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Modeling of urban canyons in tropical savannah climate: Relationship between geometric parameters and microclimate at pedestrian level

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ABSTRACT
The population increase in cities has driven a gradual process of modification from the natural to the built environment. These transformations condition a typically urban climate, often characterized by an increase in air temperature, a phenomenon called urban heat island (ICU). In the search for sustainable and resilient cities, the literature points to the compact city model, and verticalization emerges as an alternative to make population demand viable. The objective of this investigation was to analyze the effects of the geometry of urban canyons on the microclimate, based on the H/W ratio and the orientation of the roads, taking as object of study the city of Arapiraca, Alagoas, with a tropical savannah climate. To this end, computational simulation was used in the ENVI-met v.4 Beta software in predictive analysis, based on 18 hypothetical scenarios. The scenarios vary in the application of initial and progressive minimum setback to the number of floors, with the incidence of predominant ventilation perpendicular (N = 0°) and oblique (N = 45°) to the buildings, for the hot and dry period. The performance of the canyon was evaluated by comparing air temperature, average radiant temperature and wind speed at 3 p.m., the period with the highest air temperature. The results revealed that in deep canyons with the use of the initial retreat, the extension of shaded area was greater, which decreased the mean radiant temperature. However, the scenarios with the use of progressive retreat showed better performance in terms of wind speed. In this case, the oblique orientation of the vias potentiated this result.

KEYWORDS: Urban Climate. Urban planning. Bioclimatic Urbanism. Computer Simulation. ENVI-met.

1 INTRODUCTION

Population growth is one of the inducers of every cycle of changes in the urban climate, since it leads to the construction density and verticalization of urban areas, affecting local climatic conditions (MUNIZ-GÄAL et al., 2018). The increase in the height of buildings generates shadowing, influences the speed and direction of the winds, the way in which short-wave radiation is received, and the release of long-wave heat (WAI et al., 2020; XUE et al., 2020).

In this context, urban planning is an important tool with the potential to promote ideal and comfortable thermal conditions for users of outdoor spaces, while alleviating the demand for cooling in buildings (GIVONI, 1998), but, for this, the study of the urban microclimate becomes essential for the knowledge of the climatic specificities of each location based on the precepts of bioclimatic urbanism (NOGUEIRA et al., 2018; TALEGHANI, 2018).

Regarding the effects of construction densification on microclimates, it is worth highlighting the importance of the shape of urban canyons, understood as a composition formed by a street bordered by vertical buildings (TORRES, 2017). According to Afiq et al. (2012), the urban canyon can be classified based on the H/W ratio as *avenue* (H/W < 0.5), *regular* (H/W = 1) or *deep* (H/W > 2). Similarly, the value of the L/H ratio makes it possible to distinguish between *short* (L/H < 3), *medium* (L/H = 5) or *long* (L/H > 7) canyons. Canyons lined up from buildings of approximately equal height are said to be symmetrical, while a significant difference between heights is characteristic of asymmetrical canyons.

Among the factors that influence the microclimate in the urban canyon, its geometry stands out, usually expressed by the relationship between the average height of the buildings (H) and the width of the roads (W), H/W ratio; the Visible Sky Factor (SVF), which indicates the degree of obstruction of the celestial vault, and the orientation of the canyon axis (ERELL; PEARLMUTTER; WILLIAMSON, 2011). The H/W ratio and the SVF exert an influence on the incidence of direct solar radiation in the interior of the urban canyon, as well as on the capacity of radioactive thermal exchange of the interior of the canyon with the celestial vault (ACHOUR-YOUNSI; KHARRAT, 2016); and its orientation in relation to solar radiation, due to the potential to optimize the shading of the surfaces inside it, and to the predominant direction of the winds, by taking advantage of natural ventilation with increased convective thermal exchanges, benefiting urban climatic conditions (TORK et al., 2017).

The effects of the H/W ratio on the urban microclimate in hot climate cities have been the subject of several studies. In a tropical climate, it was observed that the reduction of distances between buildings increases the shading generated by the buildings on the canyon surfaces, providing a reduction in the average radiant temperature during the day, which favors thermal comfort at the pedestrian level, especially in the summer period (ANDREOU, 2013; MUNIZ-GÄAL et al., 2018). This fact indicates that the shading of buildings, caused by the height and proximity between buildings, has a greater impact on the thermal comfort of pedestrians than a condition of greater ventilation of the canyon (MUNIZ-GÄAL et al., 2018). However, it is necessary to consider that ventilation is essential to accelerate heat exchange and ensure comfort in regions with a hot climate (DE; MUKHERJEE, 2018; XUE et al., 2020).

Inserted in the tropical climatic zone, there is the tropical savannah climate (As), characterized by the occurrence of rainfall coinciding with the winter period and by presenting the absence of rainfall in the summer, combined with high temperatures. In Brazil, according to Alvares et al. (2013), the As climate covers 5.5% of the territory, about 468,366 km² and occurs mainly in the Northeast region. In the state of Alagoas, for example, the As climate occurs in 71.2% of its territory. Some studies have sought to understand the influence of the H/W ratio on the microclimate of urban canyons and pedestrian-level thermal comfort in cities with an As climate, such as Yahia et al. (2017) in Dar es Salaam, Tanzania; Sharmin et al. (2017) in Dhaka, Bangladesh; De and Mukherjee (2018) in Rajarhat Newtown, India; Huang and Chen (2020) in Kaohsiung, Taiwan; Srivanit and Jareemit (2020) in Bangkok, Thailand. But in the Brazilian context, there are still few studies to assist urban planners in the city planning process. Thus, the importance of the present study of the effects of geometric parameters of urban canyons on the microclimate of a city with a tropical savannah climate is highlighted.

2 OBJECTIVE

The present investigation aimed to analyze the effects of geometric parameters of urban canyons on the conformation of microclimates at the level of pedestrians in a city with a tropical savannah climate (As'). To this end, the city of Arapiraca, located in the semi-arid region of Alagoas, was taken as a case study.

3 METHODOLOGY

The methodological procedures adopted in the present investigation consisted of three distinct stages: (1) Selection and characterization of urban fraction with tendency to verticalization in the city under study; (2) Composition of the input data in the model for computer simulation; and (3) Elaboration of models and simulation of real and hypothetical scenarios in the Envi-met v.4 Beta software.

3.1 Characterization of the Case Study

The city of Arapiraca is located in the interior of the state of Alagoas, in the semi-arid region of Northeast Brazil, at an altitude of approximately 280 m. It has an estimated population

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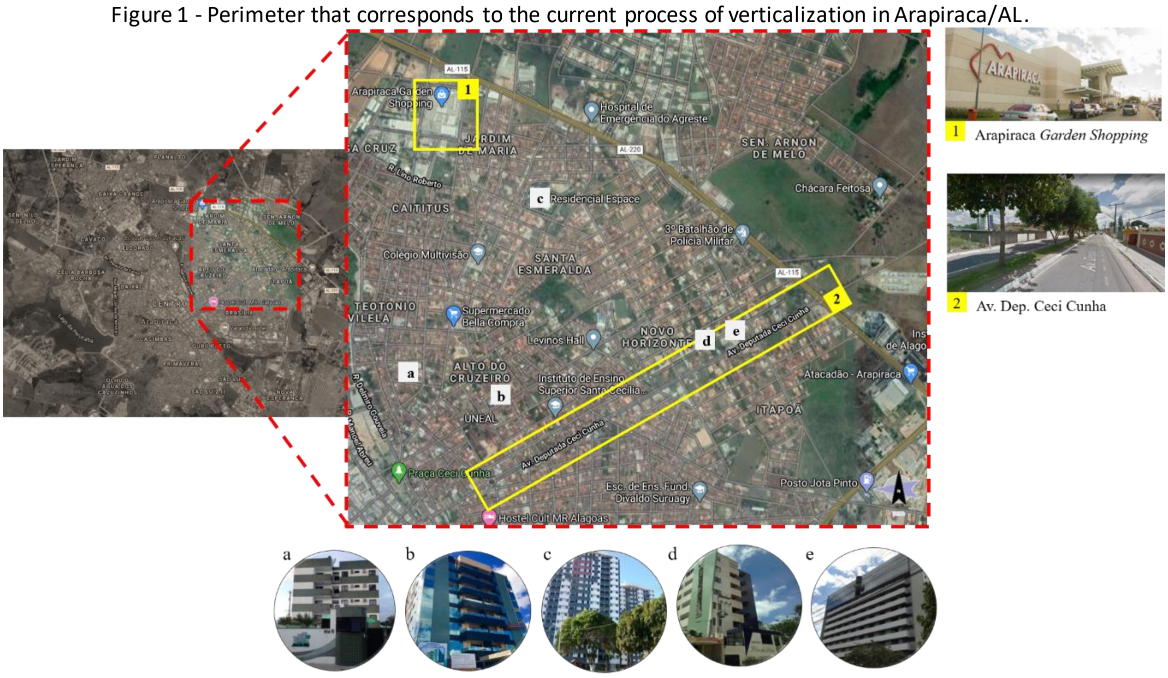
of 234,309 inhabitants (IBGE, 2021), in a territorial area of 356,179 km². It is the second largest city in the state and an important commercial and service center, showing intense population growth in recent decades.

The climate of the city is tropical savannah, type As, according to the Köppen-Geiger climate classification (BARROS et al., 2012), characterized by rainfall in the autumn-winter period, with a well-defined dry season. It has an average annual temperature of 24.7 °C, an average annual relative humidity of 73.9%, and an average annual rainfall of 890.0 mm (SILVA, 2019). The prevailing winds are from the East, with a secondary direction from the Southeast, with light and fair wind speeds, and the occurrence of calms in 13.73% of the annual hours (SILVA; BARBOSA, 2022).

The choice of the urban fraction for modeling the hypothetical urban scenarios was based on the type of fabric with a tendency to verticalization, the Dispersed Horizontal, as pointed out by Torres (2017). Recently, it was observed that in the perimeter that is configured between the city's Shopping Center (Point 1) and an important avenue that connects the highway to the center of Arapiraca (Point 2), it is composed of the following neighborhoods: Alto do Cruzeiro, Novo Horizonte, Santa Esmeralda, Itapoã, Brasília and Caititus; there is a growing change in urban land use, with the construction of vertical buildings for residential and business activities, ranging from 3 m (ground floor) to 30 m (vertical) in height, as can be seen in Figure 1.

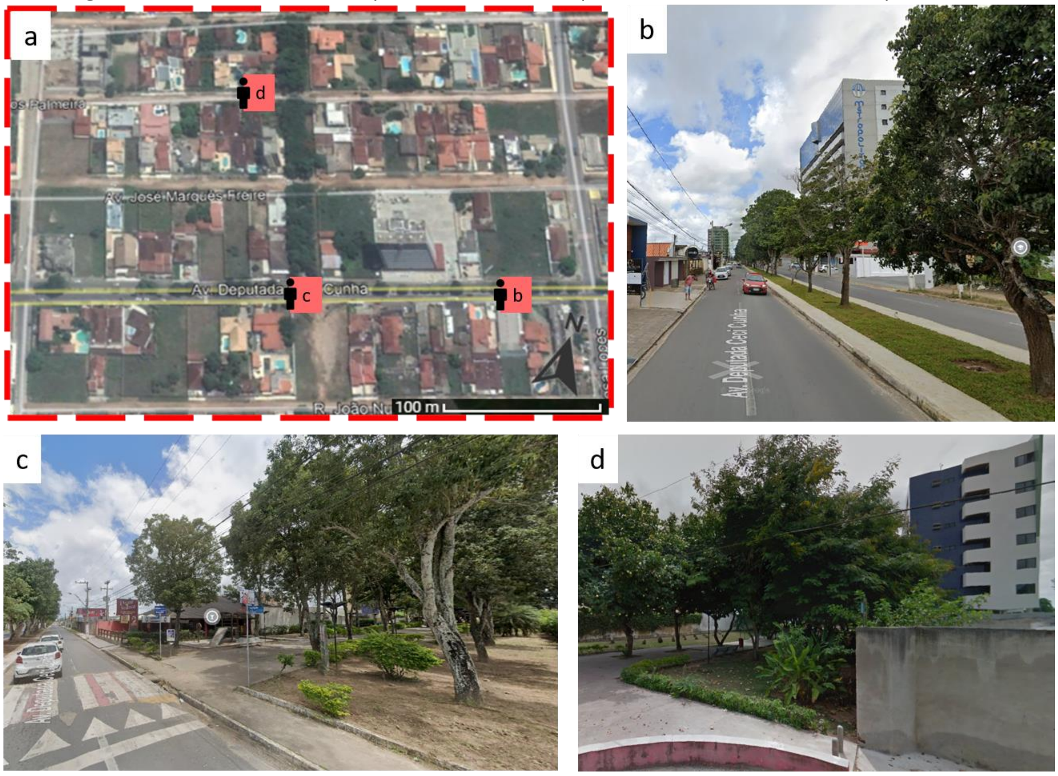
Figure 1 - Perimeter that corresponds to the current process of verticalization in Arapiraca/AL.



Source: Adapted from Google Maps, 2020.

In order to elaborate the hypothetical scenarios, we sought to understand the recurrent pattern of occupation in this urban fraction (see Figure 2a), based on the design of the blocks and lots, and on the width of the roads and sidewalks, by means of an updated cartographic base, made available by the City Hall. The Avenue has a continuously wooded median (Figure 2b), and between the blocks there is a linear green area with the presence of large trees, as shown in Figures 2c and 2d. About the characteristics observed in loco of the selected perimeter: the street covering is asphalt or natural cover, the sidewalks are made of concrete or ceramic coating, and the facades are ceramic or painted with different colors. The predominant roofing materials are ceramic tiles, fiber cement, or concrete slabs. The study area was 129,454.93 m², with a Southwest/Northeast orientation.

Figure 2 - Perimeter that corresponds to the current process of verticalization in Arapiraca/AL.



Source: Adapted from Google Maps, 2023.

3.2 Model Input Data

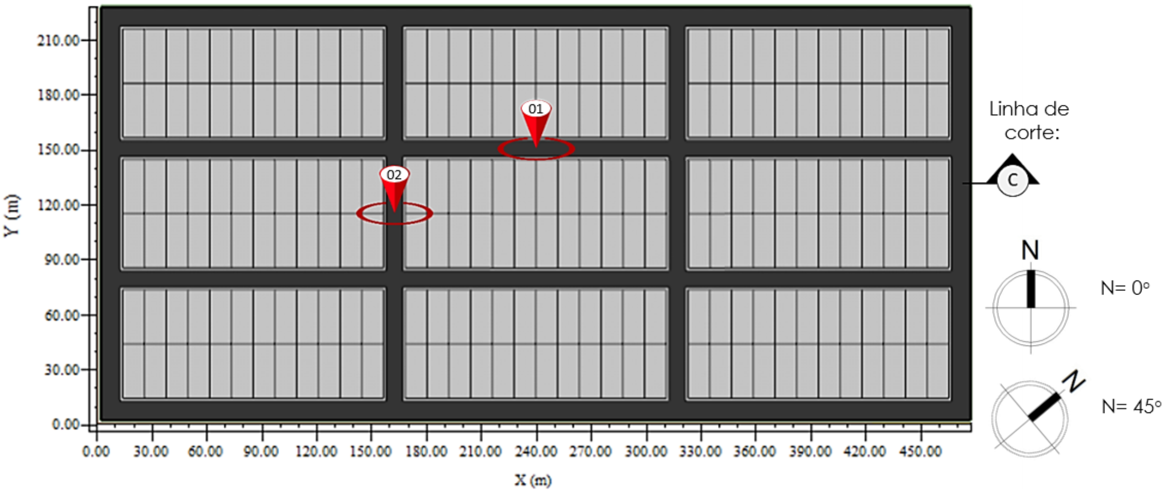
In the ENVI-met software, the simulation requires two main files: An urban configuration file, in which the study area is modeled (including the location of buildings, vegetation, soil, surfaces, and receivers); and a climate configuration file with all startup values and times (MUNIZ-GAAL et al., 2020). The process is described below.

The model of the study area was built with a grid resolution of 2 m x 2 m x 3 m, maintaining good representativeness, totaling an area of 478 m x 228 m, in 239 x 114 x 29 grids. The area consists of nine blocks with 24 lots, measuring 12 m x 30 m separated by streets 8 m wide. The number of lots per block, the average size of the lots and the width of the streets correspond to the pattern of land subdivision observed in the urban fraction adopted as a reference for the study.

The height of the top of the model was 90.98 m, obtained from the telescopic method of generating the vertical grid with an increase factor of 2%, from the height of 45 m, since the minimum height required by the model is twice the height of the tallest building inserted in the model (GUSSON, 2014). To maintain the stability of the model, 5 nesting grids were inserted around the modeled area (YANG et al., 2013). Two inclinations to the north were adopted: 0° and 45°, representative for the perpendicular and oblique incidence of the predominant ventilation (east) in relation to the buildings, respectively.

In order to analyze only the effect of the built mass, no vegetation was inserted in the scenarios. The area was modeled as shown in Figure 3. In the study scenarios, 2 receiving points were established for the collection of climatic data, in order to analyze the result of the simulations. Point 01 (120,73) is parallel to the windward and point 02 (84,66) is to leeward.

Figure 3 - Study area.



Source: Authors.

The materials used in the modeling of the hypothetical scenarios were based on the existing materials in the ENVI-met v.4 Beta software database (Chart 01).

Chart 1 - Characteristics of the materials used in the modeling of the study area and scenarios.

	ID	Material	Albedo	Emissivity
Roof	R2	Ceramic Tile	0.50	0.90
Walls	B2	Ceramic Bricks	0.40	0.90
Sidewalks	PG	Gray Concrete	0.40	0.89
Streets	ST	Asphalt	0.12	0.90
Soil	LO	Clay	0.00	0.98

Source: Authors.

The solar adjustment tool, which allows adjusting the shortwave solar radiation, calculated for the input meteorological conditions for the computer simulation, was used to adjust the incident global solar radiation to the value recorded in the reference meteorological station (INMET - A353). In some situations, solar energy fluxes estimated using ENVI-met's internal methods may be systematically too high or too low. Thus, the solar adjustment factor of 0.92 was used, according to Torres (2017).

9 p.m. was adopted as the start time of the simulation, due to the absence of solar radiation and the availability of data on specific humidity at the top of the model at 2500 m (00:00 UTC - neutral atmosphere). The specific humidity data were taken from the Natal/RN airport station, as it is the closest point with this type of data available. In order to obtain climatic

data of 2 days (two complete cycles). The first cycle is considered as a period for stability of the simulation and in the second cycle the climatic data were considered for analysis. The data of an extreme day for the hot and dry period were used for air temperature and relative humidity (SILVA, 2019). The input parameters for computer simulation are described in Chart 2.

Chart 2 - Input Data Parameters for Computer Simulation.

Parameter	Summer
Start Date	26/11/2015
Start Time	21:00
Total Simulated Hours	52
Wind Speed Measured at 10 m Height (m/s)*	2.7
Wind Direction (degrees)*	94
Roughness Length at Measurement Site	0.1
Initial Atmosphere Temperature (K)*	302.34
Specific Humidity at the Top of the Model (2500 m - g/kg)**	2.92
Relative Humidity at 2 m (%)*	62.9
Solar Adjustment Factor****	0.92

*Silva, 2019
**Data from the airport of Natal/RN obtained by the website of the Department of Atmospheric Sciences of the University of Wyoming.
*** Model Standard
****Torres, 2017.
Source: Authors.

3.3 Elaboration of Hypothetical Scenarios for Simulation

The hypothetical scenarios were modeled on the digitized base. The vertical buildings were modeled considering the remembrance of three standard lots, since the remembrance of two lots resulted in very reduced floor areas for tall buildings when the progressive setback was applied to the number of floors. The scenarios were modeled from combinations of urban parameters in order to confer variations in the geometry of the urban canyon, based on the H/W ratio.

The height of the buildings considered scenarios with low, medium and high verticalizations, based on the current pattern of number of floors existing in the city under study, resulting in buildings with 5, 10 and 15 floors, respectively. Scenarios with homogeneous and heterogeneous heights were modeled, resulting in variations in the roughness of the urban geometry. The spatial distribution of buildings with different heights in the block was made randomly by lottery, considering the same number of specimens of each height in each block.

The distance between the buildings was calculated from the application of minimum setbacks, currently in force in the city's urban planning legislation (ARAPIRACA, 2001), and progressive setbacks to the number of floors, according to Equation 1. This calculation corresponds to the same adopted for vertical buildings, according to the urban planning legislation in force in the state capital (MACEIÓ, 2007).

$$RP = (Ri + (n-2)) / 2 \qquad \text{Equation 1}$$

Where:
RP corresponds to the resulting progressive recoilment, in meters;
Ri corresponds to the initial or minimum setback, in metres, applied to the area in question; and

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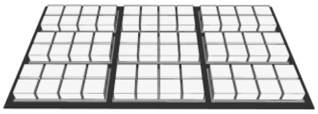
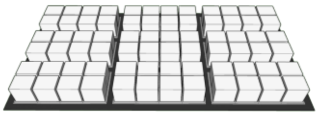
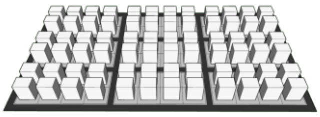
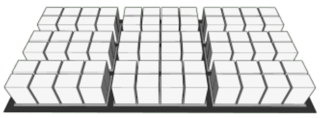
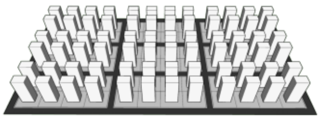
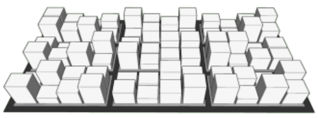
n corresponds to the number of floors in the building.

The application of the progressive setback to the number of floors resulted in greater distances between the taller buildings, conferring variations in the porosity of the urban geometry. The parameters adopted in the modeling resulted in nine hypothetical scenarios, considering the reference scenario with all single floor buildings. The change in the incidence of ventilation in the model resulted in 18 simulations being performed (Chart 3).

Chart 3 - Parameters of what-if scenarios.

Model	Vertical Standard	No. of floors	ID	Setbacks (m)		Canyon width (m)	H/W
				Front	Side/Posterior		
	Reference	1	RF	3	1,5	18	0,16
	Low	5	RI-05	3	1,5	18	0,83
			RP-05	4,5	3	21	0,7
	Medium	10	RI-10	3	1,5	18	1,6
			RP-10	7	5,5	26	1,15
	High	15	RI-15	3	1,5	18	2,5
			RP-15	9,5	8	31	1,45
	Mixed	5/10/15	RI-Mixed	*	*	18	*
			RP-Mixed	*	*	*	*

*Variable values within the urban canyon.
Source: Authors.

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The L/H ratio was constant in all scenarios. According to Muniz-Gäal et al. (2020), the variation in the relationship of this parameter has no significant effect on the sensation of thermal comfort at the pedestrian level. The comparative analysis of the results obtained was carried out from the microclimatic variability inside the canyon at 3 p.m., observed at a height of 1.5 m from the ground.

4 ANALYSIS OF RESULTS

4.1 Air Temperature

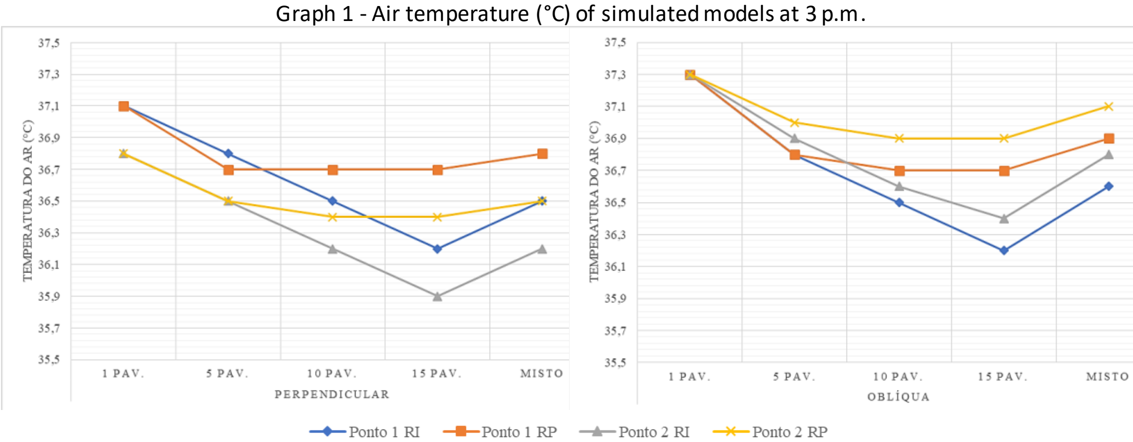
Regarding the variability of air temperature, Table 1 and Graph 1 present quantitative data at 3 p.m. The values highlighted in red are the highest of the variant under analysis, while the values highlighted in green are milder.

Table 1 - Air temperature range (°C) for 3 p.m.

Points		PERPENDICULAR					OBLIQUE				
		REF	5P	10P	15P	Mixed	REF	5P	10P	15P	Mixed
P1	RI	37,1	36,8	36,5	36,2	36,5	37,3	36,8	36,5	36,2	36,6
	RP	37,1	36,7	36,7	36,7	36,8	37,3	36,8	36,7	36,7	36,9
P2	RI	36,8	36,5	36,2	35,9	36,2	37,3	36,9	36,6	36,4	36,8
	RP	36,8	36,5	36,4	36,4	36,5	37,3	37,0	36,9	36,9	37,1

Source: Authors.

Graph 1 - Air temperature (°C) of simulated models at 3 p.m.



Source: Authors.

For the time of 3 p.m., the hottest period of the day – according to the local climate, it was possible to observe that, in the models of incidence of ventilation perpendicular to the buildings, between the points to windward (1) and leeward (2) there is a difference of, on average, 0.5°C, due to the orientation of the urban fabric, which at that point and at the time of day had a higher incidence of direct solar radiation and a smaller area of shade.

Regarding the initial and progressive setback, in the REF and 5-story scenarios the temperature remained close to the values, but from the 10-story scenario there was a growing difference between the corresponding values of each scenario, in relation to the use of progressive setback. This difference was smaller in the mixed scenarios. This is due to the fact that the shadow area is larger in the scenarios with the use of the initial retreat, compared to the scenarios with the use of the progressive retreat, which reduces the incidence of direct solar radiation. Muniz-Gäal et al. (2018) also observed lower air temperatures in scenarios with less space between buildings and related this performance to less exposure to the sun.

Thus, it is important to highlight the effect of verticalization on the behavior of air temperature, since there is a downward trend in maximum air temperature with the increase in the H/W ratio of the urban canyon. In point 1, for example, the REF scenarios presented 37.1°C and 37.3°C, in the perpendicular and oblique incidences, respectively, while the 15 floors scenarios presented the lowest air temperature values, with 36.2°C, which generated a difference of 0.9°C to 1.1°C. Thus, the influence that shading exerts on the behavior of air temperature, at the height of 1.5 m from the ground, is evident.

4.2. Average Radiant Temperature

Since several studies point to the mean radiant temperature as a climatic variable with a strong influence on urban thermal comfort indexes, such as the PET (physiologically equivalent temperature) and the MVP (predicted average vote) - together with the wind speed (KRÜGER; MINELLA, 2011; ANDREOU, 2013; XUE et al., 2020), it is expected to obtain answers regarding the influence of urban geometry on the conformation of the microclimate, in reality of a city with a tropical climate of dry savannah.

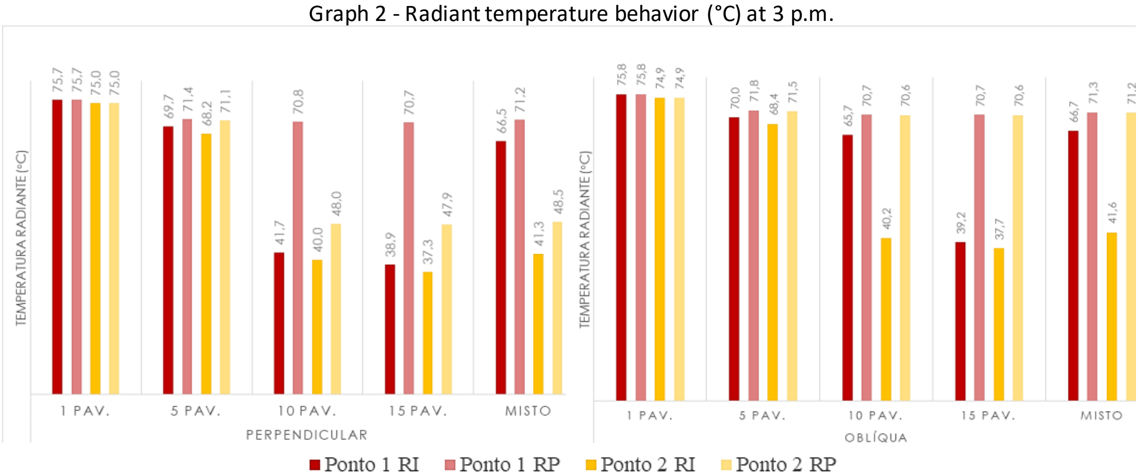
Table 2 and Graph 2 shows the quantitative data at 3 p.m. The values highlighted in red are the highest of the variant under analysis, while the values highlighted in green are milder.

Table 2 - Radiant temperature behavior (°C) for 3 p.m.

Points		PERPENDICULAR					OBLIQUE				
		REF	5P	10P	15P	Mixed	REF	5P	10P	15P	Mixed
P1	RI	75,7	69,7	41,7	38,9	66,5	75,8	70,0	65,7	39,2	66,7
	RP	75,7	71,4	70,8	70,7	71,2	75,8	71,8	70,7	70,7	71,3
P2	RI	75,0	68,2	40,0	37,3	41,3	74,9	68,4	40,2	37,7	41,6
	RP	75,0	71,1	48,0	47,9	48,5	74,9	71,5	70,6	70,6	71,2

Source: Authors.

Graph 2 - Radiant temperature behavior (°C) at 3 p.m.



Source: Authors.

In the models of incidence of predominant ventilation perpendicular to the buildings, from the analysis of the quantitative data at 3 p.m., it is possible to observe that the scenario with the highest values of radiant temperature at points 01, to the windward, and 02, to the leeward, was the REF, which has only single floor buildings, due to the soil exposed to direct solar radiation. with 75.7°C and 75.0°C, respectively. At points 01 and 02, the scenarios that presented milder temperatures (in green) were RI-15, due to the greater area of shade generated by the use of the initial setback, with 38.9°C and 37.3°C.

In point 01 of the scenarios with the use of progressive retreat, high values of radiant temperature are observed compared to the others, because at this specific time the place where it is located was not haunted, receiving direct solar radiation. It can also be seen that in shallow and deep canyons, with an H/W ratio greater than 1.0, the radiant temperature values decrease, due to the low visible sky factor, which directly interferes with shading.

The setback used also influences the behavior of the radiant temperature, because in point 02 the difference between the data obtained from the computer simulations between the scenarios using the initial and progressive setback of 15 floors reaches 10.6°C, since the ve rtical buildings with the use of the initial setback have a larger shadow area. because the built-up area on the lot has a larger area.

The orientation of the road layout in relation to the predominant direction of ventilation, treated in the present study from the angles of 0° and 45°, did not show significant difference between the scenarios, in general, however, there was an increase in the radiant temperature at point 02, to the leeward, in the RP-10, RP-15 and RP-Mixed scenarios, in the latter scenario, for example, the difference reaches 22.7°C.

4.3. Wind speed

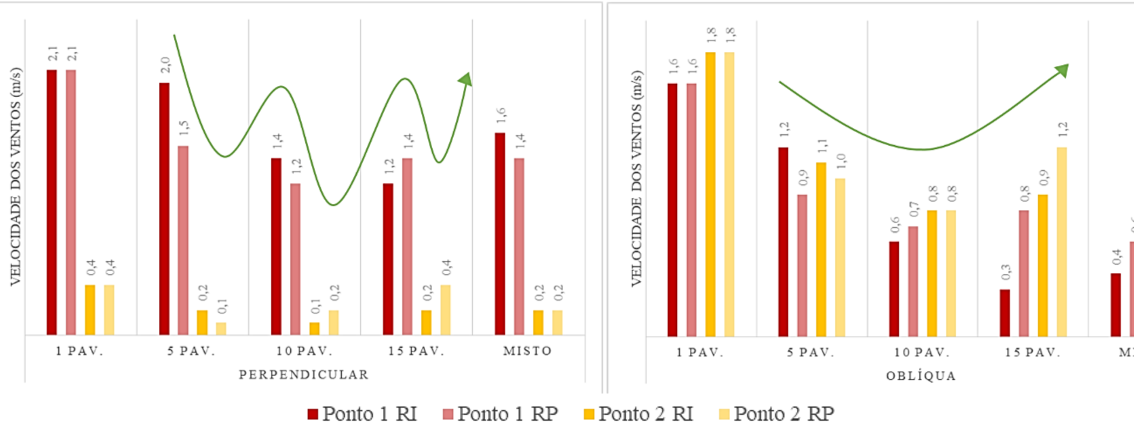
The ENVI-met software, used in the present study, considers the constant speed during the day, in this sense, it was decided to analyze the behavior of wind direction and speed at 3 pm, based on quantitative data. Table 3 and Graph 3 demonstrate, quantitatively, the behavior of wind speed at Point 01, to windward, and to Point 02, to leeward.

Table 3 - Wind speed behavior (m/s) for 3 p.m.

Points		PERPENDICULAR					OBLIQUE				
		REF	5P	10P	15P	Mixed	REF	5P	10P	15P	Mixed
P1	RI	2,1	2,0	1,4	1,2	1,6	1,6	1,2	0,6	0,3	0,4
	RP	2,1	1,5	1,2	1,4	1,4	1,6	0,9	0,7	0,8	0,6
P2	RI	0,4	0,2	0,1	0,2	0,2	1,8	1,1	0,8	0,9	1,3
	RP	0,4	0,1	0,2	0,4	0,2	1,8	1,0	0,8	1,2	1,1

Source: Authors.

Graph 3 - Wind speed behavior (m/s) for 3 p.m.



Source: Authors.

In Table 3, the data highlighted in green correspond to the highest wind speed values, while the data in red correspond to the lowest wind speed values for Points 01 and 02. Importantly, increased build density often slows down near-surface airflow (OKE, 2017), which justifies higher velocities focusing on REF scenarios.

In the hypothetical urban models of incidence of predominant ventilation perpendicular to the buildings, it is possible to observe the disparity between the point to windward (01) and leeward (02), due to the channeling of the air flow in the circulation routes with East-West axis, which generates an increase in wind speed, with a difference of up to 1.8 m/s in the RI-05 scenario. On the other hand, this difference was attenuated in the models of incidence of predominant ventilation oblique to buildings, with a difference of 0.1 m/s in the same scenario. This is because the orientation of the road layout optimized the permeability of the winds in the urban network.

Tork et al. (2017) also found that on roads oriented to the Northeast-Southeast, oblique to the prevailing wind direction, the thermal performance is superior in terms of wind speed and cross-ventilation potential. Wind speed is important for air quality and the dispersion of air pollutants and anthropogenic heat (OKE, 2017; XUE et al., 2020). Still on the issue of the orientation of the road layout, Achour-Younsia; Kharratb (2016), stated that the orientation of the streets is crucial in the evaluation of outdoor thermal comfort, as the North-South orientation, for example, perpendicular to the prevailing wind direction, allows sunlight to infiltrate during a long period of the day, especially in summer.

Regarding the adoption of the initial and progressive retreat, a pattern was observed in all scenarios: Although the wind speeds were higher in the REF and RI-05 scenarios, due to the channeling of the wind flow, but as the buildings become vertical, gradually, the speed increases in the scenarios with the use of progressive retreat. According to Torres (2017), the decrease in the porosity of the urban fabric between the building and the boundary of the lot reduces the speed of the winds, and the porosity of the urban network is determined by the rate of penetration of winds in the urban composition and it is directly related to the capacity of the buildings and the constructive arrangements to allow the dissipation of the winds through their own structure, from the distances between buildings, the occupancy rate, the existence of empty spaces and the width of the tracks.

When analyzing the behavior of wind speed in relation to urban form, two factors must be considered: porosity, mentioned earlier, and roughness, which influences the vertical profile of the wind, known as wind gradient. The mixed scenario makes it possible to analyze the roughness of the urban fabric in relation to the performance of the use of natural ventilation. In the models of incidence of predominant ventilation perpendicular to the buildings, it is noted that the mixed scenario presents results similar to the vertical scenarios, and in the models of oblique incidence, the result is repeated.

5. FINAL CONSIDERATIONS

In this study, the climatic performance of urban canyons was evaluated based on the variation of three characteristics of their geometry: H/W ratio, based on the space between buildings (use of the initial or progressive setback) and the orientation of the roads (N=0°/ N=45°); from the climate data obtained from air temperature, radiant temperature and wind speed.

The air temperature data showed no significant difference between the hypothetical urban scenarios, since the difference between them reached 0.3°C. In this case, the understanding of the microclimate of the canyon in relation to its geometry took place with the analysis of the radiant temperature and the speed of the winds. The behavior of the radiant temperature was directly linked to the shading area generated by the buildings, as it determines the amount of solar radiation to be absorbed, reflected and/or emitted. In the scenarios of deep urban canyons, there was a decrease in air temperature and radiant temperature, positive points for thermal comfort at the pedestrian level, as the shade area generated by the buildings was greater. The adoption of the initial setback enhanced this result, due to the greater occupation of the lot area, generating a more extensive shade area. The orientation of the roads did not show significant differences between the models in the behavior of the climatic variables in question.

The H/W ratio, based on the use of the initial or progressive setback, and the orientation of the roads, had a strong influence on the behavior of the winds. The results of the scenarios of incidence of ventilation perpendicular to the buildings revealed that the canyons with higher H/W ratios increased the wind speed at point 01 (windward), due to the channeling of the winds, resulting in areas of wind shadow at point 02, to leeward, and inside the lots. It is noteworthy that point 01 is located on an East-West axis, parallel to the predominant incidence of local ventilation, while point 02 is located on a path perpendicular to the predominant incidence of ventilation.

In the scenarios of incidence of oblique ventilation to the buildings, there was a decrease in wind speed, since the effect of wind channeling decreases, as well as it is possible to observe the improvement in wind permeability in the urban network, due to the orientation of the roads in a Northeast-Southeast direction. Thus, the wind speed data at points 01 and 02 came closer. The data referring to the scenarios with the use of progressive retreat, for increasing the spacing between the buildings and generating benefits to the porosity of the urban fabric, as well as in the mixed scenarios, in which there was an increase in roughness, based on the different heights of the buildings, showed superior performance to the others in the use of natural ventilation, which is one of the bioclimatic strategies in the climate in question.

This study evaluated the climatic conditions and thermal sensation of the scenarios for the tropical climate of mid-latitude savannah and without considering the effects of vegetation interactions. One of the key takeaways from this article leads to the remarkable importance of shading in reducing heat stress. Based on the aforementioned results, the geometric parameters of urban canyons strongly affect the microclimate and the level of thermal comfort at the pedestrian level, highlighting the need to develop urban planning guidelines based on these parameters.

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