, such as the tropical coastal climate. This work highlights vegetation's role in mitigating urbanization impacts, particularly in climate moderation and energy conservation. An equitable distribution of vegetation in public areas is crucial, along with effective public management in developing and implementing policies that promote urban sustainability.

Thus, tree planting significantly improves afternoon thermal comfort by mitigating excessive

heat common during this period. However, this intervention can also intensify cool sensations in the early morning and night, especially in cooler seasons like the autumn. These variations underscore the importance of careful planning in vegetation use to balance thermal comfort benefits throughout the day. Tree species selection, placement, and proper management are essential to maximize benefits and minimize potential adverse effects on Emergency Care Unit users. As Kongkoon *et al.* (2023) state, outdoor thermal comfort is directly influenced by trees and shrubs, which enhance perceived thermal comfort in outdoor spaces, particularly during afternoon periods of heightened discomfort.

Therefore, incorporating vegetation into urban design can promote the residents' well-being. When choosing between trees and shrubs, trees provide superior eco-efficiency across scenarios, suggesting that investing in trees is more advantageous to optimize outdoor thermal comfort and justify associated costs. For instance, 50% tree coverage yields the highest eco-efficiency, indicating that strategic tree placement can maximize benefits while minimizing costs (Kongkoon *et al.*, 2023).

4 Conclusion

PMV values at 02:00 pm in both scenarios were extremely uncomfortable, explained by high local temperatures and possible limitations of the BIO-met program for tropical climates. Vegetation did not show a significant influence on thermal comfort data at 08:00 pm in either season.

The spatial distribution of PMV highlighted specific areas influenced by tree planting, confirming the strategic importance of vegetation in urban microclimates. Evaluating vegetation effects on temperature, humidity, and air quality aided in selecting appropriate species and green space locations to maximize benefits, enabling healthier and more sustainable cities.

ENVI-met proved to be a valuable tool for comfort studies, allowing modeling and simulation of hypothetical scenarios and enabling analysis of how trees can contribute to thermal comfort adaptation in public spaces. Consequently, this study provides a foundation for developing urban planning projects and strategies adapted to local realities.

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