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Abstract

Amazon cities and rural villages came to fragment its green spaces, implying changes in the quality of life of its population. Despite clear warning signs, this picture of environmental degradation processes has affected flora and fauna with severe consequences throughout the forest, from points that tend to widen over time. Supported on a literature review of microclimate research in environments, which is based on the dew point temperature, another suitability has been formulated considering the importance of wind speed. By using computational records, when this variable is contained in the characterization of a person's sense of well-being in a given outdoor environment, a thermal comfort index can be established to assist in planning the construction of appropriate leisure areas, as well as identifying unhealthy environments. The results were obtained in different places, during drier summer months in the Amazon rainforest, around the city of Belém, located in the extreme north of Brazil. The best responses were registered in an environment characterized by arboreal architecture planning, followed by an environment with an intact vegetation forest.

Keywords: Arboreal planning; Thermal comfort; Rainforest; Wind speed.

1. Introduction

The Amazon rainforest covers a 4.2 million km² area, corresponding to 49.3% of Brazil's territory and 5% of the planet's surface [1]. Its complex canopy ecological systems functions like an elaborate adapted sea suspended in the air that contains a myriad of living cells, having evolved over the last 50 million years is the primary technology park the Earth has ever known because each of its organisms (numbering among trillions) is a marvel of miniaturization and automation [2]. Instead, deforestation causes effects that can modify this setting on the ecosystems of utmost importance in maintaining the planet's environmental oxygen balance [3-5]. Currently, based on deforestation rates [6], this region is targeted by agribusiness expansion, as well as illegal selective logging [7] and mining industries of commercial interest, drivers of population density, and enlargement of unhealthy cities [8].

The transition from the countryside to the cities is a natural habit of the human being who is looking for jobs, opportunities, and comfort [9]. With the growth of cities, the lack of planning related to the excess of constructions, sanitation, garbage, and all the implications for human health or the environment [10]. As a result, in the Amazon, the effects of these actions bring wreak havoc on the ecosystems, and without a project or order that comes to be attached to government programs of organization and occupation of the soil, the anthropogenic interference impacts on the rivers and the forest [11-12]. Therefore, the combination of this disastrous association requires studies and decisions about which problem should be dealt with immediately, as the population of the Amazon grows every year.

Motivated by global warming and its effects due to the lack of planning in the arborization of Brazilian cities, many researchers have proposed models of thermal comfort for public spaces in Brazilian cities. France et al. [13] consider the use of thermal discomfort index (TDI) and temperature and humidity index (THI) for tropical regions, due to the practicality of application at open environments, as indicated by [14]. Still, according to [15], these indices of thermal comfort were evaluated in the city of Vitória, Brazil, and from THI index they establishes three levels of comfort for the external environment, which are: Comfortable, for sensations between 21°C and 24°C; Slightly uncomfortable, for sensations between 24°C and 26°C; And, extremely uncomfortable for thermal sensations above 26°C. This index is appropriate for tropical regions and evaluates the stress in the urban environment [14].

In work presented by [16], the dew point temperature indicator has to determine critical thermal sensation experienced by people in a closed environment, like factories, hospitals, or schools. From this publication, using data collected over four years, we have formulated a thermal comfort index (TC index) by including the wind speed in the equation proposed by them. So, this proposal aims to present the results with this novel modification when comparing different open-air environments in the city of Belém, considered as the Metropolis of the Brazilian Amazon rainforest.

2. Material and Methods

The chosen environments are three locations around to the urban center of Belém and one in the forest place, retaining its original features. Figure 1 shows an image of select locations for study.

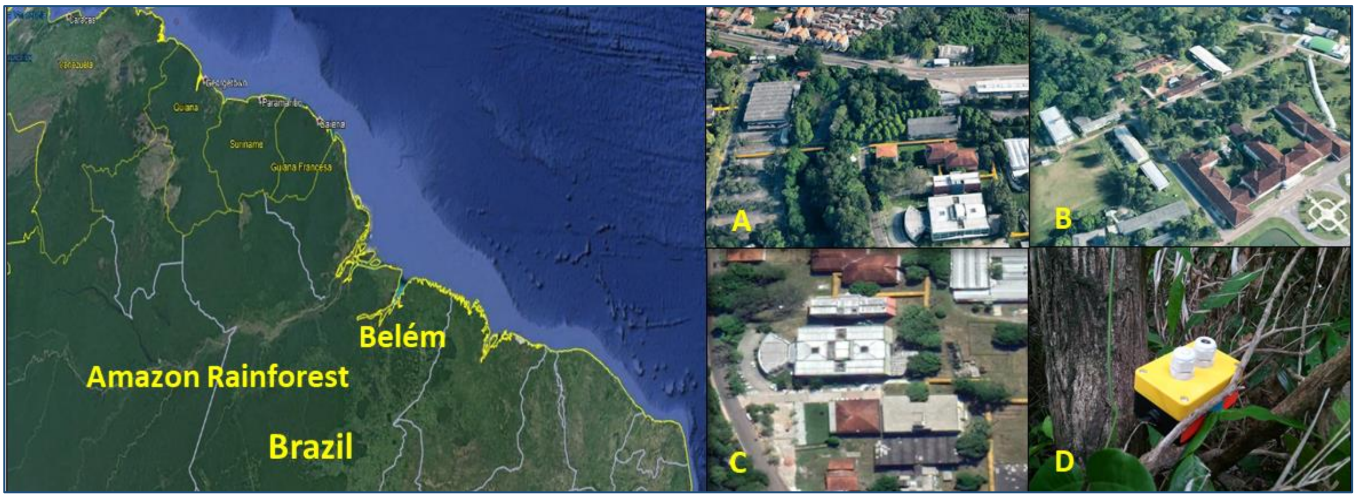

Figure 1. Selected environments. **(A)** Arboreal planning near the urban center. **(B)** Poor arboreal planning at forest fragment. **(C)** Parking lot nearby the A. **(D)** Intact natural forest around 100 km distant from Belém.

The green areas of each one are differentiated by A with landscape planning integrated into environmental preservation. Another (B), is located at a fragmented forest around A, but no planning its arborization form. Also, measurements were made in a parking lot (C), near to A, and inside a preserved natural forest (D), with difficult access for people, so far 100 km from A, B, and C.

To obtain data on environmental variables, we employ a mini mobile weather station, shipped with sensors, simple hardware, and compatibility with record storage [17]. The variables considered as an object of study are air temperature (T), relative air humidity (RH), dew point temperature (Td) and wind speed (v). The meteorological records were obtained in the course of four consecutive years, in the Amazon summer, between September and October, i.e., for the period 2016 to 2019, between 11:00 am and 3:00 pm, Responses were processed, and this collection was subsequently used for the presentation of results.

Among what is considered to be planning arboreal architecture are the wind corridors, which are free areas that allow pathways with openings towards the wind. It is notable that the direction of the wind during the summer period in Belém is constant and comes from the Atlantic, which flows across the surface in a close-to-parallel formation with the shape and direction of A (Figure 2). Also, trees are pruned at the same height and spacing between them. Its crowns start from 3 meters high so that the intercalary vegetation are shrubs planted in tracts made with reuse of materials obtained by donations. This site is a project of the Technological Institute at the Federal University of Pará.

Figure 2. Illustration of wind corridor at A location.
(1°28'19.9"S, 48°27'21.2"W)

The thermal sensation index presented by [16], was modified for an algorithm that considers the wind speed. This modification is given by:

$$TCI = 0.116 \times (T + Td) \times v.$$

This equation is valid for 0<V<5 m/s, with weak to moderate winds. It is worth mentioning that, winds considered of strong intensity, above 5 m/s, can cause trees falling during high winds in wooded environments. However, when v is not considered in the equation, the observations that set the value approximately +3 (very hot thermal environment) are valid and converge to the Talaia-Vigário equation [16]. To calculate Td, the following recurrence equation was used:

$$Td = T - (100 - UR)/5.$$

The data collected were measured and stored in the database using the computational module [17], show in Figure 3.

Figure 3. Data acquisition system [17].

3. Results and Discussion

The Amazon rainforest is in the Ecuadorian range and this geographical position influences climatic factors in the region. An essential feature in the composition of its equatorial climate, characterized by being hot and humid, is the presence of the vast Amazon basin, but there are also many local variations resulting from the topography. This combination of features creates a natural moisture flow that intensifies the heat as the incidence of sunlight is higher, causing the temperature to vary slightly throughout the year but preventing it from having the same proportions as a desert. Therefore, it is within this scenario that this proposal was developed, in which we propose a methodology based on an adequate thermal index that considers at least the basics of all this complexity.

Tables 1 shows the measurements of air temperature and relative air humidity in the four selected locations A-D (Figure 1), Table 2 shows the measurements of dew point temperature and wind speed, and Table 3 presents the TCI in these places.

Table 1. Average rates of Temperature, Relative Humidity
(September/October between 11:00 am and 3 pm)

	2016	2017	2018	2019
Temperature (°C)				
A	31.0	30.5	31.2	29.2
B	30.0	30.5	31.0	30.0
C	37.6	38.0	37.7	35.4
D	29.5	29.2	30.7	28.7
Relative Air Humidity (%)				
A	76.2	77.5	78.7	79.5
B	72.0	69.5	69.9	77.8
C	54.5	53.5	53.7	56.2
D	83.5	84.0	83.7	84.3

Source: Authors (2019).

Table 2. Average rates of Dew Point Temperature and Wind Speed
(September/October between 11:00 am and 3 pm)

	2016	2017	2018	2019
Dew Point Temperature (°C)				
A	26.4	26.0	26.9	25.1
B	24.4	24.4	24.9	25.5
C	28.5	28.7	28.4	26.6
D	26.2	26.0	27.4	25.5
Wind Speed (m/s)				
A	1.4	1.5	1.3	1.4
B	0.8	0.8	0.7	0.8
C	0.4	0.5	0.4	0.5
D	1.1	1.1	1.0	1.1

Source: Authors (2019).

Table 3. TCI to the environments assessed

Wind Speed (m/s)				
A	1.4	1.5	1.3	1.4
B	0.8	0.8	0.7	0.8
C	0.4	0.5	0.4	0.5
D	1.1	1.1	1.0	1.1

Source: Authors (2019).

To compare the comfort levels proposed by the index, the average values over the sampling period in Table 1 and Table 2 (shown in Figure 4), were used. In order to estimate the index at each location, a database was developed on a computer platform, and the results are shown according to the monitoring of the environments. With this methodology, we can infer that from the modification implemented in the Talaia-Vigário equation [16], this TC index is ideally suited for the humid tropics due to its practicality and is an evaluation method for the open-air index that allows quantifying heat stress in an urban environment.

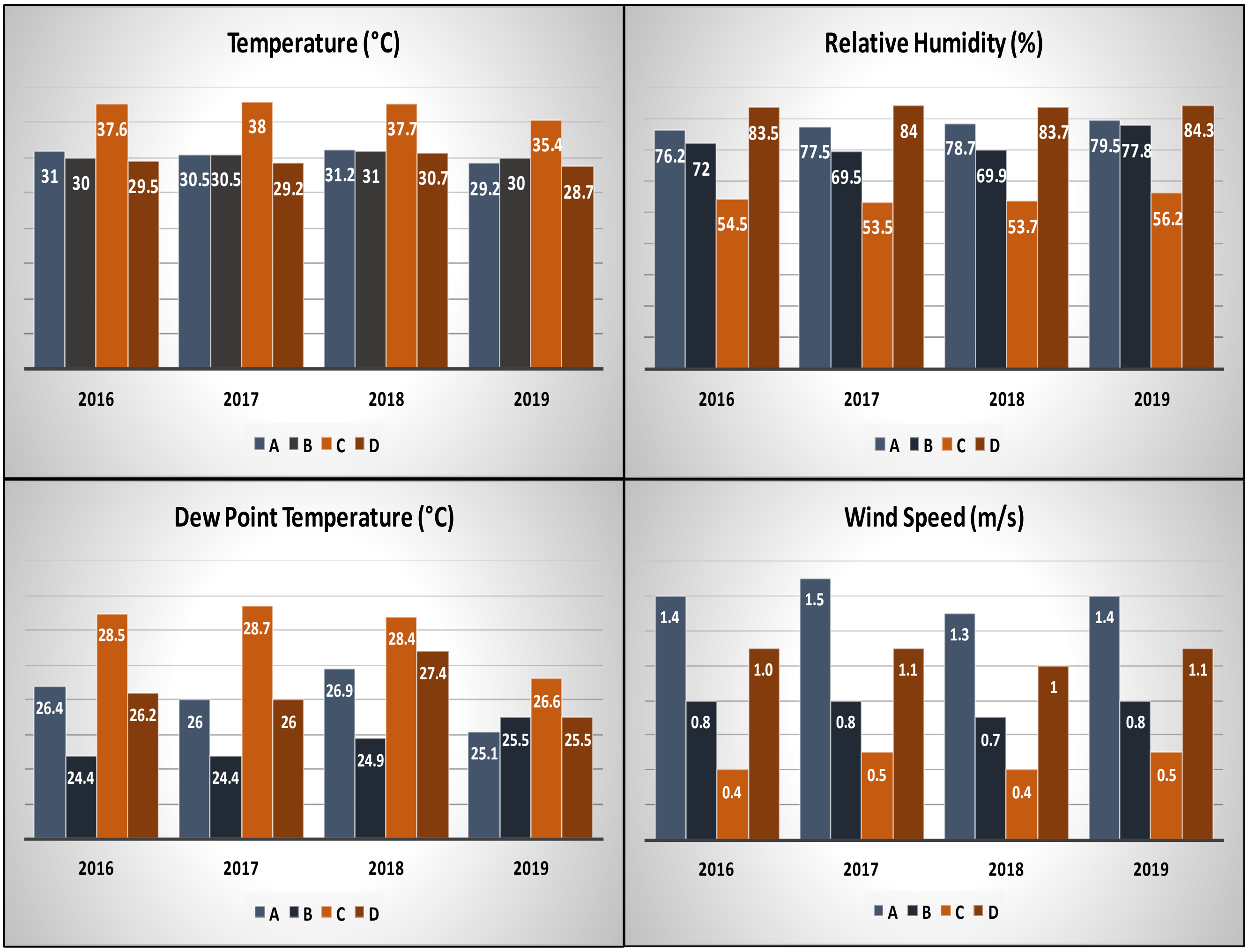

Figure 4. Average values of microclimatic variables measured between 11:00 am and 3 pm (September/October).

Except for the measurements on the parking lot, the average temperature showed no significant difference among environments. The forest also acts as a barrier for wind, which allows it to retain its moisture. Further information can be obtained from observing Figure 4: First, in deforested environments, the wind tends to be stronger; however, this does not occur in the parking lot (C), as the vegetation has been replaced by buildings that play the same role, destabilizing the systems in such a way that makes the humidity dropped rapidly (averaging 30%). In the fragmented area (B), the undergrowth has also been removed, facilitating loss of moisture and causing a decrease in the environment. The environmental conditions (landscape, climate, soil and wind) given in A, help preserve adequate soil moisture even when the precipitation in a particular season or year is reduced. It is observed that the difference in relative air humidity is slightly accentuated between A and D. This situation is associated for the fact that from A to C is a fragmented amount of vegetation, including C, which we believe is on account of the presence of a concentration of moisture, present in the region.

From the implementation of the TCI equation, the average value obtained in the A space with planning during the observation period was 9.1, while at B maintained with fragmented natural vegetation, but without planning, was 4.9 (Table 3 and Figure 4). This difference shows a significant difference in terms of the thermal sensation experienced in each of the environments. About the C parking lot, there was 3.3 which is a situation close to a hostile environment to the presence of people (TCI prox. to 3). In area D with dense forest, it remained within the average, which is a reasonable thermal comfort for the region. However, a problem of extreme heat concerning the thermal unhealthiness is found inside the urban area in the city of Belém, where it was registered that during this summer period the measurements at these times are similar to those obtained in C. Figure 5 shows the TC index (TCI normalized by the average of the best values from A).

Figure 5. TC index at locations A, B, C, and D.

As a final remark, for the use of this formulation should be emphasized that, as the work presented by [16], the conceptualize thermal sensation index, is related to critical situations of extreme cold or heat (-3 <TCI< +3). In the case of extreme heat, with risk or presence of fire, the wind is a direct participant of spreading. Thus, the use of the equation proposed by them, is related to the detection of fire risk or indoors critical situations, without the air circulation and heat conditioning, such as interiors of factories or schools. When the wind speed is considerate, the results of the combination of its speed into the equation, as is the case of public squares or parks, becomes a tool useful and effective management for evaluation of open-air space planning.

4. Conclusion

Based on the modification of a formulation presented in the technical-scientific literature, this text aimed at applicability for deforested cities located in the Amazon. The records were obtained by a sensor module in an embedded system, in which the values of air temperature, dew point temperature, humidity and wind speed have been stored. The results were verified *in situ*, among which there is an area built with the planning of wind corridors and where the highest speed was registered, followed by an intact forest, during all experiments concerning the other areas evaluated. Thus, we can conclude that the implemented TC index allows us to evaluable the thermal comfort that better represents the climatic conditions in the open-air of fragment forest. Furthermore, it is essential to consider the need to research and update this theme that is little discussed, due to the knowledge that space is much more pleasant where a larger volume of vegetation predominates. Also considering the climate can get out of control in the Amazon rainforest by a simple natural condition and by raising awareness on the deforestation problems in the region has been increasing, it may safely be stated today that the thermal sensation is becoming increasingly unbearable due to human intervention in its natural habitat. However, when unfolding this study, it is seen that some authors claim that it is not enough to plant any tree because there are some criteria to consider before planting in order to obtain thermal comfort. Studies such as this, related to local microclimate, are essential in assisting the planning and management of urban space, contributing to the construction of thermally more delightful environments, mainly in cities with a hot and humid tropical climate, with a strong tendency to become a desert, if its forest disappears.

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