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THE INFLUENCE OF AFFORESTATION ON HUMAN COMFORT IN A HUMID EQUATORIAL CLIMATE

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ABSTRACT

In this article we analyze the influence of afforestation on human comfort for the humid equatorial climate, in which were collected data of air temperature, relative humidity, air speed and sidewalk temperature. The analysis of the observed data, show the importance of afforestation, temperature decrease, increasing the relative humidity and wind speed, and drastically reducing the pavement temperature, which together favor a better thermal comfort. To quantify thermal comfort, scenarios were simulated in Envi-met that reproduce the locations where the data was collected. The results show that Envi-met reproduces well the simulated scenarios for humid equatorial microclimate. The Predicted Mean Vote and Predicted Percentage of Dissatisfied indices decrease with increasing tree density. Different scenarios can be simulated with Envi-met in this type of climate, with the aim to improve people's thermal comfort.

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INTRODUCTION

Microclimate studies have fundamental importance in cities, since it is necessary to offer thermal conditions compatible with human thermal comfort, regardless of external climatic conditions. One of the methods to provide quality of life to the population and healthier cities is the presence of green areas in urban centers, as they provide control of solar radiation, humidification of the air, shade, and the appropriate use of materials for temperature control. For Lima et. al. (2006), urban afforestation has positive effects on cities and is of great importance in urban space, being a subject of interest to researchers and the population, since it contributes to the reduction of heat islands, energy consumption and psychological well-being of the population. In regions with hot climates, as is the case of Macapá city, where high temperatures are prevalent throughout the year, it becomes necessary to implement green areas as a subsidy to achieve urban thermal comfort. The places that provide shade are the most sought after by users, however, the current urban structure present in Macapá city, such as the growth of verticalization, causes changes in the design of the city, thus reducing the presence of wooded areas and creating surfaces with high temperatures, making it impossible for the user to enjoy these spaces. According to Silva & Romero (2010), microclimate simulation allows for the understanding of urban climate related phenomena and to evaluate mitigation and adaptation strategies before their implementation. It assists in understanding the urban microclimate of the city and the improving the quality of life of the inhabitants. The field measurements were performed at Avenida Leopoldo Machado, one of the main avenues of the city of Macapá, Amapá state, which is characterized by its length and the high concentration of pedestrians and vehicles circulating on the avenue. Macapácity is located in the extreme north of Brazil, being considered an Amazon city in the middle of the world, for being cut by the equator and bathed by the Amazon River. It has been found, through site visits, thatthe urban forestation is not constant throughout its entire length of five kilometers. Regarding its urban morphology, Macapá city, over the years has been transformed according to the economic needs of the region and the accelerated urbanization process. New buildings are increasingly appearing to transform the urban landscape, causing impacts on urban thermal comfort, on the environment and on the population's quality of life. With this, we seek to analyze the influence of afforestation on one of the main avenues of the city of Macapá, through measurements of climatic variables and microclimate simulations in ENVI-met, enabling us to demonstrate the behavior of these variables in urban thermal comfort.

MATERIALS AND METHODS

The methodological procedures used were divided into three stages: the first corresponds to the measurements of the climatic variables, the second step corresponds to the use of computational urban microclimate simulation, with the aid of the ENVI-met version 4.0 program and thethird stage consist in validating the numerical simulations. The cut-off for the measurements were performed on July 20, 2018, at 6, 9, 12, 18 and 21 hours. Using portable meteorological devices, taking measurements such as air temperature (anemometer), air speed, relative humidity (hygrometer) and surface soil temperature (infrared thermometer), taken at three different points on the avenue, called Point 1 (no trees), Point 2 (regular tree density), and Point 3 (high tree density). These scenarios are shown in Figure 1. The classification of tree densities was determined by Labaki's (2011) experimental and qualitative research, where the author seeks to understand the role of vegetation and its influence on urban thermal comfort.

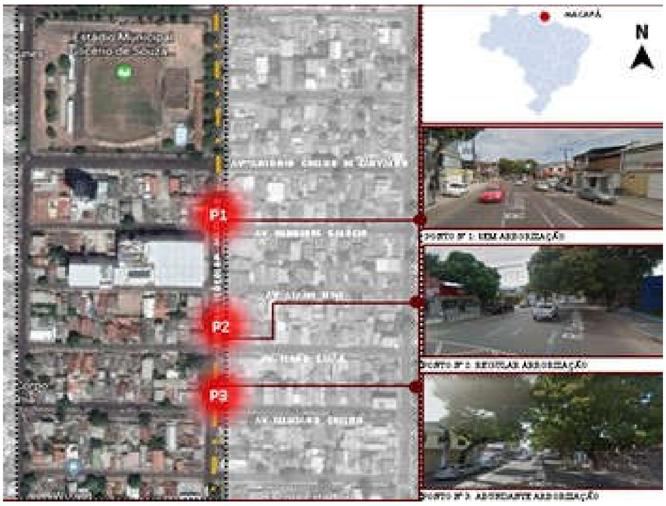

Figure 1. Measuring points at Leopoldo Machado Street: Point 1 (P1), Point 2 (P2) and Point 3 (P3)

The second step corresponds to the use of computational urban microclimate simulation, with the aid of the ENVI-met version 4.0 program. The basic spatial data input settings were entered, filling in the: input file, the simulation day, names and folders, and basic meteorological settings. The data for the modeling, such as building heights and dimensions, were collected through Google Earth measurements and on-site data. The basic meteorological data adopted, were obtained from the climatological station at the airport of Macapá city and from the National Institute of Meteorology (INMET). The data obtained are the wind speed at 10 meters from the surface (m/s) with a value of 1.5 m/s, wind direction (in degrees) is 40, ground roughness (station) is 0.1, air temperature at 2 meters is 31.89 ºC, specific humidity at 2,500 meters is 8.91 g/Kg and relative humidity at 2 meters is 87%. Three hypothetical models were configured on Leopoldo Machado Avenue: Model 1 simulates a scenario without trees, Model 2 simulates the conditions of regular trees, and Model 3 simulates a scenario with higher tree density, in order to compare the numerical results of these simulations with the data observed at Points 1, 2, and 3, respectively. These models are presented in Figure 2.

The species Mangifera L, popularly known as mango, is present in the urban arborization. According to Lima (1993), as it is a fruit tree, it is not recommended for urban areas, due to the fall of the fruit, obstruction of channels, damage to the power grid, traffic signs and traffic of vehicles and pedestrians.

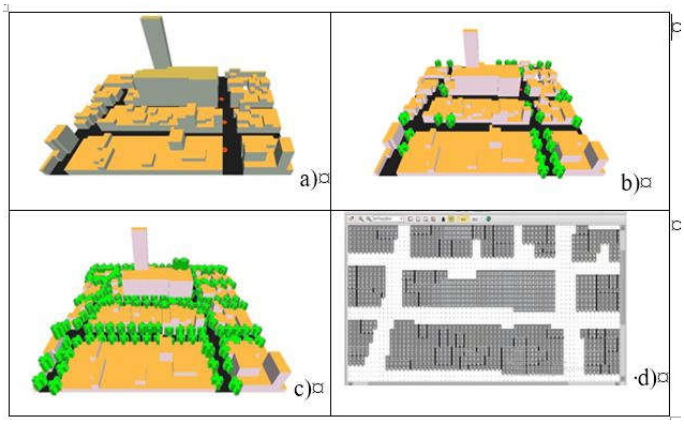

Figure 2. Modeling of the three scenarios on Leopoldo Machado Street: a) Model 1, b) Model 2, c) Model 3 and d) Projection

However, to be able to perform the simulation according to the real scenario found in the city, the tree was modeled in the Albero option, creating a three-dimensional figure for insertion in the modeling. In the third stage, after validating the model simulations, the indices Predicted Mean Value - PMV and the Percentage of Dissatisfied People - PPD are calculated to make inferences about the influence of afforestation on urban comfort.

RESULTS AND DISCUSSION

In Celis, et. al [2021] the influence of paving on the urban microclimate of Avenida Leopoldo Machado was analyzed, the asphalt temperature values were close to 60ºC, while points with the presence of trees decreased to 26ºC. The Envi-met software was able to reproduce values close to those observed.

Table 1 shows the observed and simulated 2m temperature data at the three evaluation points. Regarding the values measured by instruments of air temperature it can be observed that the afforestation, with its shading effect, contributes to the decrease in temperature mainly at times of greater solar radiation. At 12:00 noon, the temperature was 34ºC at Point 1 (no trees), 32.4ºC at Point 2 (regular density of trees) and 32.1 at Point 3 (greater density of trees) a decrease of up to 1.9ºC. At 15:00 hours the temperature at Point 1 was 35.1ºC, at Point 2 was 33.6ºC and at Point 3 was 32.2ºC, a decrease of up to 2.9ºC. The averages of all temperature measurements including the hours of 06:00 and 21:00 without shade effect show that the average temperature at Point 1 was 30.7°C, decreasing to 29.9°C at Point 2 and 29.4°C at Point 3. The air temperatures of the Envi-met simulated models are somewhat warmer than the observed temperatures, however they track the time series of observed temperature values well. The average temperatures of the simulated models are 32.4°C for Model 1 at Point 1, 32.1°C for Model 2 at Point 2, and 31.4°C for Model 3 at Point 3.

Table 1. Comparision of Air Temperature at 2m (ºC) between Envi-met models and observed data for Points 1, 2 and 3

Hour	Point 1		Point 2		Point 3	
	Model 1	Observed	Model 2	Observed	Model 3	Observed
06:00	26.7	26.1	26.6	25.8	26.3	25.5
09:00	31.2	31.2	31.0	29.5	31.0	29.1
12:00	34.5	34.0	34.2	32.4	33.5	32.1
15:00	36.4	35.1	36.0	33.6	35.1	32.2
18:00	33.6	29.4	33.2	29.5	32.2	29.5
21:00	31.8	28.5	31.5	28.5	30.6	28.4
Mean	32.4	30.7	32.1	29.9	31.4	29.4

About the influence of the density of forestation on the relative humidity of the air, it has been found that the values measured by the instruments were higher than 70%, above the recommended by the World Health Organization (WHO), which considers the ideal level of humidity between 40 and 70%. Table 2 shows that the daily average relative humidity becomes higher with the increase in tree density, thus causing a reduction in the range of air temperature. The observed average relative humidity was 76.5%, 1, 77.1% and 77.8% in the Points1, 2 and 3 respectively. The results of the Envi-met models for relative humidity, show that they track well with the time series of observed data, the relative humidity of the models increases with increasing tree density. The average relative humidity in Model 1 was 74.6º, increasing to 75.6% in Model 2 and to 79.1% in Model 3.

Table 2. Comparison of relative humidity (%) between Envi-met models and observed data for Points 1, 2 and 3

Hour	Point 1		Point 2		Point 3	
	Model 1	Observed	Model 2	Observed	Model 3	Observed
06:00	94.1	81.8	94.1	82.4	95.1	81.2
09:00	87.1	78.2	87.6	77.6	88.5	81.0
12:00	73.8	75.9	75.1	72.9	78.6	75.4
15:00	60.6	72.4	62.5	76.3	67.2	75.9
18:00	64.9	71.4	66.1	72.6	71.4	72.1
21:00	67.0	79.3	68.3	81.2	74.2	81.1
Mean	**74.6**	**76.5**	**75.6**	**77.1**	**79.1**	**77.8**

Regarding wind speed, it was observed from the wind speed measurements by instruments, that its values decrease with a greater density of afforestation. In Table 3, it can see that these wind speed differences are more significant when comparing their values at Point 1 (no afforestation) with Point 3 (higher density of afforestation). The average values of wind speed, considering all the time, were 1,52 m/s at point 1, 1,32 m/2 at point 2 and 1,24 m/s at point 3. The results of the Envi-met models for air velocity show that lower values than the observed ones, however they follow well the time series of the observed data, The averages of air velocity, considering all times, were 0.76 m/s in Model 1, 0.42 m/s in Model 2 and 0.72 m/s in Model 3. There is a discrepancy in Model 2's average being lower than that of Model 3, which could be better studied with increased resolution in the simulations and therefore a better configuration of the afforestation, buildings and houses in the Envi-met models.

Table 3. Comparison of velocity at 2m (m/s) between Envi-met models and observed data for Points 1, 2 and 3

Hour	Point 1		Point 2		Point 3	
	Model 1	Observed	Model 2	Observed	Model 3	Observed
06:00	0.86	1.20	0.46	0.96	0.82	1.28
09:00	0.75	1.21	0.37	1.41	0.75	1.18
12:00	0.75	1.55	0.41	1.54	0.72	1.18
15:00	0.71	1.76	0.41	1.63	0.69	1.11
18:00	0.72	1.88	0.43	1.34	0.69	1.36
21:00	0.75	1.57	0.44	1.04	0.70	1.37
Mean	**0.76**	**1.52**	**0.42**	**1.32**	**0.72**	**1,24**

The results of the Envi-met simulations are able to capture the behavior of the observed data for air temperature, relative humidity, air speed, and sidewalk temperature. Therefore, the Envi-met simulations for these simulations are expected to capture the behavior of the thermal comfort indices PMV and PPD. Table 4 shows the values for these indices. In ENVI-met, the calculation is performed using the BioMet plugin, where the software takes as reference the following standard data: man aged 35 years, height 1.75 meters and weight 75 kilos. For the thermal resistance values offered by the clothing, the values are given in clo units (stating clothing insulation), in accordance with ISO Standard 7730, the following clothing parameters were considered: light shirt with short sleeves, pants, sneakers, underwear and thin socks. In Table 4, it is observed that in the period between 09:00 and 15:00, the PMV index is greater than 3.5, which in Fanger's climatic scale is called very hot (characteristic of a humid equatorial climate), for which the PPD discomfort index was 100% for the three models. The highest values of the PMV comfort index were 6.9 in Model 1, 5.1 in Model 2, and 4.6 in Model 3. It is observed that with the increase in the density of afforestation the indices of PMV comfort and PPD discomfort decrease, indicating an improvement in the indicators of thermal comfort. The mean PMV index, considering all times, was 3.7 for Model 1 (no trees), decreasing to 3.2 in Model 2 (regular tree density) and decreasing even more to 2.8 in Model 3 (higher tree density). While the average PPD discomfort index, considering all times, was 77.9 in Model 1 (no trees), decreasing to 77.6 in Model 2 (with regular tree density) and 74.7 in Model 3 (with higher tree density).

Table 4. PMV and PPD (%) for Models 1, 2, 3 at Points 1, 2, 3 repectively

Hour	Model 1 and Point 1		Model 2 and Point 2		Model 3 and Point 3	
	PMV	PPD	PMV	PPD	PMV	PPD
06:00	0.4	9.7	0.6	11	0.5	10.0
09:00	4.8	100	4.7	100	4.6	100
12:00	5.7	100	5.1	100	4.6	100
15:00	6.9	100	4.5	100	3.6	100
18:00	2.4	90.5	2.3	89.5	2.0	80.7
21:00	1.8	66.9	1.8	65.5	1.6	57.6
Mean	**3.7**	**77.9**	**3.2**	**77.6**	**2.8**	**74.7**

In Figure 3, one can observe the PMV comfort index throughout the simulated area for each of the models at 2:00 PM. The effect of shading, both from trees and buildings, can be seen in the decrease of the PMV index. In Model 1, without trees, the PMV is higher than 4.05, even in areas with shaded buildings and houses. In Model 3, with higher tree density, the PMV decreases in almost the entire area, including the points shaded by buildings and houses.

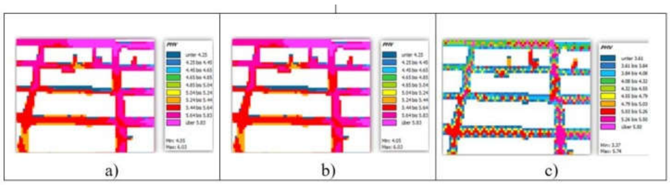

Figure 3. Analysis of the PMV comfort index in: a) Model 1 (no trees), b) Model 2 (regular tree density) and Model 3 (higher tree density)

CONCLUSION

The data collected at the three observation points allowed us to analyze the influence of urban forestation on the microclimate of the city located in a humid equatorial climate. The analysis of the observed data confirms that the increase in afforestation on Avenida Leopoldo Machado decreases soil temperature, increases the relative humidity of the air, decreasing wind speed, whose combined effects make the thermal sensation of heat present a decrease in temperatures, allowing a better urban thermal comfort and consequently of its inhabitants. The software ENVI-met 4.0 has been used for studies of urban microclimate, especially in high and medium latitudes, in this paper we present simulations of Envi-met in the city of Macapá that is cut by the equator, and in a humid equatorial climate. The results obtained in this work demonstrate that the program correctly reproduces the urban microclimate at latitude zero. Therefore, it opens up the possibility of simulating different scenarios in Envi-met for this type of climate, modifying the type of sidewalk, the type of forestation, as weel the urban environment with a better solar orientation of the houses in order to take advantage of natural lighting and natural ventilation in order to improve the urban thermal comfort so necessary in a humid equatorial climate.

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