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SUSTAINABLE BIOCLIMATIC STRATEGIES FOR RIVERSIDE DWELLINGS IN THE BRAZILIAN AMAZON

Estratégias bioclimáticas sustentáveis para habitações ribeirinhas na Amazônia brasileira

Estrategias bioclimáticas sostenibles para viviendas ribereñas en la Amazônia brasileña

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Abstract: The present research presents an unprecedented study, which verified bioclimatic strategies for the riverside region of the Brazilian Amazon, through the analysis of the international literature, data collection and qualitative analysis of the microclimatic situation of a local stilt house and the thermoenergetic simulation of the strategies presented in the literature. The results show that the dwelling analyzed presents internal values of air temperature and relative humidity that are constantly high, as well as low values of wind speed. On the other hand, the simulations pointed out efficient and economically feasible strategies to improve the comfort conditions of the analyzed dwelling and also provided an analysis of the internal microclimatic situation of the same dwelling if it were built with another typology. We conclude that human comfort conditions can be improved with the adoption of viable and easily implemented solutions.

Keywords: Sustainability, thermal comfort, bioclimatic strategies, Amazon.

Resumo: A presente pesquisa apresenta um estudo inédito, que verificou estratégias bioclimáticas para a região ribeirinha da Amazônia brasileira, através da análise da literatura internacional, coleta de dados e análise qualitativa da situação microclimática de uma habitação local da tipologia palafita e a simulação termoenergética das estratégias apresentadas na literatura. Os resultados mostram que a habitação analisada apresenta valores internos de temperatura do ar e umidade relativa constantemente altos, assim como baixos valores de velocidade do vento. Por outro lado, as simulações apontaram estratégias eficientes e economicamente viáveis para melhorar as condições de conforto da habitação analisada e também forneceram uma análise da situação microclimática interna da mesma habitação, caso fosse construída com outra tipologia. Conclui-se que as condições de conforto humano podem ser melhoradas com a adoção de soluções viáveis e de fácil implementação.

Palavras-chave: Sustentabilidade, conforto térmico, estratégias bioclimáticas, Amazônia.

Resumen: La presente investigación presenta un estudio inédito, que verificó estrategias bioclimáticas para la región ribereña de la Amazonia brasileña, a través del análisis de la literatura internacional, la recolección de datos y el análisis cualitativo de la situación microclimática de un zancudo local y la simulación termoenergética de las estrategias presentadas en la literatura. Los resultados muestran que la vivienda analizada presenta valores internos de temperatura del aire y humedad relativa constantemente elevados, así como valores bajos de velocidad del viento. Por otro lado, las simulaciones señalaron estrategias eficientes y económicamente viables para mejorar las condiciones de confort de la vivienda analizada y también proporcionaron un análisis de la situación microclimática interna de la misma vivienda, si se construyera con otra tipología. Se puede concluir que las condiciones de confort humano pueden mejorarse adoptando soluciones factibles y fáciles de aplicar.

Palabras clave: Sostenibilidad, confort térmico, estrategias bioclimáticas, Amazonas.

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1. INTRODUCTION

The vernacular architecture that underlies the riverside dwellings of the state of Amazonas, Brazil, occurs in the construction of several factors, which originate in caboclo culture, in the water cycle, the materials available in the region and local climatic conditions. In the most isolated areas it is possible to find houses built in wood with a straw cover, reflecting the indigenous influence, but in the regions near the urban centers we can see the influence of industrialized materials.

Based on this, the dwellings of the Amazon region, located on the banks of local rivers, should be compatible with the annual variation of the watercourse and in this context, three types of house are predominant: the stilt (A), the floating (B) and the house supported on the ground (C), as in Figure 1. Both typologies are basically built of local wood, with thin walls, metallic tile roofs and without the use of lining.

Figure 1: Constructive typologies of the region.

Source: The authors.

In this region, high values of air temperature and humidity, as well as low air speed, typical of hot and humid climate regions, are impacting factors in the daily routine of riverside dwellers, especially in the internal conditions of the dwellings. In view of this, the international literature suggests some strategies that can be efficient for regions of the same climatic type.

Yldiz and Arsan (2011) point out the importance of the openings area and orientation of the facades aiming at the best utilization of the prevailing winds. Cheng, Ng and Givoni (2005) argue that the composition of the walls, orientation of the room and openings, as well as the effect of the color of the external closings can directly affect the internal air temperature of the dwellings. For the authors, color is one of the most effective and economical means of reducing internal temperature in hot and humid climate regions, corroborating with research by Givoni (1994) and Synnefa, Santamouris a Akbari (2007), when they state that the effect of reflectance of the roof by means of color reduces internal cooling loads, hours of discomfort and temperature peaks.

Chungloo and Limmeechokchai (2007) verified the performance of the chimney effect together with the spraying of water on the roof and indicated these strategies as positive in the reduction of internal temperatures in Thailand, a region of the same climatic type as Manacapuru-AM. Another effective bioclimatic strategy for hot and humid climate regions is geothermal, which uses underground buried pipes, causing the soil to become a sink of the ambient air through the conduction of the buried pipe (SANUSI, SHAO AND IBRAHIM, 2013).

The high values of relative humidity of the internal air are influenced by several factors, such as human presence and activity in the place, electronic equipment, rate of change and air flow in the rooms, release and absorption of moisture through the hygroscopic surfaces of the materials and, of course, the moisture content of the external air (WOLOSZYN et al 2009). At times, high humidity values in indoor environments are neglected in some research, even though it has important consequences on the health of dwellers: growth of microorganisms (mold, bacteria and fungi), air quality, building durability and implications on the consumption of energy (SIMONSON; SALONVAARA; OJANEN, 2002; WOLOSZYN et al., 2009; DOE; KUBOTA, 2015).

SIMONSON; SALONVAARA; OJANEN (2002) suggest that fans, air conditioning and heating can assist in the control of internal humidity, however in hot and humid climates such mechanisms may not be able to control the latent load, and humidity ends up exceeding the recommended limits of 60% to 70% (ASHRAE Standard 55, 2010). Nematchoua (2015) states that permeable internal coatings such as wood and plaster show a marked improvement in the indoor environment when compared to environments with impermeable coatings such as paint and plastic. The permeable coatings of the walls provide moisture absorption when it is very high, as well as its release when it is low (NEMATCHOUA, 2015). Simonson, Salonvaara and Ojanen (2004) state that the use of hygroscopic materials, besides improving internal humidity levels, contributes to the diffusion of pollutant gases through the envelope, reducing the internal concentration of contaminants.

Another form of control of the internal air relative humidity was investigated by Woloszyn et al. (2009), who states that the use of the moisture-damping capacity of building materials, more specifically wood, combined with the effect of ventilation, are effective ways to reduce daily amplitude and humidity variations. Lucas et al. (2001) corroborates the importance of ventilation in the use of hygroscopic structures, pointing to its potential to minimize condensation in very humid places.

As for air speed, Lobo and Bittencourt (2003) state that indoor air movement is acceptable between 0.5 m/s and 2.0 m/s and that upper limits could cause turbulence problems instead of comfort conditions. However, they point out that for hot and humid climates, higher speeds can promote thermal comfort, compensating for such disadvantages. Likewise, when analyzing the speed limits for hot and humid climates established by ASHRAE 55 (2010) and ISO 7730 (2005) norms, Cândido et al (2010 a) suggest changes in the maximum internal wind speed limits, taking into account that the air movement that is considered uncomfortable in other types of climate can be considered as comfortable in hot and humid climates. The authors' research found values of acceptance between 0.80 m/s and 1.60 m/s, data directly related to the thermal perception, in which the user's indoor climate expectancy varies according to the context in which the dwelling is inserted (DE DEAR, LEOW, FOO; 1991).

Wong et al. (2002) observed that the air movement has an influence on the comfort feeling of the residents of Singapore, alleviating the effects of high temperature and increasing the sensation of comfort of inhabitants, considering that the occupants prefer to first take adaptive measures of environmental control (window, fan, air conditioning) to later resort to personal adjustments involving thermoregulation (clothing, bath, drinks), which corroborates the adaptive approach, in which the user of a naturally ventilated environment is considered a dynamic subject who interacts with his surroundings adjusting to the internal temperature, and not a passive occupant, subject only to the internal conditions (DJAMILA; CHU; KUMARESAN, 2013), factors that are favorable to the application of natural ventilation strategies. On the other hand, Nguyen, Singh and Reiter (2012) affirm that in situations of very high temperature and humidity adaptive actions may not be as effective, which may indicate the need for association of bioclimatic strategies to HVAC systems.

Another strategy with positive potential is the one analyzed by Kubota, Chyee and Ahmad (2009), who analyzed the potential of night ventilation in Malaysia, a hot and humid climate region, and observed that this strategy provides better thermal comfort conditions for twin houses compared to other ventilation strategies, proving to have great potential in the elimination of the use of air conditioning at night - AC. Of course, the performance of night ventilation depends on environmental climatic conditions as well as the physical parameters of the dwelling, however it is a passive, inexpensive cooling technique that can contribute to reduce the cooling load of the dwelling, besides improving the thermal comfort of occupants (KUBOTA; CHYEE; AHMAD, 2009).

Toe and Kubota (2015) also highlight the potential of night ventilation for cooling the indoor environment and suggest the use of exhaust fans and atriums to increase the rate of ventilation of the dwelling throughout the night, noting that openings close to the ceiling favor release of hot air.

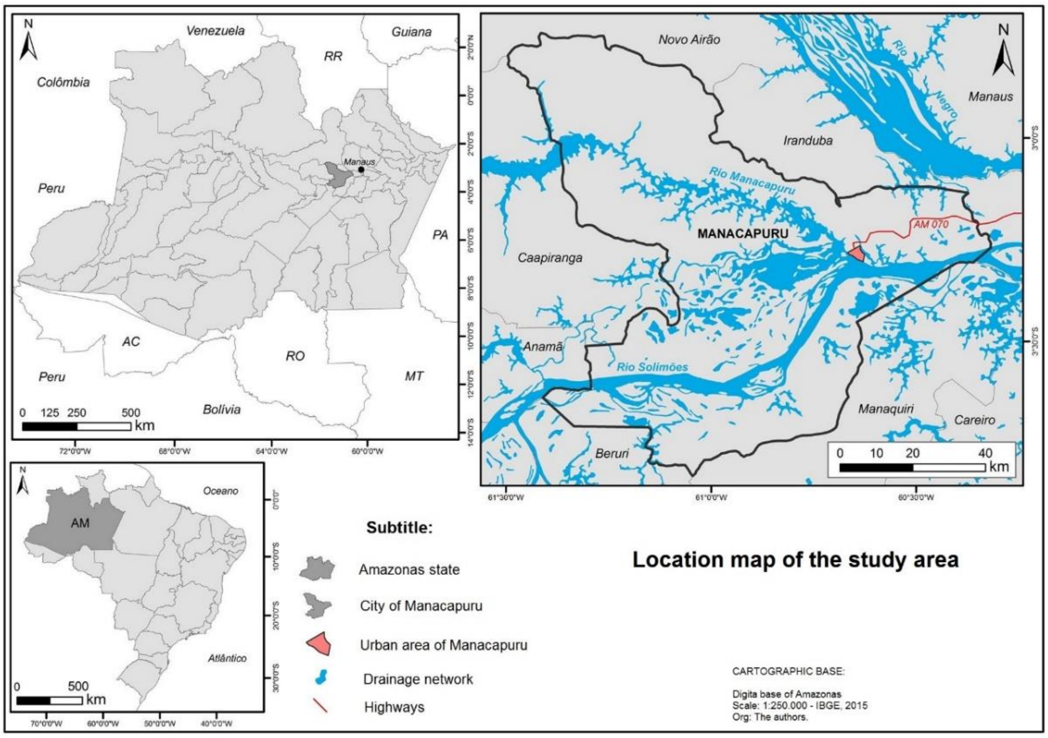
In naturally ventilated buildings, the facade ends up taking on greater importance in thermal performance, leaving climatic conditions behind, therefore the increase of the relation between wall and window proves to be favorable in the improvement of comfort when allied to the horizontal devices of shadowing in the four facades (LIPING; HIEN, 2007; YILDIZ; ARSAN, 2011). Givoni (1994) also suggests that facades oriented at 30º to 120º angles oblique to dominant winds, combined with the use of openings in the windward and leeward walls, can provide effective cross ventilation.

Based on these observations, the objective of this research is to present an unprecedented study, which qualitatively analyzes the microclimatic scenario of riverside dwellings in the Amazon region through the collection of indoor meteorological data of a dwelling, as well as to analyze the effectiveness of some of the strategies pointed out in the literature for the same climatic type, by means of thermoenergetic simulations, with the purpose of discussing, understanding and indicating possible bioclimatic strategies for riverside dwellings of the stilt typology (built on pilotis) and house supported on the floor typology in the Amazon region.

1.1 Location of the study area and climatic characterization of the region

The study area comprises the municipality of Manacapuru, Amazonas, located on the banks of the Solimões River, where the research was carried out in two riverside communities of the municipality, "Pesqueiro" and "Rei Davi - Calado" (Figure 2).

Figure 2: Location map of the study area.



Source: Celuppi *et al.* (2019).

The region of the Brazilian Amazon to which the study area belongs is classified according to Alvares *et al*. (2013) as "tropical zone without a dry season," which means annual averages of air temperature in the range of 26.7ºC, with little seasonal variation, as well as annual precipitation of 2,420 mm, with August being the driest month, in which the monthly precipitation is in the range of 80 mm, while Dubreuil *et al.* (2018) classifies the climate of the Manacapuru region as "Am" (hot monsoon climate).

As for the large-scale atmospheric circulation and the predominant wind patterns in the study region, Paccini *et al.* (2018) point out that the low-level daily winds, according to the period from 1979 to 2014, are predominantly north-northeast, originating in the northeast Atlantic.

2. METHOD

2.1 Collection of meteorological data

For the collection of internal meteorological data, this study was based on the work of Hwang et al., (2009), who verified the correlation between thermal sensation and thermal dissatisfaction for tropical climate regions. For this collection, a portable automatic meteorological station (Figure 3) was used, which was exclusively developed for the present research, with the following sensors:

- Dry bulb and wet bulb temperature sensors to obtain data on temperature and relative humidity, which collected data at 10 minute intervals.
- Anemometer, to obtain wind speed and direction data, which will collect data at 1 minute intervals;
- Black globe thermometer to obtain the mean radiant temperature (MRT), which will collect data at 10 minute intervals.

Figure 3: Portable automatic meteorological station used in the research.

Source: The authors.

The aforementioned instrumentation was connected to a system for reading and collecting data on an SD memory card. It was decided to install the mentioned station in a single dwelling of the stilt typology. For this, we looked for a wooden stilt house, with metallic tile roof and without lining, a characteristic typology of the locality analyzed.

The portable automatic meteorological station was installed in the "Pesqueiro" riverside community, in the municipality of Manacapuru, in the state of Amazonas, measuring 48 uninterrupted hours, from August 15 to 17, 2017. The meteorological station was installed in a room in the central area of the residence, which collected data every 1 minute. The collection of meteorological data took place from 10 a.m. on August 15, 2017 until 10:55 a.m. on August 17, 2017.

Data from the INMET meteorological station in the city of Manacapuru, located 9 km away from the housing analyzed, were used to collect external data regarding air temperature, relative humidity and wind speed. The use of data from this meteorological station was considered, considering that the different microclimates of this region are directly influenced by the local climate, which according to Ribeiro (1993), considers between 15 to 150 km, as an appropriate spatial scale for the local climate. Consequently, because there is no urban influence in this location, the local climate is strongly influenced by the regional climate (MONTEIRO, 1976; RIBEIRO, 1993; OKE, 2004; GOBO, GALVANI, WOLLMANN et al. 2018) and this transfer of information from higher scales to lower scales of the climate can be seen through the work of Palus (2014), Groth and Ghil (2011, 2015) and Jajcay et al. (2016).

For the analysis of the data collected in the field during the three days of measurements, they were tabulated and consolidated in a Microsoft Excel® worksheet for graphic treatment and were later discussed.

To build the wind rose, shown in figure 16, we used WRPLOT View - Version 8.0.2 - Wind Rose Plots for Meteorological Data Software.

2.1 Thermoenergetic simulations

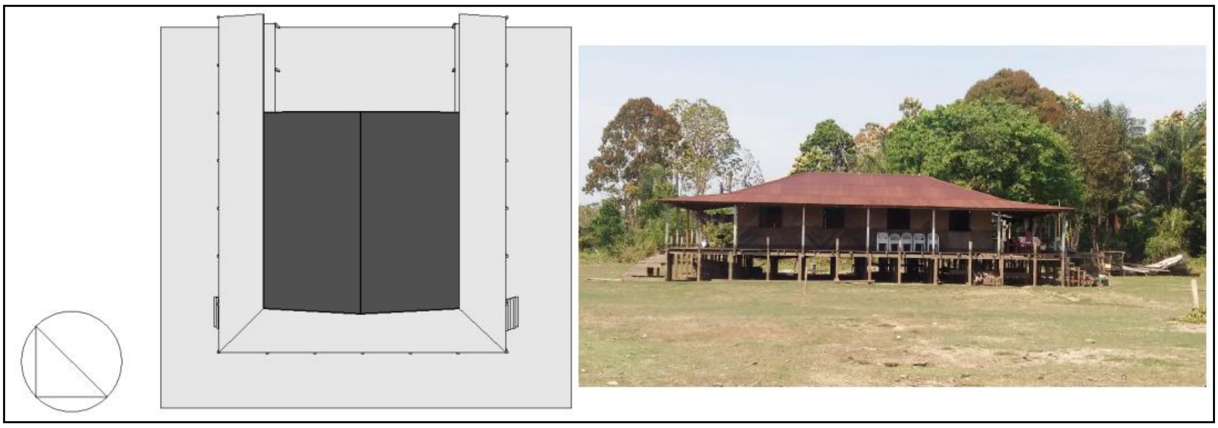
In order to understand and validate strategies pointed out in the literature, we used the DesignBuilder simulation software version v6.0.0.125. For the hourly climatic data (air temperature, wind direction and speed) of a full year, data from the city of Manacapuru - AM were used. Such climatic data were obtained through the Laboratory of Energy Efficiency in Buildings of UFSC - LabEEE.

DesignBuilder is a tool that was released in 2005 by DesignBuilder Software Ltda. as a graphical interface for the EnergyPlus software. It is an instrument to identify the impact of energy consumption considering factors such as volumetry and zoning, allowing the testing of several solutions based on their cost-effectiveness, facilitating decision making.

Freire et al. (2013) verified the adequacy of the Autodesk Ecotec Analysis and DesignBuilder software as tools to be used in the evaluation of thermal performance of buildings, and DesignBuilder stood out in thermoenergetic simulations, providing great reliability in the results, having as a differential "resources that contemplate dynamic phenomena in buildings, according to usage patterns, such as the activation of shading and ventilation devices associated with values of radiant energy and air temperature" (FREIRE et al. 2013 p. 8), making it a favorable tool for this research.

The model used in the study was based on the dwelling where the portable automatic meteorological station (CELUPPI et. al 2019) was installed in the Pesqueiro community during the on-site research period and is oriented with the main north-west facade, as shown in Figure 04.

Figure 4: Orientation of the simulated model.

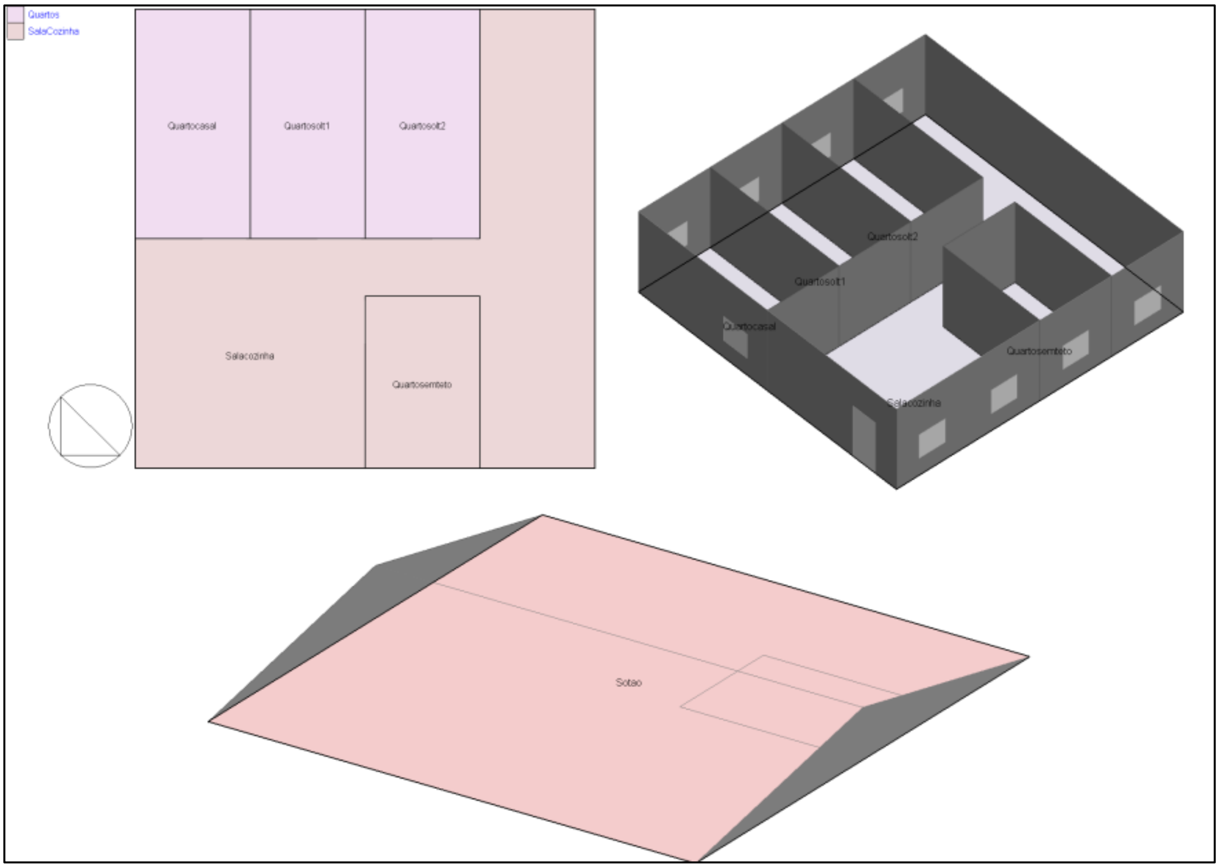


Source: DesignBuilder. Org.: The authors.

In the thermodynamic simulation, a building must consist of one or more fully enclosed thermal zones, with each of these zones representing a room or space within the building. Each thermal zone can have different geometries, and therefore different areas and volumes, as well as different input data for thermal calculations: occupancy profiles, metabolic activities, lighting profiles, equipment, HVAC systems, ventilation, among other variables required in the calculations.

In the elaborated models, 6 thermal zones were adopted, being 5 zones as domestic environments and an unoccupied space representing the attic of the house. The occupied thermal zones were named as: "QUARTOCASAL", "QUARTOSOLT1", "QUARTOSOLT2", "SALACOZINHA", "QUARTOSEMTETO" and the unoccupied thermal zone, named "SOTAO", as in Figure 5. The "QUARTOSEMTETO" and "SOTAO" thermal zones are interconnected, because this room does not have lining.

Figure 5: Simulated thermal zones.



Source: DesignBuilder. Org.: The authors.

As occupancy criteria, three people were adopted for the purpose of internal gain during the day, from 6:00 am to 6:30 p.m., and six people during the night, from 6:30 p.m. to 6:00 a.m. The lighting power adopted was 2 W/ m²-100 lux and 150 lux target illuminance. Likewise, the total sum of the internal equipment adopted for the buildings was 1 W/m².

External walls, windows, floors, ceilings, and balconies were assumed to be made of 2.3 cm "cumaru" wood, following the thermal, conductivity and specific heat properties of the "oak radial" material in the DesignBuilder software, as it does not have "cumaru wood" in its database.

In order to understand the effectiveness of some of the bioclimatic strategies identified in the introduction of this research, different types of coverings were simulated, giving rise to the analyzed models.

- Model 1: called "dwelling built on pilotis with oxidized metallic roof", using 0.4 mm zinc and surface finish of oxidized metal.

• Model 2: called "dwelling built on pilotis with metallic roof painted white", using 0.4 mm zinc and white paint.

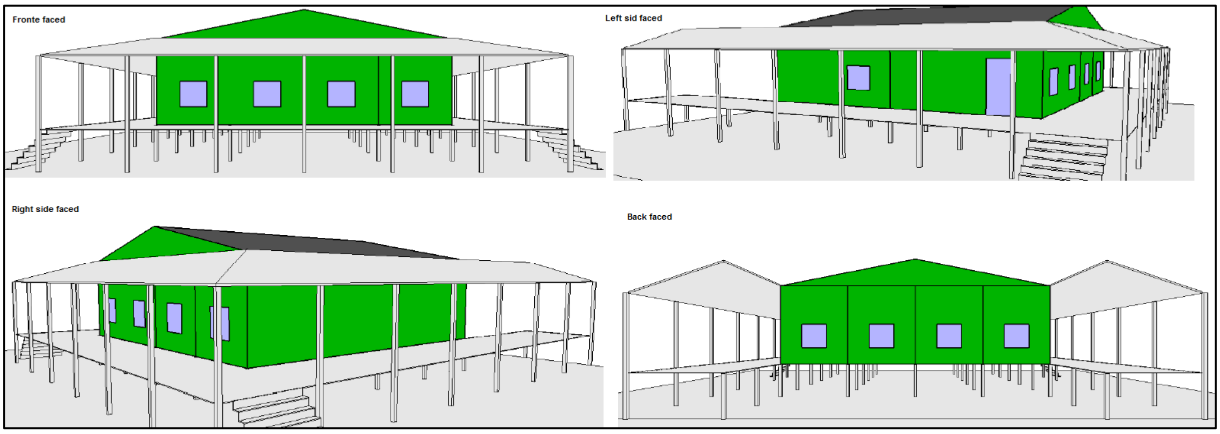
• Model 3: called "dwelling built on pilotis with cumaru wood roof", with coverages of material identical to the one of the walls, with 2.3 cm.

• Model 4: called "dwelling built on pilotis with sandwich tile", covered with 0.4 mm zinc plates in the outside and inside, and EPS thermal insulation with 3 cm between plates, with new paint in the white color.

• Model 5: identical to model 1, however, without eaves.

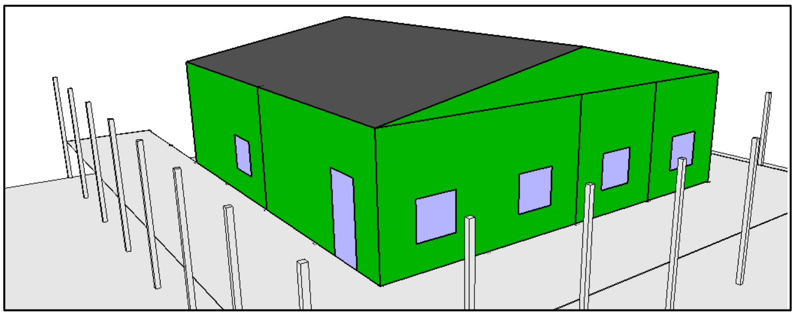
The geometric profile of models 1 to 4 are identical (Figure 6). Model 5 (Figure 7) is different because it does not have eaves, that is, the balcony areas on the sides, like the other models. The differential of this model is not to have eaves on the balconies and this simulation had the intention to verify the behavior of the building without the shadowing caused by the eaves in the facades of the building.

Figure 6: Models 1 to 4.



Source: DesignBuilder. Org.: The authors.

Figure 7: Model 5.

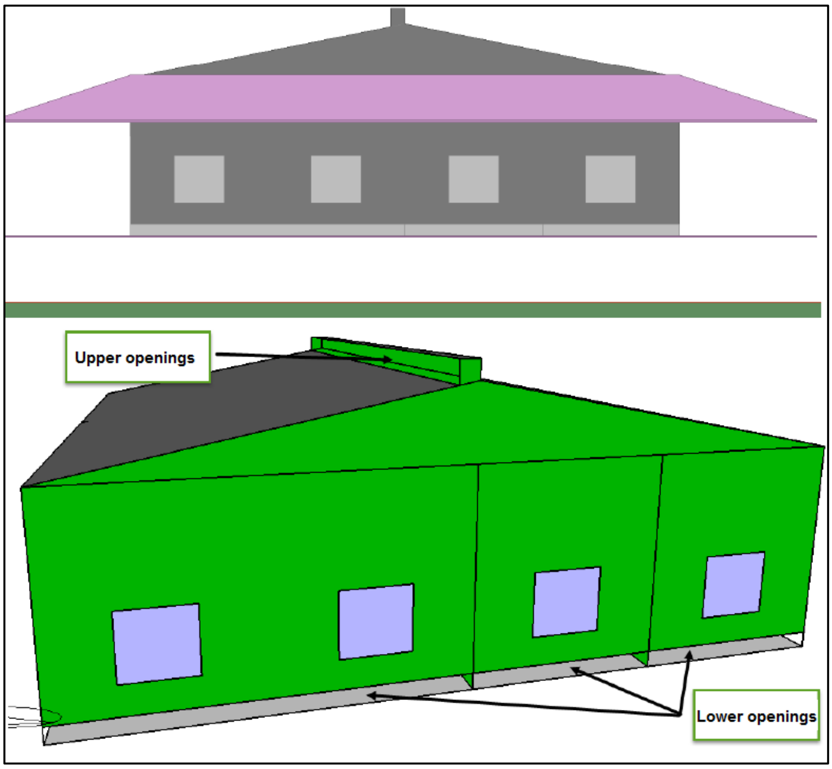


Source: DesignBuilder. Org.: The authors.

Model 6 (Figure 8) was also created in order to verify the chimney effect. In this model, openings were added on the side of the chimney and in the lower part of the zones. For the calculation of the CFD model, a specific day was chosen during the year (July 30 at 12.00 p.m.) and the option of "calculated natural ventilation" was used, in which the software automatically calculates the airflow based on several parameters, such as coefficients and climatic data.

The windows were modeled as Doors in DesignBuilder, considering that they are made of wood. The floor was modeled with exterior floor, therefore the heat exchange was carried out with the outside air, not with the ground.

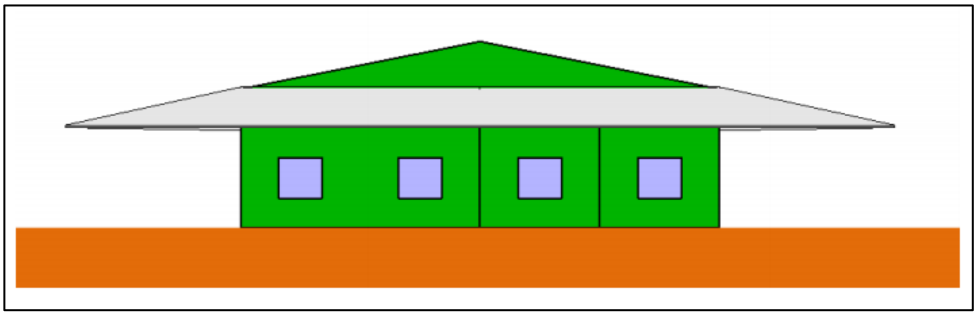
Figure 8: Model 6 - Chimney effect.



Source: DesignBuilder. Org.: The authors.

We also created model 7 (Figure 9), which is identical to model 1 (plain oxidized sheet metal - 0.4 mm zinc coverage and oxidized surface finish), in order to represent and understand the performance of the analyzed dwelling if built directly on the ground, rather than built using the pilotis (dwelling of the stilt typology).

Figure 9: Model 7 - Dwelling built directly on the floor.



Source: DesignBuilder. Org.: The authors.

It should be noted that we tried to simulate the three dwelling models found in the region: stilts, floating and house built directly on the ground. However, it was not possible to simulate the "floating" dwelling because the software does not have the algorithm for simulating dwelling over water. Based on this, the results of the simulations between typologies compares only the "stilt" and "house on the ground" models.

Table 1 presents the synthesis of surface properties of simulated materials on the roof of the models.

Table 1: Surface properties of roofing materials.

	Roof type	Thermal Absorptance	Solar Absorptance	Reflectance	Visible Absorptance
Model 1 and 6	Oxidized roof	0.12	0.85	0.15	0.85
Model 2	White Metallic Roof	0.9	0.2	0.5	0.2
Model 3	Wood	0.9	0.5	0.8	0.5
Model 4	Sandwich Tile	0.9	0.2	0.5	0.2
Model 5	Oxidized roof without eaves	0.12	0.85	0.15	0.85
Model 7	Oxidized roof	0.12	0.85	0.15	0.85

Source: NBR 15220 and DesignBuilder. Org.: The authors.

3. RESULTS AND DISCUSSION

3.1 Qualitative microclimatic characterization of the dwelling

Frontczak and Wargocki (2011), in a review of the literature on the most influential factors on indoor comfort, analyzed aspects related to thermal comfort, visual comfort, acoustic comfort and good air quality, concluding that users consider thermal comfort as the most important parameter in the internal quality of an environment and, in view of this, the challenge of current research on thermal comfort is to find effective strategies to overcome the discomfort state, using as little energy as possible (ZAIN; SHAHRIZAM; BAKI, 2007).

Given the relevance of thermal aspects of comfort, we analyze here the meteorological data collected inside the dwelling, which were tabulated and consolidated in a Microsoft Excel® spreadsheet for graphical treatment. The daily averages of wet bulb temperature (WBT), dry bulb temperature (DBT), relative air humidity (RH) and average and maximum wind speed (WIND SPEED) were used, according to Table 2.

Table 2: Daily averages.

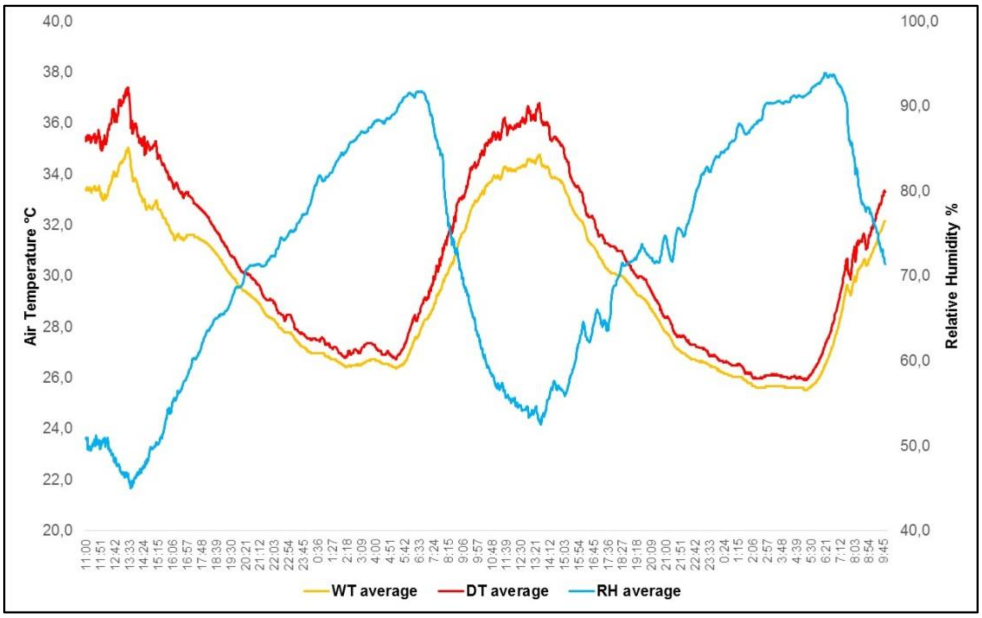
Date	Ave. DBT	Ave. WBT	Ave. RH	WIND SPEED Ave.	WIND SPEED Max.
8/15/2017	33.0 °C	31.5 °C	58.7%	0.0 m/s	1.6 m/s
8/16/2017	30.7 °C	29.7 °C	72.8%	0.0 m/s	1.6 m/s
8/17/2017	27.7 °C	27.1 °C	86.9%	0.0 m/s	1.7 m/s

Source: The authors.

There is a discrepancy in the data during the three days of analysis regarding the averages of August 15, 2017, which overestimate the afternoon and evening data, as measurements began at 10:00 am, the same as on August 17, 2017, where dawn and morning data are overestimated, as measurements ended at 10:50 am. Thus, the average data for August 16, 2017, can be considered the most characteristic for the analysis period, as they comprise data measured over 24 hours, ie a full day of analysis. Thus, averages with high air temperature and relative humidity, as well as low wind speed, are perceived.

In Figure 10, the graph corresponding to the DBT, WBT and internal RH time progression during the analysis period is observed. DBT ranged from 25.9°C to 37.4°C, while WBT ranged from 25.5°C to 34.9°C. The air RH ranged from 45% to 93.6%. It is observed that in the cooler periods throughout the day, that is, at dawn, the RH reaches its maximum values, reaching 90%, making the dwelling uncomfortable.

Figure 10: Time progression of dry and wet bulb temperatures and relative humidity of indoor air.

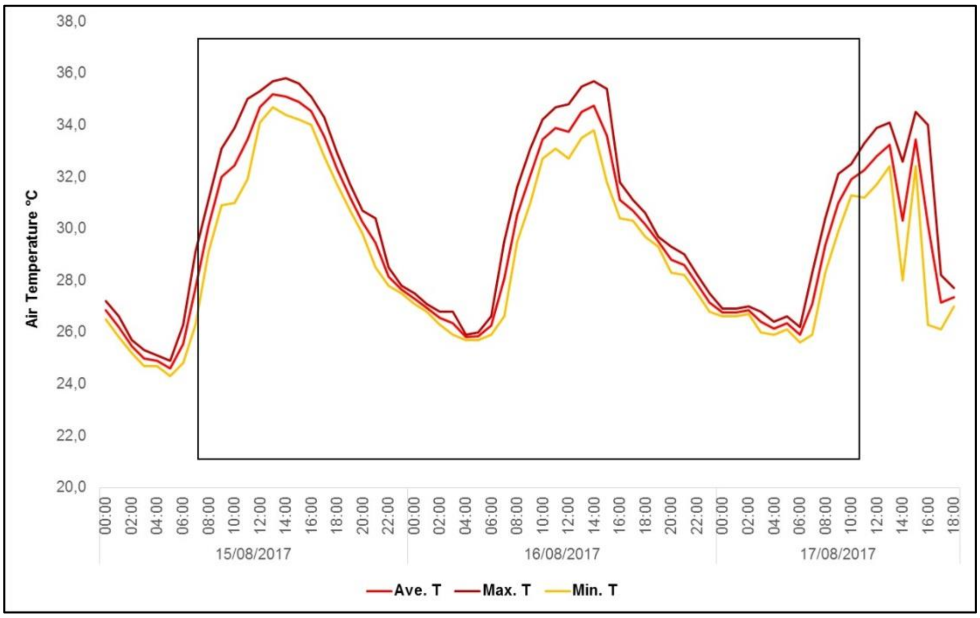


Source: The authors.

In Figure 11, we can see the data regarding the maximum, average and minimum external air temperature, obtained through the INMET automatic meteorological station, located in the urban area of Manacapuru-AM. The data comprised within the table highlighted in the figure represent the time simultaneous to the internal measurements. If in the internal measurements of average temperature, data were collected in the range of 25.9°C and 37.4°C, the average external data indicate values ranging from 24.8°C to 35.2°C, which shows that the dwelling analyzed gives residents average temperature ranges higher than the external environment.

When analyzing the maximum external temperatures, it is noticed that they are in the range of 24.9°C to 35.8°C, ie the internal average values exceed the external maximum values. The minimum external temperatures are in the range of 24.3°C to 34.7°C. It is important to highlight that the INMET meteorological station is located in the urban area of the municipality, which means, in theory, that it is influenced by the urban climate, denoting higher external temperatures than in the rural areas of the municipality.

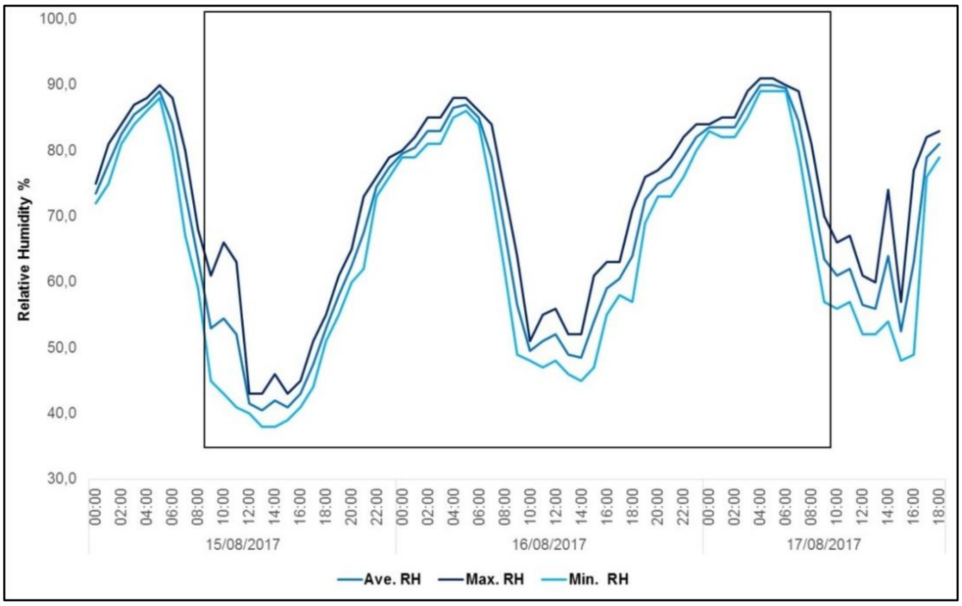
Figure 11: Time progression of external air temperature.



Source: The authors.

Figure 12 shows the data regarding external RH. The average data present values in the range of 40.5% to 89%, while the internal average data (Figure 10) present values between 45% and 93.4%. It is observed here again that the values of the average internal data exceed the average external values and such values are influenced by several factors such as: human presence and activity, equipment, rate of air change and flow in the rooms, release of the absorption of humidity through hygroscopic surfaces of materials (dwelling and furniture) and humidity content from outside (WOLOSZYN et al., 2009).

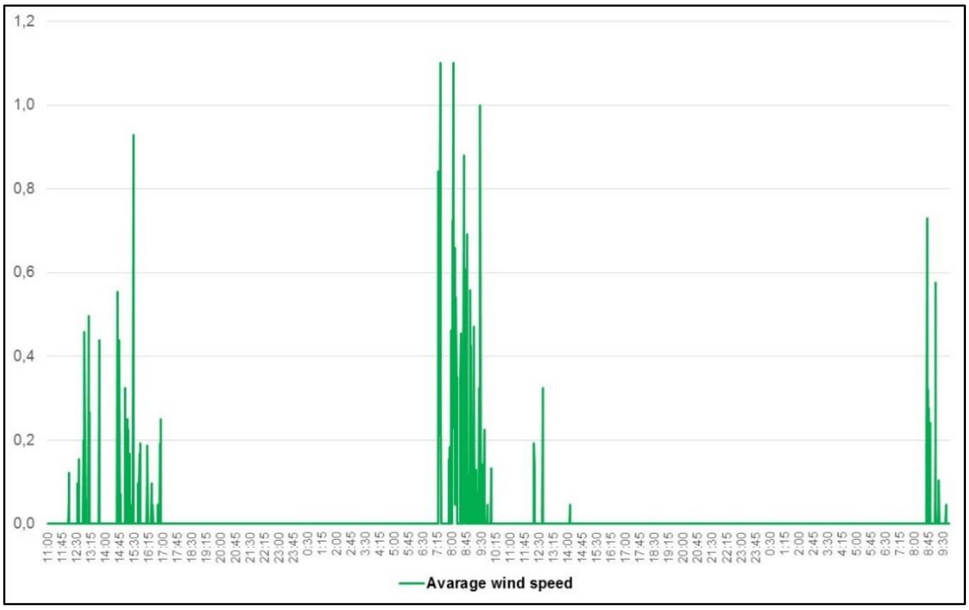
Figure 12: Time progression of external air relative humidity.



Source: INMET. Org.: The authors.

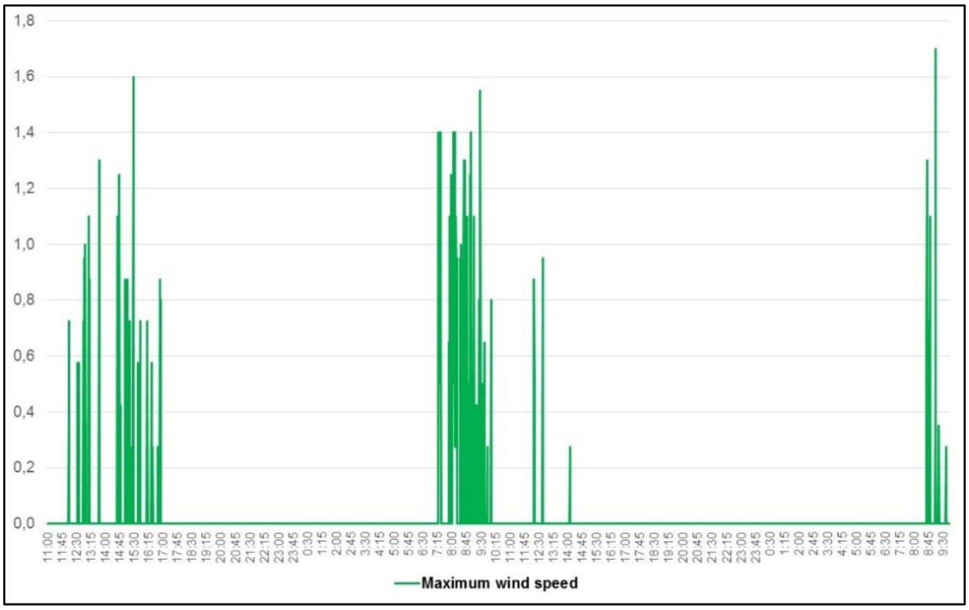
Figures 13 and 14 show, respectively, the data regarding the average and maximum internal wind speed, while Figure 15 shows the average and maximum wind relative to the external environment. The average internal speeds are in the range of 0 to 1.1 m/s, while the maximum speeds are in the range of 0 to 1.6 m/s. It should be noted that the maximum values observed here are wind gusts that occurred over a short period of time, as shown in Figure 11.

Figure 13: Average hourly speed of internal wind.



Source: The authors.

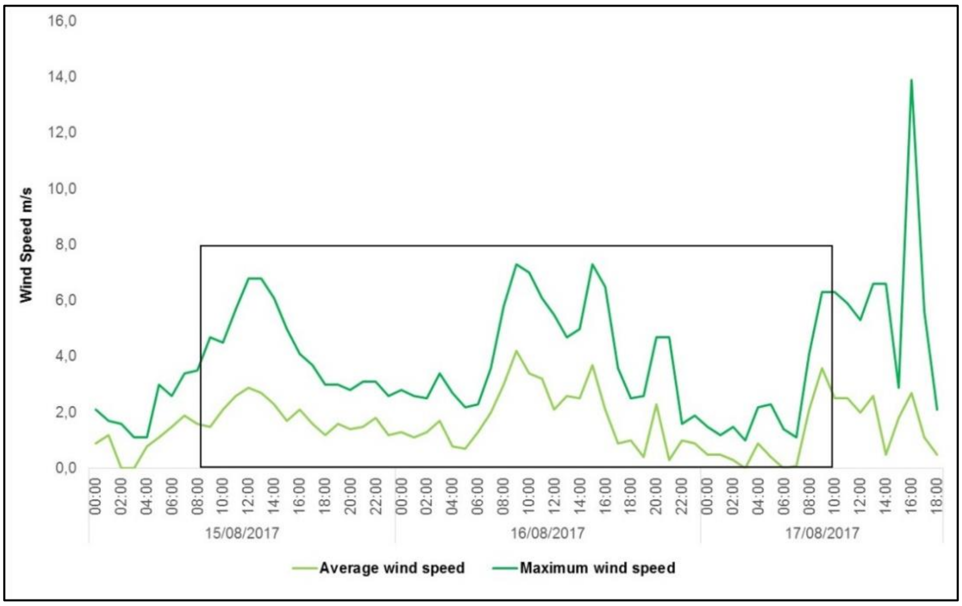
Figure 14: Maximum hourly speed of internal wind.



Source: The authors.

Still observing the external data (Figure 15) that comprise the simultaneous period of internal measurements, it is noticed that the average external speeds are in the range of 0 to 4.2 m/s, while the maximum (gusts) values are between 0.1 to 7.3 m/s. It is important to remember that the INMET automatic meteorological station wind sensor is located 10 m high, while the indoor portable automatic meteorological station wind speed sensor is 1.75 m high.

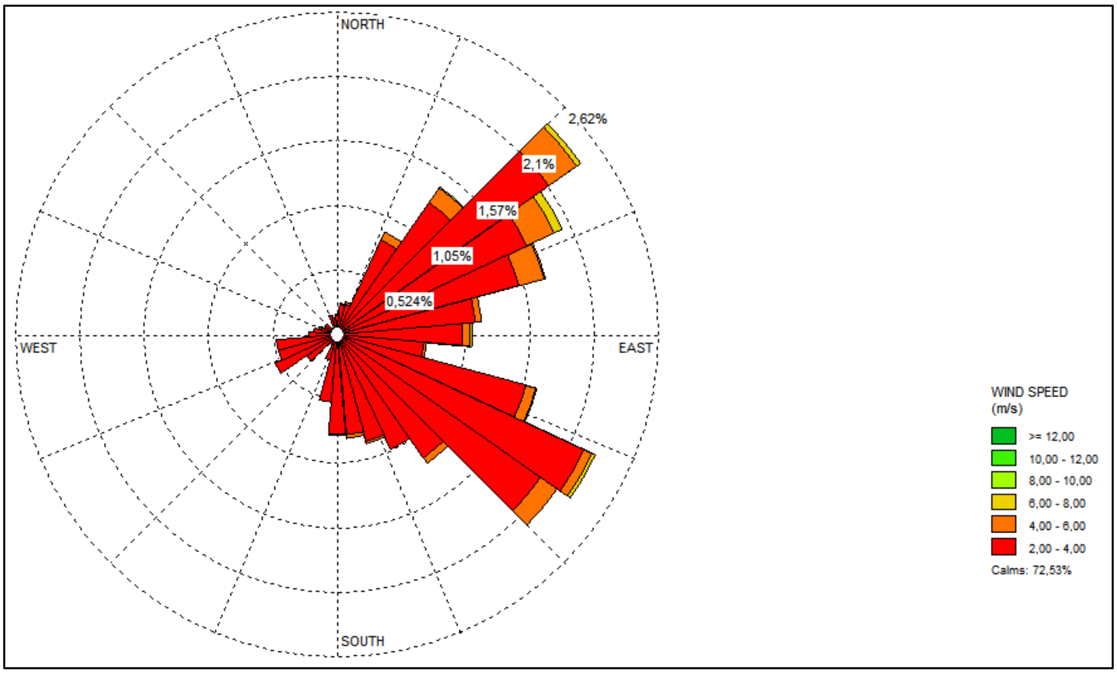
Figure 15: Average and maximum hourly speed of external wind.



Source: INMET. Org.: The authors.

Using data from the INMET meteorological station, located in the urban area of Manacapuru, a wind rose was developed to analyze the average wind speed and direction for a one-year period (July 2017 to June 2018). According to Figure 16, the wind speed is low throughout the year and the prevailing wind direction for the study region is northeast/southeast. Therefore, it is recommended that local dwellings use the main openings in this direction to make the most of natural ventilation.

Figure 16: Wind rose for the period between June 2017 and July 2018.



Source: The authors.

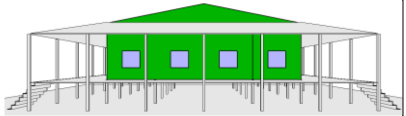
3.2 Thermoenergetic simulations

The thermoenergetic simulations carried out aimed to analyze the thermal behavior of some of the solutions analyzed in the introduction to this research. The most important parameters considered in the verification and comparison of the solutions were the thermal comfort according to the ASHRAE Adaptive method, the indoor ambient temperature and the relative humidity of the created models.

It is important to highlight that in the simulations performed only natural ventilation was considered and no influence of active HVAC (heating, ventilation and air conditioning) systems was considered. For the calculation of natural ventilation, option "Calculated Nat. Vent." was used.

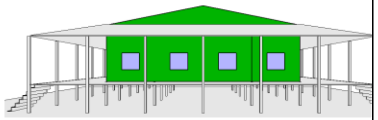
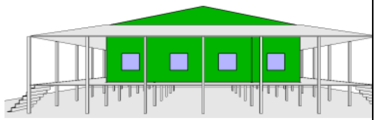
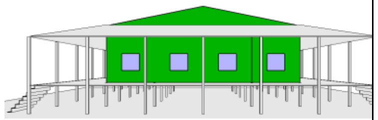
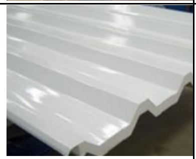
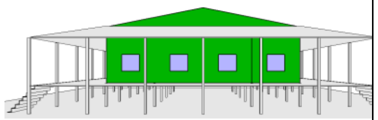
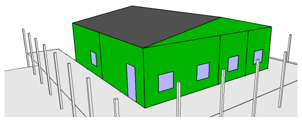
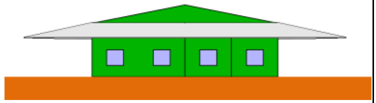
Table 3 presents the physical properties of "oak" wood, which in the simulations represented the external walls, windows, floors, ceilings and balconies. Oak was used because the software does not have "cumaru" wood for simulation, and also because of the physical proximity of both species. Table 4 presents the physical properties of the materials simulated as coverage in the analyzed models, except for "model 6: chimney effect." This table also presents the synthesis of simulated models.

Table 3: Physical properties of oak wood (exterior walls, windows, floors, ceilings and balconies) in simulated dwelling.

MATERIAL: OAK WOOD	GRAPHIC REPRESENTATION	CONDUCTIVITY (W/m-K)	SPECIFIC HEAT (J/kg-K)	DENSITY (Kg/m³)	THERMAL ABSORPTANCE	SOLAR ABSORPTANCE	REFLECTANCE	VISIBLE ABSORPTANCE
		0.190	2390.0	1070.0	0.9	0.5	0.8	0.5

Source: The authors.

Table 4: Physical properties of materials simulated as coverage.

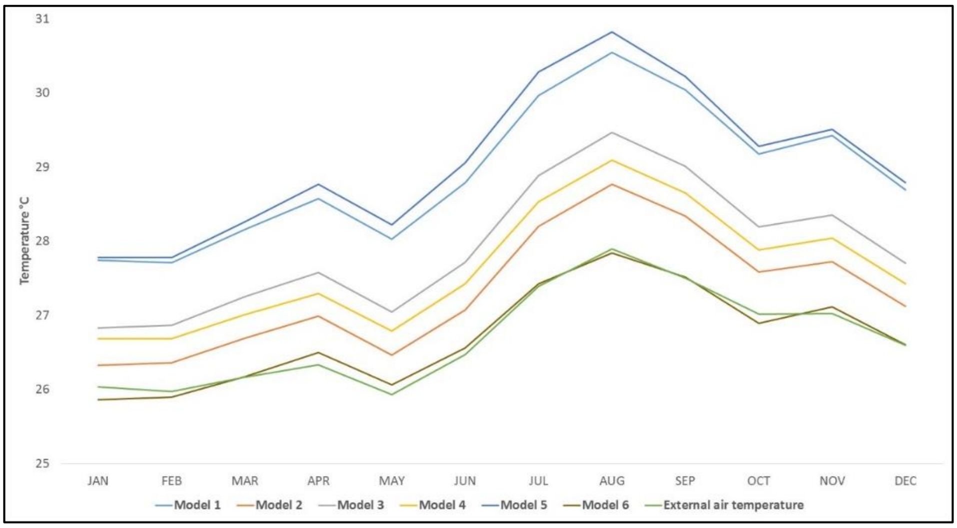
MATERIALS USED IN SIMULATED MODELS	MATERIAL	GRAPHIC REPRESENTATION	CONDUCTIVITY (W/m-K)	SPECIFIC HEAT (J/kg-K)	DENSITY (Kg/m³)	THERMAL ABSORPTANCE	SOLAR ABSORPTANCE	REFLECTANCE	VISIBLE ABSORPTANCE
MODEL 01: Dwelling built on pilotis with oxidized metallic roof and eaves: *Zinc 0.4 mm.*			113.0	390.0	7000.0	0.12	0.85	0.15	0.85
MODEL 02: Dwelling built on pilotis with metallic tile roof painted white: *Zinc 0.4 mm.*			110.0	380.0	7200.0	0.9	0.2	0.5	0.2
MODEL 03: Dwelling built on pilotis with coverage in oak (cumaru) wood.			0.190	2390.0	1070.0	0.9	0.5	0.8	0.5
MODEL 04: Dwelling built on pilotis covered with sandwich tile painted white: *Zinc 0.4 mm; EPS Thermal Insulation: 3 cm.*			Zinc: 110.0 EPS: 0.040	Zinc: 380.0 EPS: 1400.0	Zinc: 7200.0 EPS: 15.00	0.9	0.2	0.5	0.2
MODEL 05: Dwelling built on pilotis with oxidized metallic roof, without eaves: *Zinc 0.4 mm.*			113.0	390.0	1070.0	0.12	0.85	0.15	0.85
MODEL 07: Dwelling built on the ground, with oxidized metallic roof, with eaves: *Zinc 0.4 mm.*			113.0	390.0	1070.0	0.12	0.85	0.15	0.85

Source: The authors.

Figure 17 shows the average monthly temperatures of the simulated models (Model 1: Dwelling built on pilotis with oxidized metallic roof – Model 2: Dwelling built on pilotis with metallic roof painted white – Model 3: Dwelling built on pilotis with wood roof – Model 4: Dwelling built on pilotis with sandwich tile – Model 5: Dwelling built on pilotis with oxidized roof without eaves – Model 7: Dwelling built with oxidized roof directly on the ground), along with external air temperature. It is noticed that the year-round external air temperature variation is small, around 2°C.

Also noteworthy is a maximum temperature variation of 2°C between Model 2 and Model 5, which presented the lowest and highest monthly averages respectively.

Figure 17: Average monthly temperatures for models 1, 2, 3, 4, 5 and 7.



Source: DesignBuilder. Org.: The author.

Model 2, which uses the metallic roof painted white, had the best thermal performance when compared to the others, as it offers lower monthly average temperatures for August, at around 28.77°C. The simulation of this model confirms the effectiveness that the color strategy, pointed out earlier in this paper, by Cheng, Ng and Givoni (2005), can offer to improve comfort conditions for hot and humid climate regions, considering the solar radiation received by the dwelling. The authors also state that this strategy is one of the most effective and economical means to reduce the internal temperature in regions with climatic conditions such as those in Manacapuru - AM.

Similarly, the simulation of model 2 confirms the notes previously made by Synnefa, Santamouris and Akbari (2007), who found in their research that by increasing the reflectance of the roof through coverage, it is possible to reduce hours of discomfort and temperature peaks according to local climatic conditions.

However, model 7, in which the dwelling is supported directly on the ground, whose difference from model 1 is the heat exchange between the floor and the ground, because it is supported directly on the ground, presented the best thermal performance among all simulated models. The monthly average for August was 27.84°C, corroborating the observation made by Celuppi et al (2019), who verified statistically, through perceptive responses from residents of this region, that the dwelling built directly on the ground provides better comfort conditions for occupants.

On the other hand, model 5 (dwelling built on pilotis with oxidized metallic roof, without eaves) presented the highest values of air temperature, with the average of August being 30.83°C, confirming the recommendations made by Givoni (1994) as to eaves for shading the openings and aid in natural ventilation in rainy seasons. However, it is important to note that the lack of eaves on the balconies in this model did not significantly influence the thermal behavior of the building based on monthly average temperatures, however Brazilian standard NBR 15.575 (2013) considers the shading of openings for this region as a relevant passive bioclimatic strategy in comfort.

Annual simulations were performed to verify the thermal comfort of all environments of the dwelling, according to the ASHRAE55 adaptive comfort model, with 90% and 80% of acceptance limits.

As shown in Table 5, the model that showed the most uncomfortable hours throughout the year for most internal environments was model 5, with oxidized roof and no eaves. In this model, the "SALACOZINHA" environment presented 3587 hours of discomfort for ASHRAE55 90%, and 3063 hours of discomfort for ASHRAE55 80%.

When comparing model 1 (dwelling built on pilotis with oxidized metallic roof) and model 5 (dwelling built on pilotis with oxidized metallic roof, without eaves), which have the same type of roof but with differences in the eaves of the balconies, it can be seen that the shading caused by these eaves on the respective facades has little impact on the hours of discomfort in the annual basis analyzed, showing that among the strategies simulated here, oxidized metallic tile presents the most unfavorable scenario to thermal comfort conditions and, unfortunately, it is the most common coverage typology in the study region.

Table 5: Physical properties of materials simulated as coverage.

Thermal Zones	Model 1		Model 2		Model 3		Model 4		Model 5		Model 7	
	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]
Quartocasal	663,25	342	336,75	55,25	466,75	186,25	332,5	89,75	635,75	332	306	17
Quartosolt1	1093,75	635,5	432,25	132,75	719,5	368,5	532	215	1121,75	676,5	322	25
Quartosolt2	1201,75	701,75	431	149	782	409	603,5	251,75	1227,75	739,25	229	24
Salacozinha	3437,75	2888,5	2595	1856,75	2860,25	2211,75	2551,5	1831,75	3587,25	3063,5	2183	1326
Quartosemteto	3578	3061,25	2485,25	1685,75	2886,25	2241,75	2371	1649,75	3663,75	3174,5	2418	1557

Source: DesignBuilder and ASHRAE55. Org.: The authors.

The models with the best thermal results for their occupants were model 2 (dwelling built on pilotis with metallic roof painted white) and model 4 (dwelling built on pilotis with sandwich tile), among the models simulated in the stilts typology. The results between them are very close, however, in model 2, the thermal zones of the "QUARTO" were more comfortable, while in model 4 the "SALACOZINHA" and the "QUARTOSEMTETO" indicated less uncomfortable hours. These close results can be explained by the fact that the sandwich tile can block the solar gains, however this strategy hinders the heat output of the environments, ie the thermal losses through the roof that occur in model 2.

When comparing the simulation results of model 2 (dwelling built on pilotis with metallic roof painted white) and model 1 (dwelling built on pilotis with oxidized metallic roof), which showed 3438 hours on ASHRAE55 90% and 2889 hours on ASHRAE55 80%, a reduction of uncomfortable hours by 25% and 36% was observed, respectively, in the average values over a year.

Model 7 (dwelling with oxidized metallic roof built directly on the ground) showed an even larger reduction, 35% and 54%. This means that the heat exchange with the ground provides greater thermal comfort for the occupants, compared to models built on pilotis, whose floor heat is exchanged with external air, often superior.

The white-painted roof instead of the oxidized sheet metal as well as the dwelling supported on the ground are positive solutions in improving comfort for riverside dwellings. However, it is important to consider that for dwellings built on the river banks, the dwelling supported on the ground faces the flood and ebb cycle.

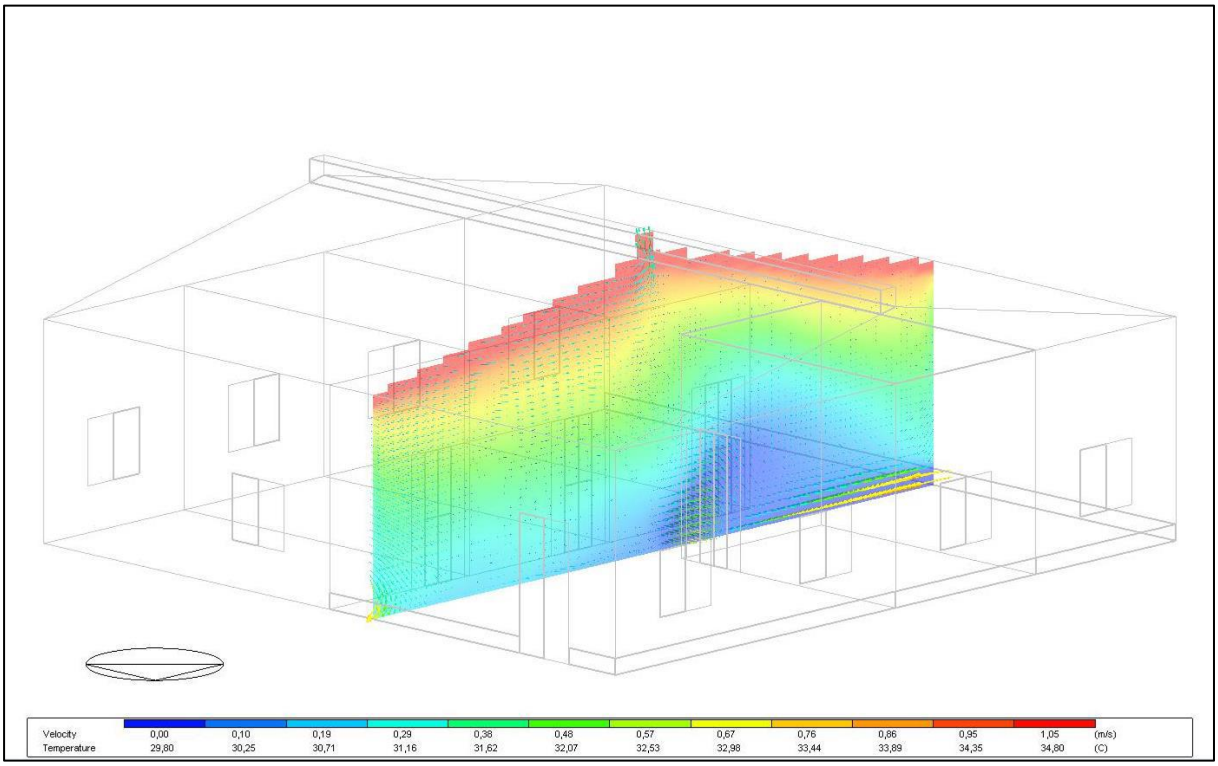
Due to the proximity of the thermal behavior found between model 2 (dwelling built on pilotis with metallic roof painted white) and model 4 (dwelling built on pilotis with sandwich tile), it is noticed that the sandwich tile does not have significant comfort benefits compared to the plain metallic tile painted white, in addition to being economically less viable.

It is concluded that the surface properties, reflectance and solar absorbance were determinant and provided a greater number of comfortable hours for the occupants among the simulated roofing solutions.

In order to verify the chimney effect in the simulated model, representing the dwelling that was the object of study of this research (Model 1), CFD (Computer Fluid Dynamic) simulations were performed, presented in model 6. In this model, openings were added in the lower areas and on the side of the chimney at the top of the roof. As previously mentioned, for the calculation of the CFD model, a specific day was chosen during the year (July 30 at 12.00 p.m.) and the option of "calculated natural ventilation" was used, in which the software automatically calculates the airflow based on several parameters, such as coefficients and climatic data.

It is observed in the cross section (Figure 18) that the internal air temperature near the roof reaches values approximately 5°C higher when compared to some areas in the lower part of the building.

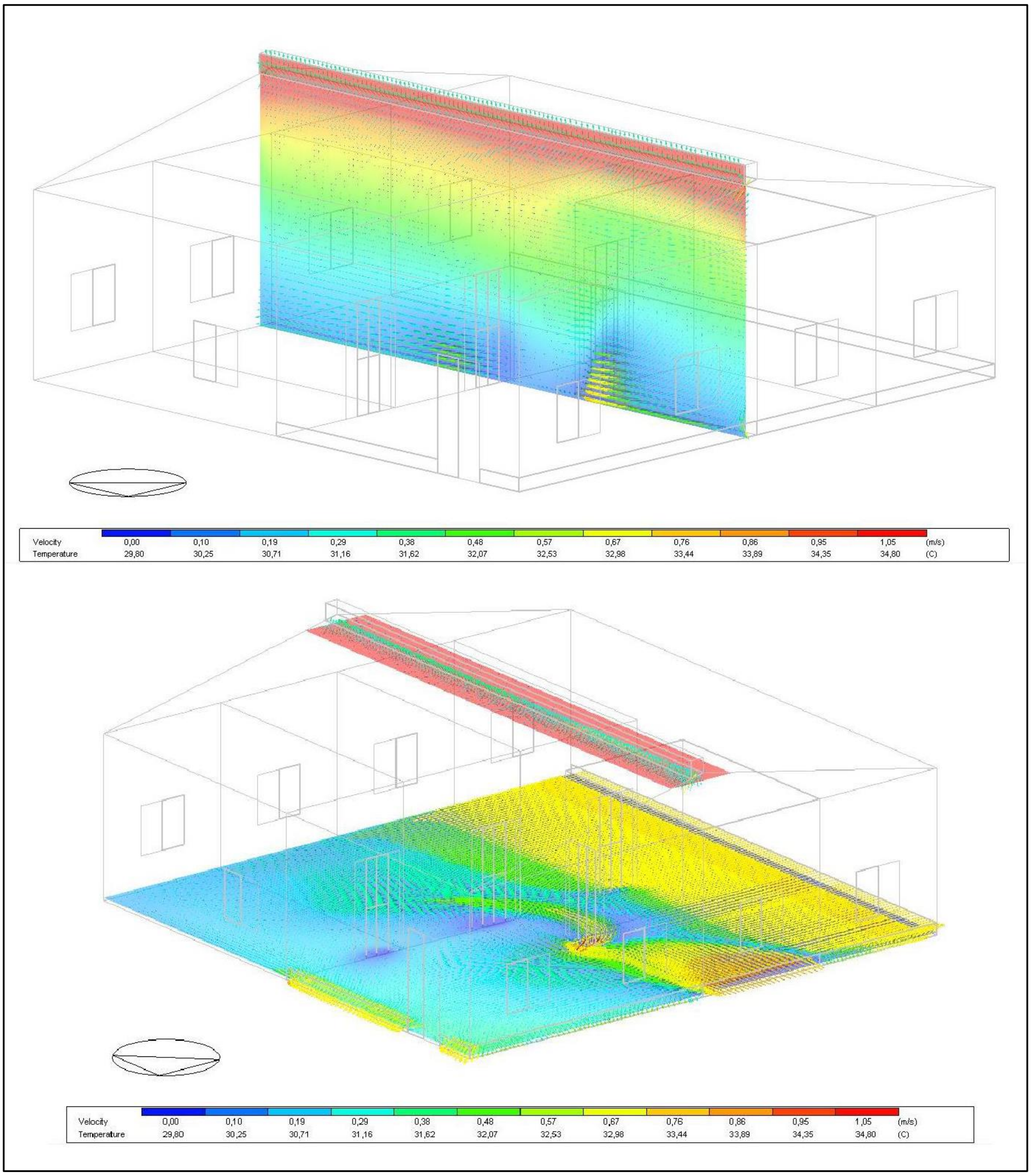
Figure 18: Temperature gradient in model 6 simulation - chimney effect.



Source: DesignBuilder. Org.: The author.

In the longitudinal and horizontal sections (Figure 19), the temperature gradient inside the building is again observed. The natural convection of the air is observed, that is, the warmer air outlet in the upper opening and the less warm air inlet through the lower openings, characterizing the chimney effect as a favorable strategy for the study region. This result was also found in an experiment conducted by Chungloo and Limmeechokchai (2007), in Thailand, a region with climate similar as that of the city of Manacapuru, in the state of Amazonas. Thus, the constructive solution with lower and upper openings, presented in this model, is a good strategy for improving the thermal comfort conditions for riverside dwellings in the study region.

Figure 19: Temperature gradient - longitudinal and horizontal section.



Source: DesignBuilder. Org.: The author.

4. FINAL CONSIDERATIONS

Regarding the meteorological data collected in the dwelling analyzed here, very high values of temperature and relative humidity, as well as low values of air speed, were observed, which represents the relationship between the local building typologies and the climatic conditions of that region. These data corroborate and point to the need to study bioclimatic strategies that can be applied in that region.

The period of on-site data collection limited the research to a seasonal analysis during the year. This was due to the logistics of access to the study area, as well as the lack of investment to fund a field research with a longer period of analysis.

As for the simulations, the local climate presented temperatures with monthly averages with few seasonal variations, as presented in the survey results. Strategies were presented capable of optimizing the comfort conditions of the riverside dwellings of the Brazilian Amazon region, also demonstrating the comparison between the mentioned simulated strategies with the purpose of pointing out which of them has greater application viability.

The limitation of the study regarding the simulations was that it was not possible to simulate the "floating" typology, as the software used does not have an algorithm for simulation of dwellings over water, which made it impossible to compare the three typologies.

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