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RESEARCH ARTICLE

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THE INFLUENCE OF AFFORESTATION ON DECREASING PAVEMENT SURFACE TEMPERATURE IN A HUMID EQUATORIAL CLIMATE

Anneli Maricielo Cárdenas Celis[1,*], José Walter Cárdenas Sotil[2] and André Alons Cárdenas Celis[3]

[1]Department of Post-Graduation in Architecture, University of Lisboa, Portugal
[2]Department of Computer Science, Federal University of Amapá, Brazil
[3]Department of Physiotherapy, Federal University of Amapá, Brazil

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****Corresponding author:***
Anneli Maricielo Cárdenas Celis

ABSTRACT

The avenue Leopoldo Machado is one of the main mobility routes of Macapá city, northern Brazil, because it connects the northern hemisphere with the southern hemisphere of the city, it presents inconstancy in the afforestation along its length, which makes it difficult for people to move around adequately. The present study focuses on analyzing the urban microclimate in the area, to understand the influence of the surface temperature of urban pavement on urban thermal comfort. It employed as a method, field measurements of soil temperature with an infrared thermometer on three types of materials and numerical simulations with ENVI-Met software to verify that in situ soil temperatures are reproduced by these simulations. The in loco results showed the influence of materials and afforestation on soil temperature, with a decrease of up to 23.8°C at points with higher tree density. The computational models simulated with Envi-met were successful in reproducing the observed values of soil temperature, which allows the use of this software to study the properties of various sidewalks together with various afforestation scenarios for cities with humid equatorial climate to mitigate the effects of urban warming.

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INTRODUCTION

Over time the increase in urban population and its activities without the necessary planning have caused drastic effects to the natural and built environment. These modifications, such as the reduction of green areas, increase in vehicle traffic and soil sealing, etc., generate several environmental problems to the microclimate that contribute to the increase in average air temperatures and thermal discomfort. The effects of rapid urbanization, increasing urban population and their activities in the natural environment and built environment have caused numerous impacts on cities, they alter the microclimate and increase discomfort in the urban environment (DOBBERT, 2015). Due to the urbanization process, these modifications in the landscape generate several environmental problems, such as soil sealing, high concentration of pollutants, increased temperature, changes in ventilation parameters, etc. These modifications favor the appearance of the urban heat island phenomenon (UHI), it occurs mainly in cities with high rates of urbanization and is characterized by urban areas that are warmer than the less urbanized neighborhood (GARTLAND, 2010).

Gartland (2010) reports that the first studies on urban climate began in the 19th century in London. Luke Howard showed that the ground surfaces in urban areas are warmer than surfaces in rural areas, because the coatings created by men and highly employed in urban areas are mostly composed of dark-colored materials and impermeable, which causes the absorption and storage of heat, and lack of moisture for evaporation. Subsequently, further research began to focus on climate change in relation to the urbanization process and its expansion, using knowledge from various fields, such as physics, architecture, urbanism, meteorology, etc. Regarding anthropic interventions in natural space, Romero (2000), highlights urbanization, which by replacing vegetation cover with paving and verticalization, produces disturbances in the daily thermal cycle, due to the difference between the amount of solar energy received and the thermal capacity of building materials. Since vegetation not only helps humidify the air through the process of photosynthesis, but also favors air renewal and works as a thermoregulatory mechanism, in which heat is absorbed through transpiration, as the foliage, despite its dark coloration, works as a light collector, in which most of the absorbed radiation is used in its metabolic process.

While the removal of this vegetation cover and its replacement by paving causes the increase of temperature indexes, since all the radiation absorbed by these materials is transformed into heat, they also affect the porosity of the soil and make the land surface impermeable, which alters drainage conditions, reduces the site's humidity, and intervenes in local rainfall (ROMERO, 2000). Frota & Schiffer (2003), consider that some care should be taken regarding the floor covering around the buildings and the extension of the surfaces intended for pedestrians, due to the power in which the materials must store heat. Especially in cities with a humid equatorial climate, as is the case of Macapá city, in the state of Amapá, due to its high temperatures, because during the day these surfaces raise the air temperature and at night, when they cool down, they heat the surrounding air, both inside and outside the buildings. According to Romero et al. (2019), the different types of materials used in buildings have their own behaviors and properties, with different patterns of total reflectivity or albedos, these will interfere with the amount of absorbed radiation, causing temperature to rise. For Neto (2015) the cities have a large gathering of these materials and a small amount of afforestation, in addition, their soil is almost entirely covered by impermeable materials and with dark tones, which contributes to the absorption of solar energy, and have a large capacity for heat storage. These characteristics interfere with atmospheric factors and contribute to the appearance of heat islands in an urban area. De Mello, Martins and Neto (2009) state that when materials with properties appropriate to the climate are not used, thermal discomfort will be generated and will interfere in the production of urban climate, and may also lead to health problems for the residents of the region, so it is considered important studies that address this issue, to enable the rational use of materials according to the climate and quality of life for the population. These studies dedicated to the analysis of urban climate help in understanding the relationship between the rise in air temperature and the decrease in permeable surface area, because it is known that paving has a major impact on urban climate, since the higher the rate of paved surfaces, the greater the heat gains and the greater the emission of heat into the urban space and its repercussions on the climate. Oliveira (1985) considers that one way to minimize high temperature rates would be if urban areas were built with light-colored materials and had a high density of trees, because much of the incident solar energy would be reflected. Gartland (2010) elucidates strategies capable of mitigating the effects of the heat island, such as the replacement of dark-colored elements by lighter ones, which contribute to the reduction of thermal energy absorption, like concrete sidewalks, in addition, he also proposes the reduction of atmospheric pollution, and the planning of green areas, aiming to provide shaded areas that contribute both to the user's well-being and to the reduction of energy consumption.

For Tsoka et al. (2017), the use of clear sidewalks shows positive effects in decreasing the ground surface temperature, consequently the heat transfer to the air, resulting in minimal changes in air temperature. However, the fresh material has high reflective capacity of solar radiation, which affects the thermal sensation mainly during the summer, which can negatively interfere with the thermal comfort of pedestrians. These characteristics affect mainly cities where the hot climate predominates, as is the case of Macapá. In this climate, high temperatures can contribute to the deterioration of asphalt and concrete sidewalks, and the technology of cold sidewalks is an alternative to mitigate this type of problem (LI, 2012). Li (2012), emphasizes that despite the potential of cold material to considerably decrease the temperature, its application may contribute to glare during the daytime period, due to the increased albedo, which causes visual discomfort. Therefore, effectiveand viable temperature reduction solutions, other than high albedo, should be explored, as other thermal properties of the materials used in paving, also determine the temperature of the ground sidewalk and nearby air, such as thermal conductivity, thermal emissivity, density, etc. In this sense, the thermal environment of the city is understood as important for the proposition of strategies that can mitigate the negative effects of the phenomena resulting from urban background heating, such as heat islands and global warming. In this aspect, the present work sought to analyze the influence of shading by afforestation on the pavement temperature of an avenue in the city of Macapá-AP, through in loco measurements of microclimate variables and insertion of climatic data in the computer simulation program ENVI-met 4.0, to demonstrate the influence on thermal comfort.

MATERIALS AND METHODS

The methodological procedures of this work were divided into two main phases:

Measurement of microclimatic variables: Measurements were taken with the aid of three portable meteorological devices at three points on Leopoldo Machado Avenue, one of the avenues of great flow of people in the city of Macapá-AP. The city of Macapá, located in the northern region of Brazil, is cut by the equator line and bathed to the east by the Amazon River, factors that configure it as a humid equatorial climate, thus is characterized by high temperatures and high rainfall rates. Initially, urban growth was the result of large economic projects and public policies for the settlement and development of the Amazon, where since 2011 there were changes in its urbanization process, especially in geometry and structure. The city is going through a verticalization process in the center and surroundings, while in the outlying areas there is the creation of horizontal lots, the process is presented in a disorderly and unstructured way. These are aspects that modify the urban landscape and consequently cause impacts on the urban climate and the quality of life of the population. The avenue chosen as the object of study in this article, is due to the high concentration passers by and its morphological characteristics.Visits were made in loco that allowed the observation that the density of trees and the presence of pavement are not constant throughout the length of the avenue, a fact that makes it impossible for pedestrians to circulate in an adequate and thermally uncomfortable way. The measurement points of climate variables are characterized by the difference in tree density and pavement present along the avenue. The measurements were performed on July 20, 2017, at three points on Leopoldo Machado Avenue, designated as Point 1 (no afforestation), Point 2 (regular afforestation), and Point 3 (abundant afforestation) and ground surface measurements as indicated in Figure 1, in the Brasilia time zone: 06:00, 09:00, 12:00, 15:00, 18:00, and 21:00 hours. The infrared thermometer Dual Lase brand, model HT-817 has been used for the values of the sidewalk surface temperatures, its response time is a maximum of 0.15s, its measurement range is between -50ºC to +650ºC.

Figure 1. Trajectory of the measuring points at Av. Leopoldo Machado - Macapá, Amapá

Use of the computer simulation software, ENVI-met 4.0: The thermal performance simulation of hypothetical scenarios on Leopoldo Machado Avenue was performed with ENVI-met 4.0 software, developed by Michael Bruse, which has been used in scientific research on simulating the microclimate of urban space, and can simulate the surface-tree-air interaction of an urban environment (BRUSE, 2014). To start the ENVI-met 4.0 program, it was necessary to enter the basic spatial data input settings, filling in the: input (modeling) file, the simulation day, names and folders, and basic meteorological settings. The basic meteorological data adopted, were obtained from the climatological station at the airport Macapá city and the National Institute of Meteorology (INMET). The data obtained at the beginning of the simulation, at 03:00 hours of 20/07/2017, 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, soil roughness (station) is 0.1, air temperature at 2m (ºC) is 31.89, specific humidity at 2,500 meters (g/kg) is 8.91 and relative humidity at 2 meters (%) is 87. To calculate the potential temperature, it was necessary to calculate the temperature and pressure at 2500m, these values were obtained by interpolation. Due to the low resolution of the model compared to the dimensions of the avenue in the modeling stage three scenarios were modeled to simulate the temperature on the asphalt. These models were named as: Model 1 in which the avenue has no trees in order to compare the soil temperature between the model and the on-site measurement at Point 1, Model 2 in which the intention is to reproduce the avenue with the real trees on the simulated date in order to compare the soil temperature between the model and the on-site measurement at Point 2 and Model 3 with the avenue with a higher density of vegetation in order to compare the soil temperature between the model and the on-site measurement at Point 3. The data for the modeling such as building heights and dimensions were collected through Google Earth measurements and on-site data. An area of 205 x 160 meters was modeled around the avenue using 82x64 grids on the horizontal with a resolution of dx=dy=2.5 meters. In the vertical 30 grids were configured with a resolution of 3 meters. The soil type in the model was configured with the option Asphalt Road - [ST] for the road, where there is vehicle traffic and Concrete sidewalk lights- [PL] for the parking lots and sidewalks. Figure 2 shows the three model types configured in Envi-met 4.0, the points in red are the on-site measurement points with the infrared thermometer.

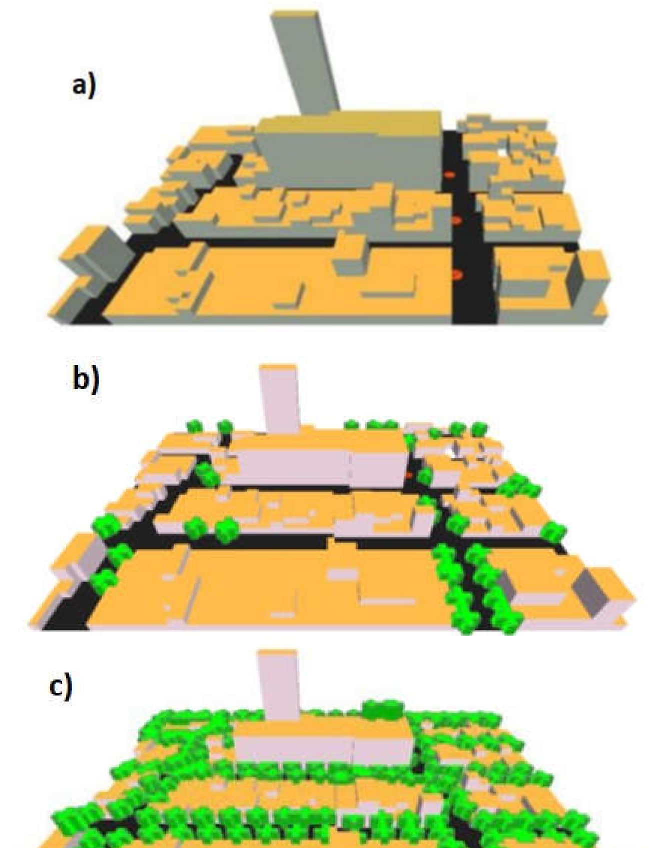

Figure 2. Models in ENVI-met 4.0 software for the study area: a) Model 1, b) Model 2 and c) Model 3

RESULTS AND DISCUSSION

To measure the effect of material type on soil temperature, we compared on-site measurements of asphalt on the street, cement or concrete on the sidewalk, and soil around trees for each of the 3 points chosen. Figure 3a compares the on-site asphalt street temperature measurements for Points 1 (no trees), 2 (regular trees) and 3 (abundant trees). At 12:00 PM the asphalt temperature was 59.2°C at point 1, decreasing relative to this temperature by 4.7°C at point 2 and 22.1°C at point 3. At 3:00 PM the asphalt temperature was 60°C at point 1, decreasing relative to this temperature by 1.9°C at point 2 and 27.6°C at point 3. Figure 3b compares the on-site measurements of the sidewalk cement temperature for Points 1, 2 and 3. At 12:00 pm the cement temperature was 55.3°C at point 1, decreasing in relation to this temperature 7.4°C at point 2 and 22.2°C at point 3. At 3:00 pm the cement temperature was 58.6°C at point 1, decreasing in relation to this temperature 16.4°C at point 2 and 26.4°C at point 3. Figure 3c compares the on-site measurements of the ground temperature around the trees for Points 2 and 3. At 12:00 PM the ground temperature was 47.5°C at Site 2, decreasing from this temperature by 15.2°C at Site 3. At 3:00 PM the ground temperature was 37.6°C at Site 2, decreasing from this temperature by 5.6°C at Site 3. From the results it is observed that the effect of shading by the afforestationis determinant in the drastic decrease of the soil surface temperature. On the other hand, from Figures 3a, 3b and 3c, comparing simultaneously the surface temperature of these three materials, it is observed that the temperature of asphalt tends to be higher than the temperature of cement and is higher than the temperature of soil.

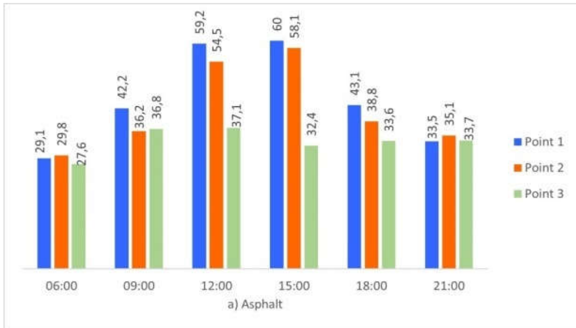

Figure 3a

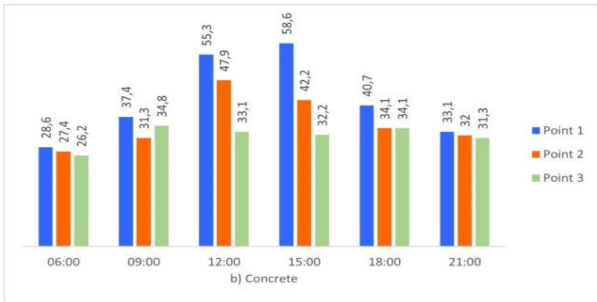

Figure 3b

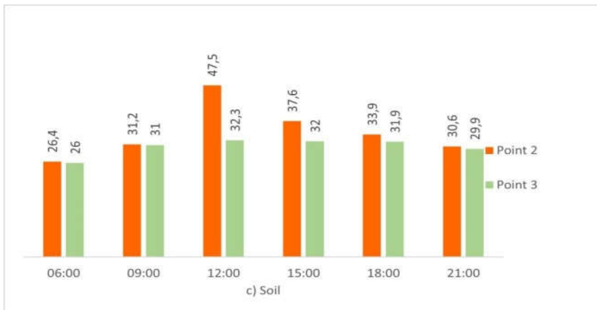

Figure 3c

Figure 3. Soil temperature (ºC) at the three measurement points: Point 1 (no trees), Point 2 (regular trees) and Point 3 (abundant trees) in a) asphalt, b) concrete and c) soil

The asphalt surface temperatures resulting from the three models simulated in Envi-met are compared with the values measured in situ with the infrared thermometer. At Point 1, with no trees, the asphalt temperatures from Model 1 are compared with those measured in situ at this point. At Point 2, with regular trees, Model 2 asphalt temperatures are compared to on-site measurements at this point, and at Point 3, with higher tree density, Model 3 asphalt temperatures are compared to on-site measurements. The error between the model value and the observed value is calculated as the absolute value of the difference between these values. Figure 4a shows that the asphalt temperatures of Model 1 follow well the observed values with the largest error of 8ºC (13% relative error) at 12:00 hours and the smallest error of 0.5ºC (1.4% relative error) at 09:00 hours. Model 1 is in general presents slightly lower temperatures than the observed ones. In Figure 4b it can be seen that the asphalt temperatures of Model 2 follow well the observed values in most of the times with the smallest error of 1°C at 09:00 and 18:00 hours (relative error of 2.5%), the largest error is 19.4°C (relative error of 33%) at 15:00 hours. It can be seen that the Model 2 configuration was shaded more by the trees than the real configuration, simulations with finer resolution can help to better configure this model. In Figure 4c it can be seen that the asphalt temperatures of Model 3 track well at all times, the model responds well to the effect of shading caused by a higher density of trees. The model got the temperature right at 21:00 hours and the largest error was 4.8°C (13% relative error) at 09:00 hours. In general, the models simulated by Envi-met 4.0 reproduce well the values observed in situ in a humid equatorial climate.

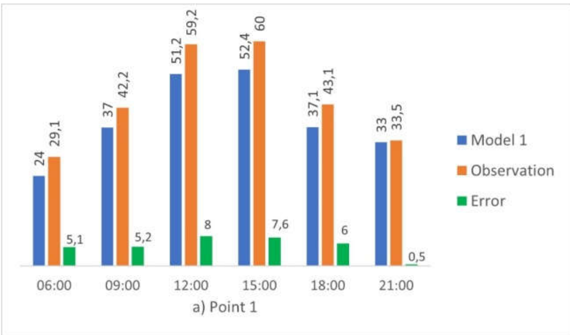

Figure 4a

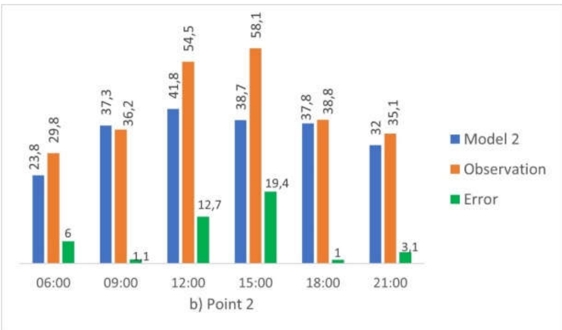

Figure 4b

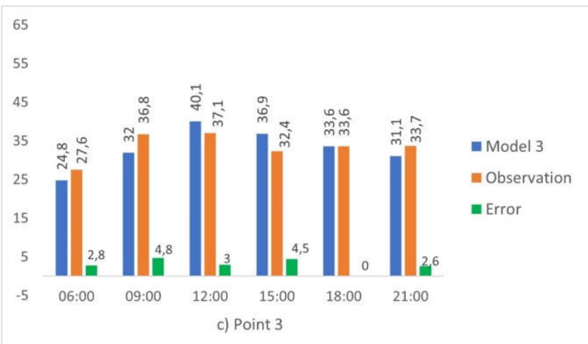

Figure 4c

Figure 4. Comparison of soil temperature (ºC) between models and observed data: a) Point 1, b) Point 2 and c) Point 3

CONCLUSION

From the results obtained through in loco measurement it is possible to confirm that the material used in the paving of Leopoldo Machado Avenue influences the urban microclimate, the temperature values of asphalt are close to 60ºC, while the temperature of the concrete used in the sidewalks reaches 58.6ºC, which favors the formation of heat islands. In addition, it was verified in loco that in the points where there is presence of forestation, the soil temperature decreased up to 26ºC. The computer simulations with Envi-met 4.0 are able to track the sidewalk temperature measurements taken in situ with different tree densities, with the effect of tree shading being the main factor in decreasing the temperature analyzed in this work. This opens up possibilities of using Envi-met in future research with different types of sidewalk materials, light or dark, and with different tree shade scenarios to analyze the effect on decreasing high sidewalk temperatures in cities located at the equatorial latitude, and therefore positively impacting on thermal comfort indices. Analyzing the data, one can conclude that the conventional asphalt paving widely used in Brazilian cities has higher average temperatures than other materials. In fact, it would be the replacement of dark paving with light-colored paving, such as permeable interlocked sidewalk or the whitetopping technique, making them lighter in color when performing the mix composition, since the lighter coloration causes a greater effect on the albedo value. Besides replacing the conventional paving, it is necessary to adopt other measures, such as creating a green corridor as a way to mitigate the problems caused by thermal discomfort, especially in cities located on the equator, as is the case of Macapá, which receive high incidence of solar radiation throughout the year and need strategies to mitigate the high temperatures.

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