Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 86, 2024

Effects of surface roughness on natural ventilation variability in urban canyons in a tropical savanna climate

Luana Karla de Vasconcelos Brandão
PhD student in the Postgraduate Program in Architecture and Urbanism, UFAL, Brasil.
luana.brandao@arapiraca.ufal.br

Ricardo Victor Rodrigues Barbosa
Teacher of the Postgraduate Program in Architecture and Urbanism, UFAL, Brasil.
rvictor@fau.ufal.br

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 86, 2024

ABSTRACT
This article analyzed the effects of surface roughness on the variability of natural ventilation within urban canyons, based on the variation of two morphological parameters: The H/W ratio, based on the space between buildings, and the orientation of the roads (N = 0°/ N = 45°). As an object of study, the city of Arapiraca, with a tropical savannah climate (As), located in the semi-arid region of Alagoas, is located. The methodology adopted was based on predictive analysis, through computer simulation, using the ENVI-met v.4 Beta software. 18 hypothetical urban scenarios were elaborated, which varied in terms of the application of initial and progressive minimum setback to the number of floors, with incidence of predominant perpendicular (N = 0°) and oblique (N = 45°) ventilation to the buildings, for the hot and dry period. The climatic performance of the canyons was evaluated, quantitatively and qualitatively, through wind speed and direction data at 3 p.m., at a height of 1.5 m from the ground. The results showed that the scenarios with low surface roughness, with the application of progressive setback, buildings of different heights and incidence of the predominant oblique ventilation to the buildings, presented more favorable conditions for the use of natural ventilation for thermal comfort outdoors, at the pedestrian level. In view of the results found, the need for urban planning guidelines that are aligned with local bioclimatic strategies and the precepts of urban sustainability and resilience is highlighted.

KEYWORDS: Urban climate. Urban planning. Urban morphology. Bioclimatic urbanism. ENVI-met.

1. INTRODUCTION

The roughness (Zg) of an urban structure is defined as a parameter that expresses the geometric morphology of the surface, whose concept means the measurement of the aerodynamic roughness of the surface, related to the height of the elements, as well as to the shape and distribution of their density, directly affecting the speed of the air masses that reach the urban structure (Oke *et al.*, 2017). It is known that this variable interferes with the vertical profile or wind gradient (Torres, 2017). In addition, Oke *et al.* (2017) highlighted that surface roughness influences wind permeability conditions and, consequently, the thermal environment within an urban structure.

Stimulating the increase in wind speed, reducing the thermal load and increasing the dispersion of anthropogenic heat and pollutants in the urban environment are essential issues in the study of the urban climate (De; Mukherjee, 2018; Xue *et al.*, 2020). Urban morphology is intrinsically linked to the speed of the winds at the pedestrian level. In this sense, surface roughness is a factor that can be used to quantify the intensity of its effects (Chen *et al.*, 2017). Several studies have indicated that the higher the surface roughness, the less amount of airflow that can pass through the boundary layer (Wen; Juan; Yang, 2016; Mohammed; Salman, 2018; Lobaccaro *et al.*, 2019).

Different urban elements, understood as primary 3D units, can be obstacles to the adequate permeability of winds within the urban structure, especially buildings. Unlike vegetative elements, buildings are impermeable, inflexible, and usually pointed (Oke *et al.*, 2017). In this way, the speed of the winds on the pedestrian scale is reduced in areas with high surface roughness, generating an increase in thermal load and, consequently, thermal discomfort (Kouklis; Yiannakou, 2021; Brandão; Barbosa, 2023).

ISSN 2318-8472, v. 12, n. 86, 2024

The method for measuring wind and thermal conditions may vary according to the scale of approach and the available technology. The Frontal Area Index (FAI) is an essential parameter for assessing surface roughness and analyzing urban ventilation corridors, and is more suitable for mesoscale studies (Li *et al.*, 2022; Xu; Gao, 2022). However, it does not cover thermal conditions.

Computational Fluid Dynamics (CFD) models can be used at the meso and microscale, in addition to estimating wind and thermal conditions, such as the ENVI-met software, which simulates urban models from local meteorological data and collected *in loco* (Perini *et al.*, 2017; Ma *et al.*, 2020). On microclimatic scales, it is also possible to estimate the speed and direction of the winds through measurement campaigns at a specific point, but this methodology requires advanced technology equipment at a high cost (Blocken, 2015; Papadopoulou *et al.*, 2015). This makes the latter alternative unfeasible in many research realities, whether for academic purposes or for urban planning.

The scale for analyzing the climatic effects of a built complex on surface roughness is the urban canyon, an urban unit for the study of constructive densification through verticalization. Understanding how the urban form can contribute to enhance the use of natural ventilation and, thus, generate favorable conditions for thermal comfort, is essential in the urban planning process of cities.

2. GOAL

The present article aimed to analyze the effects of surface roughness on the variability of natural ventilation within urban canyons from the variation of two morphological parameters: the H/W ratio and the orientation of the roads, in a city with a tropical savannah climate (As). As a case study, the city of Arapiraca, located in the Brazilian semi-arid region, was taken.

3. METHODOLOGY

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

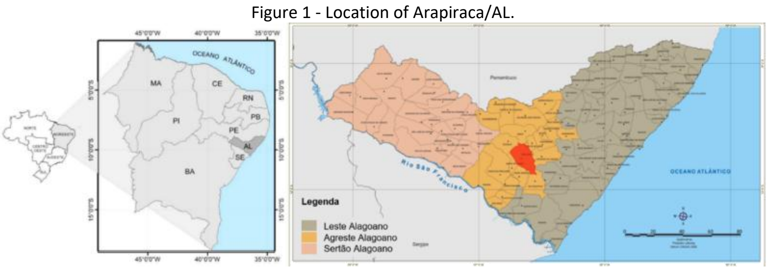
3.1 Case Study Characterization

Located in the interior of the state of Alagoas (Brazil), the city of Arapiraca is located in the semi-arid region of the Brazilian Northeast, at an altitude of approximately 280 m. It has an estimated population of 234,309 inhabitants (IBGE, 2021), in a territorial area of 356,179 km². In recent decades it has experienced intense population growth, and has developed as an important commercial and service center.

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 86, 2024

Figure 1 - Location of Arapiraca/AL.



Source: Adapted from SEPLAG/AL (2022).

According to the Köppen-Geiger climate classification (Alvares *et al.*, 2012), the climate of Arapiraca is tropical savanna (As). Regarding climatic characteristics, the city presents: Average annual temperature of 24.7°C, average annual relative humidity of 73.9% and average annual rainfall of 890.0 mm (Silva, 2019). The prevailing winds are from the East, with a secondary direction from the Southeast, with weak and good wind speeds, and the occurrence of calms in 13.73% of the annual hours (Silva; Barbosa, 2022).

As the urban unit studied was the urban canyon, 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 (Torres, 2017). In order to contribute to the vertical growth of the city, it became important to select a study area where it is possible to observe implanted buildings and the construction of new ones, especially in the northern part of the city. Thus, the perimeter that corresponds to *Avenida Deputada Ceci Cunha* was selected.

Avenida Deputada Ceci Cunha is a valued area of the city, for commercial and residential use, where some of the city's buildings are located. In the perimeter that divides the Novo Horizonte and Itapuã neighborhoods, it is possible to observe several urban voids and larger lots. Thus, Figure 2a presents the urban fraction selected as the study area of the present research.

Figure 2 - Selected study area at *Avenida Deputada Ceci Cunha* (a), seen from the perspective of the pedestrian (b).

Source: Adapted from Google Earth (2024) and personal archive.

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 86, 2024

For the elaboration of the hypothetical scenarios, it was sought to understand the recurrent pattern of occupation in this urban fraction, based on the design of the blocks and lots, and the width of the roads and sidewalks, through an updated cartographic base, made available by the City Hall. The Avenue has a central median continuously wooded (Figure 2b) and between the blocks there is a linear green area, with the presence of large trees.

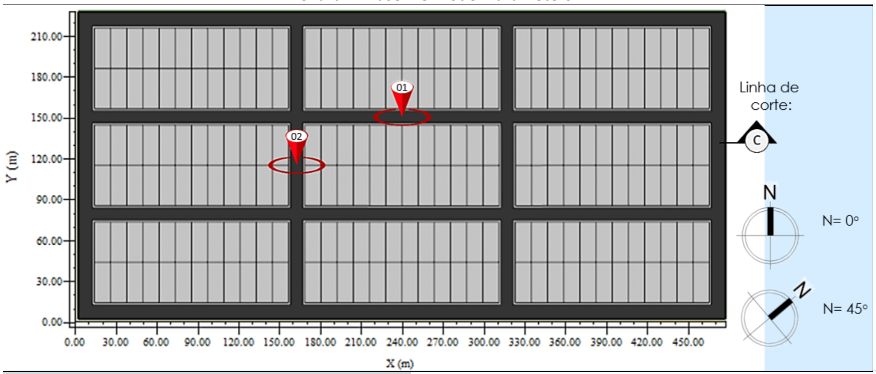
Regarding the characteristics observed *in loco* of the selected perimeter: The street covering is asphalt or natural roofing, the sidewalks are in concrete or with ceramic coating, and the facades are ceramic or painted with different colors. The predominant roofing materials are ceramic tiles, fiber cement or concrete slabs. The study area was 129,454.93m², with a Southwest/Northeast orientation.

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 values and start-up 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 consisted 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. In order to analyze only the effect of the constructed mass, no vegetation was inserted in the scenarios. The area was modeled as shown in Chart 1.

Chart 1 - Baseline Model Parameters.



Model size (m)	478 m x 228 m
Model size (Grid)	239 x 114 x 29
Grid size	2 m x 2 m x 3 m
Number of blocks	9
Number of lots per block	24
Lot size	12 m x 30 m

Source: The authors.

Comentado [RD1]: TRADUÇÃO DO TEXTO DESTA IMAGEM:

Cutting line:

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 86, 2024

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, given that the minimum height required by the model is twice the height of the tallest building inserted in the model (ENVI-met, 2024). To maintain the stability of the model, 5 nesting grids were inserted around the modeled area (Brandão, Barbosa; 2023). 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 the study scenarios, 2 receiving points were established for the collection of climate data, in order to analyze the results of the simulations. Point 01 (120.73) is located parallel to the windward and to point 02 (84.66), located to the leeward. The materials used in the modeling of the hypothetical scenarios were based on the materials in the ENVI-met v.4 Beta software database (Chart 02).

Chart 2 - Characteristics of the materials used in the modeling of the study area and scenarios.

	ID	Material	Albedo	Emissividade
Coberta	R2	Telha cerâmica	0.50	0.90
Walls	B2	Tijolos cerâmicos	0.40	0.90
Sidewalks	PG	Concreto cinza	0.40	0.89
Streets	ST	Asfalto	0.12	0.90
Soil	LO	Argiloso	0.00	0.98

Source: The authors.

Comentado [RD2]: Aqui o correto é "Coberta" mesmo ou: Cobertura?
Se for Coberta mesmo, favor colocar: Covered.
Se for Cobertura, favor colocar: Penthouse

A solar adjustment factor of 0.92 was used, according to the calibration of Torres (2017) for Arapiraca. The simulation started at 9 p.m., due to the absence of solar radiation and the availability of a neutral atmosphere. The specific humidity data were taken from the airport station of Natal/RN, as it is the closest point with this type of data available. In order to obtain climate data for 2 days (two complete cycles). The first cycle is considered as a period for simulation stability and in the second cycle, the climate 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 3.

Chart 3 - Input Data Parameters for Computer Simulation.

Parameters	Summer
Start date	26/11/2015
Starting time	21:00
Total simulated hours	52
Wind speed measured at 10 m height ($m.s^{-1}$)*	2.7
Wind direction (degrees)*	94
Length of roughness at the measurement site	0.1
Initial temperature of the atmosphere (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 from the website of the Department of Atmospheric Sciences of the University of Wyoming.
*** Model standard.
****Torres, 2017.
Source: The authors.

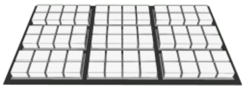
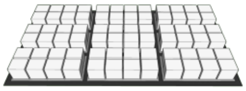
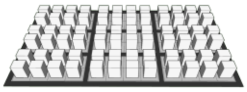
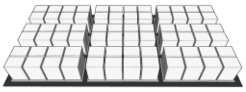
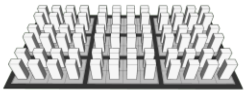
GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 86, 2024

3.3 Elaboration of Hypothetical Scenarios for Simulation

The hypothetical scenarios were modeled on the scanned basis (see Chart 4).

Chart 4 - Parameters of what-if scenarios.

Model	Verticalization pattern	No. Pav.	ID	Setbacks (m)		Width Canyon (m)	H/W
				Frontal	Side/ Posterior		
	REF.	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
	Average	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: The authors.

The vertical buildings were modeled considering the remembrance of three standard lots, in view of the need to apply the progressive setback to the number of floors. The scenarios

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 86, 2024

were modeled from combinations of urban parameters, in order to confer variations in the surface roughness of the urban canyon, based on the H/W ratio.

The height of the buildings considered scenarios with low, medium and high verticalization, based on the current standard 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 surface roughness. The spatial distribution of buildings with different heights on the block was randomly drawn, 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 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 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 retreat, in meters;
Ri corresponds to the initial or minimum setback, in meters, applied in the area in question; and
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 tallest buildings, conferring variations in the porosity of the urban geometry. Thus, the parameters adopted in the modeling resulted in 18 simulations. The present study focused on analyzing the wind conditions, comparatively, from the data of wind speed and direction. Data extraction was done at 3 p.m., the hottest period of the day, at a height of 1.5 m from the ground.

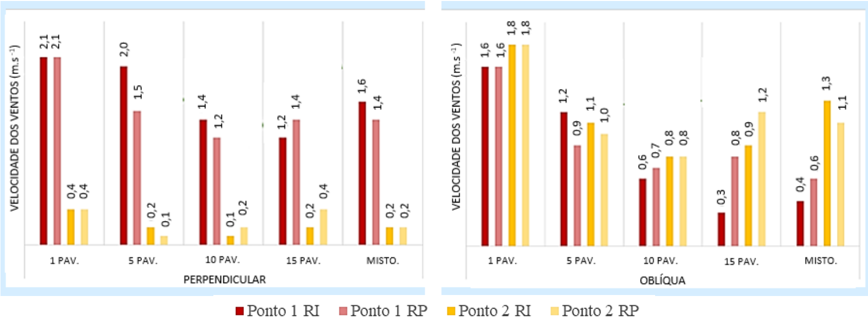
4. ANALYSIS OF THE RESULTS

4.1. Wind speed

The ENVI-met software considers the constant speed during the day, in this sense, the behavior of wind speed and direction was analyzed at 3 p.m., based on quantitative data. Graph 2 demonstrates, quantitatively, the behavior of wind speed at Point 01, to the windward, and at Point 02, to the leeward.

ISSN 2318-8472, v. 12, n. 86, 2024

Figure 3 - Wind speed behavior graph (m.s^{-1}) for 3 p.m.



Source: The authors.

The high surface roughness, due to the increase in construction density, generally slows down the airflow near the surface (Oke, 2017), which justifies the higher speeds being concentrated in the REF scenarios. Regarding the adoption of initial and progressive setbacks, a pattern was observed present in all scenarios: although wind speeds were higher in the REF and RI-05 scenarios, resulting from the channeling of the flow of winds, but as the buildings gradually verticalize, the speed increases in scenarios with the use of progressive retreat.

The spacing between buildings can generate different wind flow regimes in the urban canyon. The use of initial and progressive minimum recoil demonstrated two of the three regimes pointed out by Oke *et al.* (2017): Skimming flow and conveyor interference flow, respectively. The first type is characterized by the flow above the roof "jumping" across the tops of buildings with less tendency to enter the canyons of the streets, reducing wind speeds, and even generating areas of ventilation shade inside the canyon. While the second, the distance that separates the buildings does not prevent the winds from entering the interior of the canyon.

Regarding the orientation of the canyons, in the hypothetical urban models of incidence of the predominant ventilation perpendicular to the buildings, it is possible to observe the disparity between the windward point (01) and the leeward point (02), due to the channeling of the air flow in the circulation routes with the East-West axis, which generates an increase in wind speed, with a difference of up to 1.8 m.s^{-1} in the RI-05 scenario. In the models of incidence of predominant ventilation oblique to buildings, this difference was attenuated, with a difference of 0.1 m.s^{-1} in the same scenario in question. This is because the orientation of the road layout optimized the permeability of the winds in the urban fabric. Tork *et al.* (2017) also found that on roads oriented to the Northeast-Southeast, oblique to the predominant wind direction, the thermal performance is superior in terms of wind speed and the potential for cross ventilation. Wind speed is important for thermal comfort, air quality, and the dispersion of air pollutants and anthropogenic heat (Oke, 2017; Xue *et al.*, 2020).

4.2. Wind direction

The qualitative analysis of the behavior of the winds was done through profiles and 2D maps, prepared using the Leonardo software. Leonardo is an ENVI-met interface, which offers a

Comentado [RD3]: TRADUÇÃO DOS TEXTOS DESTA IMAGEM (COLOQUEI SÓ UMA VEZ, DAÍ PODE REPLICAR NOS QUE SE REPETEM):

WIND SPEED
MIXED
PERPENDICULAR
OBLIQUE

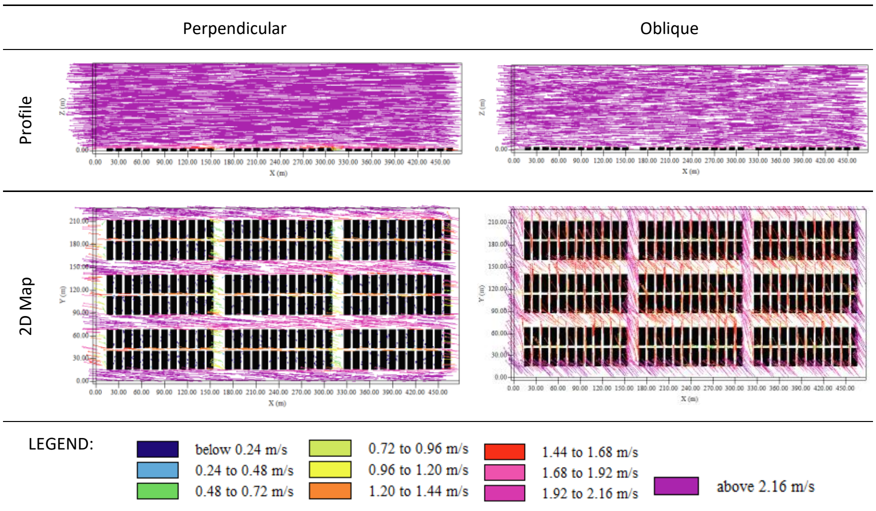
Point 1
Point 2

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 86, 2024

wide range of visualization options, from simple sections or 2D maps to 3D flow paths. Chart 5 presents the profiles and 2D maps of the REF model, in the incidence of the predominant perpendicular and oblique ventilation to the buildings.

Chart 5 - Ventilation profiles and maps, REF model of perpendicular and oblique ventilation incidence.



Source: The authors.

In the profiles, it can be seen that in the intra-urban layer there is a decrease in wind speed, however, as the buildings have the same height, the vertical profile of the wind does not change significantly. In the maps of the REF scenario of N = 0°, it is possible to observe that the incidence of the prevailing winds parallel to the circulation routes with the East-West axis leads to the channeling of the winds, which generates an increase in the speed of the winds, reaching more than 2,16 $m.s^{-1}$. The increase in wind speed on the roads parallel to the predominant direction of natural ventilation generates the formation of areas of air stagnation on the perpendicular roads, and on the leeward side of the buildings it is possible to observe the formation of areas of ventilation shadows.

Chart 6 presents the profiles and 2D maps of the other models, in the incidence of predominant ventilation perpendicular to the buildings. Based on the analysis of the profiles, it is observed that high roughness alters the permeability of the air flow, and the speed of winds in the urban network decreases, especially in models using the initial minimum setback, which coincides with the results found by Brandão and Barbosa (2023). However, in scenarios using progressive retreat, this effect was reduced. For example, the RI-15 scenario presented the speed of 1.44 $m.s^{-1}$ to 1.68 $m.s^{-1}$, while the RP-15 scenario, came to present speeds above 2.16 $m.s^{-1}$, a difference that can reach 0.72 $m.s^{-1}$.

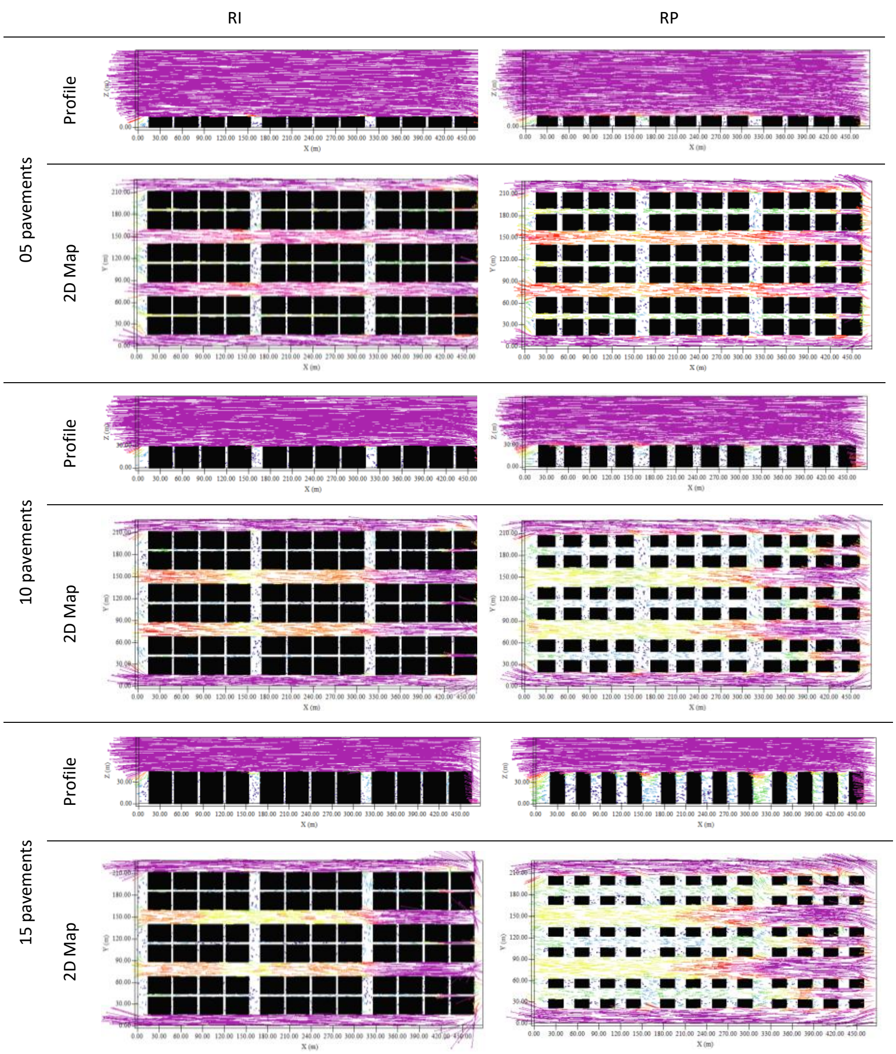
The 2D maps show that the use of progressive setback enhances the permeability of air flows in the urban fabric, which reduces the areas of wind shadow to leeward, less presence

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 86, 2024

of wind channeling in the East-West directions, which configures more favorable conditions for thermal comfort at the pedestrian level. At point 01, to the windward, the wind speed varies between 1.20 m.s^{-1} and 1.44 m.s^{-1} in the RI-15 scenario, while at the same point in the RP-15 scenario, the value increases to between 1.44 m.s^{-1} and 1.68 m.s^{-1}. At point 02, to the leeward, in the RI-15 scenario the wind flow presented speeds below 0.24 m.s^{-1}, and in the RP-15 scenario, between 0.24 m.s^{-1} and 0.48 m.s^{-1}.

Chart 6 - Profiles and maps of ventilation at 3 p.m., of incidence of perpendicular ventilation to buildings (N = 0°).



GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

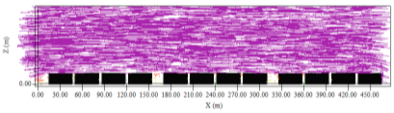
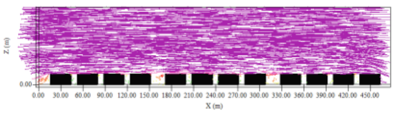
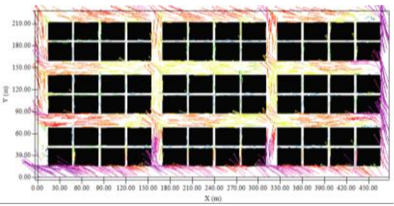
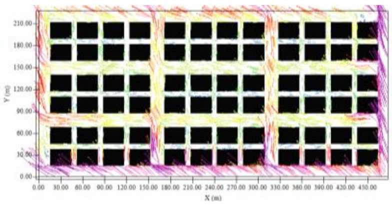
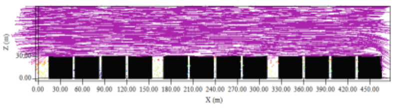
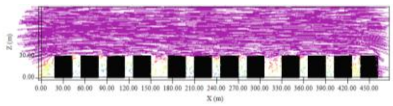
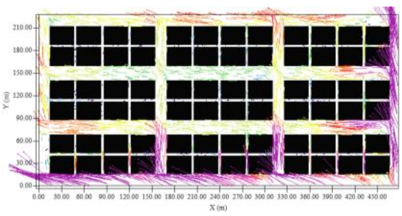
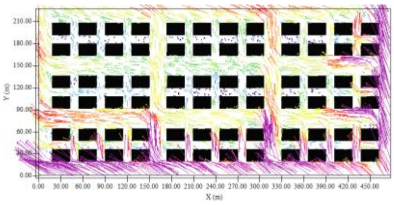
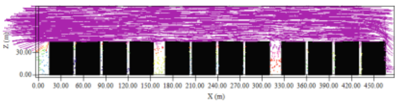
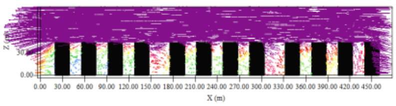
ISSN 2318-8472, v. 12, n. 86, 2024

LEGEND: below 0.24 m/s; 0.24 to 0.48 m/s; 0.48 to 0.72 m/s; 0.72 to 0.96 m/s; 0.96 to 1.20 m/s; 1.20 to 1.44 m/s; 1.44 to 1.68 m/s; 1.68 to 1.92 m/s; 1.92 to 2.16 m/s; above 2.16 m/s

Source: The authors.

Chart 7 presents the profiles and 2D maps of the other models, in the incidence of the predominant oblique ventilation to the buildings.

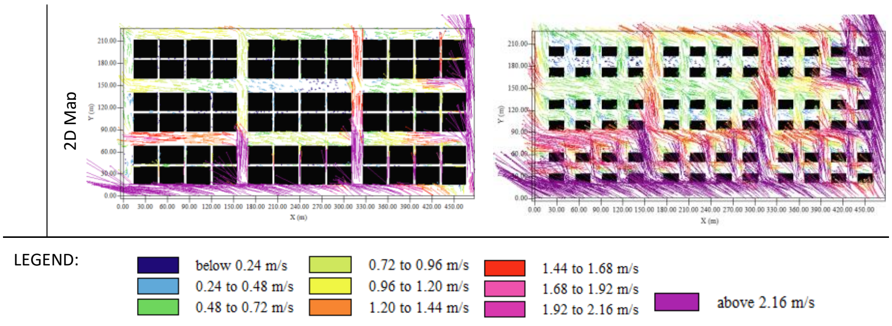
Chart 7 - Profiles and maps of ventilation at 3 p.m., of incidence of oblique ventilation to buildings (N = 45°).

		RI	RP
05 pavements	Profile		
	2D Map		
10 pavements	Profile		
	2D Map		
15	Profile		

Comentado [RD4]: Checar os textos desta coluna, porque eles não estão visíveis, parece que parte da imagem ficou por cima.

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 86, 2024



Source: The authors.

Regarding the analysis of the profiles, the results were not different from those observed in the models of incidence of predominant ventilation perpendicular to the buildings, because here the surface roughness remains with high rates due to the vertical buildings presenting equal heights. In models using the initial minimum setback, the wind flow regime is still characterized as skimming, due to the small space between buildings, which substantially decreases the wind speed at the pedestrian scale. It is worth noting that, according to Freitas and Azerêdo (2021), the use of natural ventilation helps in the thermal comfort of pedestrians in regions with a tropical climate, as is the case of the present object of study.

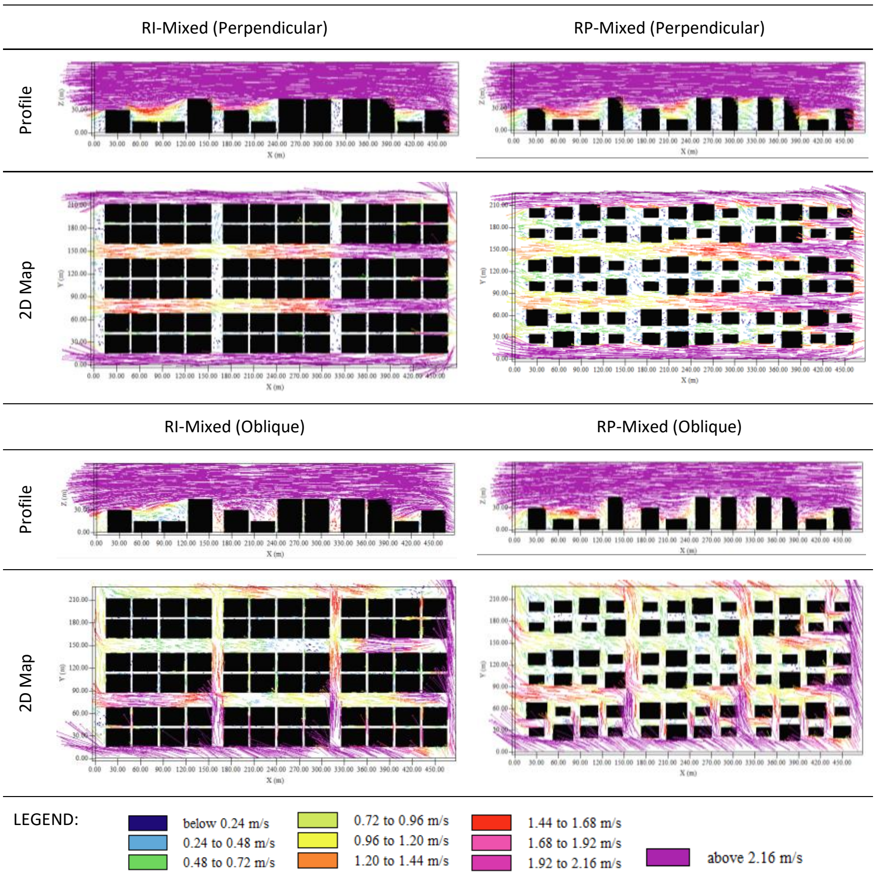
In the maps of the scenarios of incidence of oblique ventilation to buildings, it is possible to observe that the models with the use of progressive setback remain with more favorable conditions for the use of natural ventilation, due to a better permeability of the air flow. At point 01, to the windward, the wind speed varies between 0.24 $m.s^{-1}$ and 0.48 $m.s^{-1}$ in the RI-15 scenario, while at the same point in the RP-15 scenario, the value increases to between 0.72 $m.s^{-1}$ and 0.96 $m.s^{-1}$. At point 02, to the leeward, in the RI-15 scenario the wind flow is between 0.96 $m.s^{-1}$ and 1.20 $m.s^{-1}$, and in the RP-15 scenario, between 1.44 $m.s^{-1}$ and 1.68 $m.s^{-1}$.

Chart 8 presents the results obtained from the mixed scenarios (RI/RP):

GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 12, n. 86, 2024

Chart 8 - Profiles and maps of ventilation at 3 p.m., incidence of perpendicular and oblique ventilation.



Source: The authors.

Regarding the mixed scenarios, the profiles demonstrate how surface roughness influences the behavior of winds, their way of displacement, from being lamellar (in blades) to becoming turbular (Oke *et al.*, 2017), and their speed. This reduces the areas of wind stagnation between the vertical buildings, increasing the speed of the winds on the pedestrian scale, promoting better conditions of thermal comfort inside the canyon. A similar result was also observed by Mohammed and Salman (2018).

Regarding the 2D maps, the low surface roughness optimized the use of natural ventilation to the windward and leeward, because by generating the form of whirlwind displacement, it promotes the entry of a greater flow of winds into the interior of the blocks, which guarantees conditions of thermal comfort in the urban environment. The adoption of progressive setback and the orientation of the roads obliquely enhances this effect and reduces the areas of wind shadow to leeward.

ISSN 2318-8472, v. 12, n. 86, 2024

5. FINAL CONSIDERATIONS

When analyzing the behavior of wind speed in relation to urban form, two factors must be considered: Porosity and roughness, which influence the vertical wind profile, known as the wind gradient. The mixed scenario made it possible to analyze the surface 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 presented results similar to the vertical scenarios, and in the models of oblique incidence, the result was repeated and enhanced.

This study evaluated the climatic conditions and the thermal sensation of the scenarios for the mid-latitude savanna tropical climate and without considering the effects of vegetation interactions. One of the main conclusions of this article leads to the remarkable importance of surface roughness in wind permeability and, consequently, in wind speed. Based on the aforementioned results, the geometric parameters of urban canyons strongly affect the microclimate and thermal comfort at the pedestrian level, highlighting the need to develop urban planning guidelines based on these parameters.

REFERENCES

ACHOUR-YOUNSI, S.; KHARRAT, F. Outdoor thermal comfort: Impact of the geometry of an urban street canyon in a Mediterranean subtropical climate - Case study Tunis, Tunisia. **Procedia - Social and Behavioral Sciences**, v. 216, p. 689-700, 2016. DOI: http://dx.doi.org/10.1016/j.sbspro.2015.12.062.

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; JOSÉ LEONARDO DE MORAES GONÇALVES, J. L. de M.; SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v. 22, n. 6, p. 711-728, 2013. DOI: 10.1127/0941-2948/2013/0507.

ANTONINI, E.; VODOLA, V.; GASPARI, J.; DE GIGLIO, M. Outdoor Wellbeing and Quality of Life: A Scientific Literature Review on Thermal Comfort. **Energies**, v. 13, 2020. DOI: 10.3390/en13082079.

BLOCKEN, B. Computational fluid dynamics for urban physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations. **Build. Environ.**, v. 91, p. 219-245, 2015. DOI: http://dx.doi.org/10.1016/j.buildenv.2015.02.015.

BRANDÃO, L. K. de V.; BARBOSA, R. V. R. Modelagem de cânions urbanos em clima tropical de savana: relação entre os parâmetros geométricos e o microclima ao nível do pedestre. **Revista Nacional de Gerenciamento de Cidades**, v. 11, n. 83, p. 2318-8472, 2023. DOI: https://doi.org/10.17271/23188472118320234706.

CHEN, Y-C.; FRÖHLICH, D.; MATZARAKIS, A.; LIN, T-P. Urban Roughness Estimation Based on Digital Building Models for Urban Wind and Thermal Condition Estimation - Application of the SkyHelios Model. **Atmosphere**, v. 8, n. 247, 2017. DOI: 10.3390/atmos8120247.

Código de Obras e Edificações no Município de Arapiraca. **Lei Municipal nº 2.220**, de 2001. Recuperado em 02 de abril de 2023, de www.arapiraca.al.gov.br.

Código de Urbanismo e Edificações do Município de Maceió. **Lei Municipal nº 5.593**, de 8 de fevereiro de 2007. Recuperado em 20 de abril de 2023, de www.maceio.al.gov.br.

DE, B.; MUKHERJEE, M. Optimisation of canyon orientation and aspect ratio in warm-humid climate: Case of Rajarhat Newtown, India. **Urban Climate**, n. 24, p. 887–920, 2018. DOI: https://doi.org/10.1016/j.uclim.2017.11.003.

ISSN 2318-8472, v. 12, n. 86, 2024

FREITAS, R.; AZERÊDO, J. **Urbanismo bioclimático e cidades sustentáveis**. [recurso eletrônico] / organizadores: Ruskin Freitas, Jaucele Azerêdo. Recife: Ed. UFPE, 2021.

GIVONI, B. **Climate considerations in building and urban design**. New York: John Wiley & Sons, 1998.

Instituto Brasileiro de Geografia e Estatística - IBGE. (2010). **Censo Demográfico - 2010**. Arapiraca: IBGE. Recuperado em 15 de janeiro de 2023, de www.ibge.gov.br.

LI, L.; ZHAO, Z.; WANG, H.; SHEN, L.; LIU, N.; HE, B-J. Variabilities of Land Surface Temperature and Frontal Area Index Based on Local Climate Zone. **IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing**, v. 15, 2022. DOI: 10.1109/JSTARS.2022.3153958.

LOBACCARO, G.; ACERO, J. A.; MARTINEZ, G. S.; PADRO, A.; LABURU, T.; FERNANDEZ, G. Effects of Orientations, Aspect Ratios, Pavement Materials and Vegetation Elements on Thermal Stress inside Typical Urban Canyons. **Int. J. Environ. Res. Public Health**, v. 16, n. 3574, 2019. DOI: 10.3390/ijerph16193574.

KOUKLIS, G.-R.; YIANNAKOU, A. The Contribution of Urban Morphology to the Formation of the Microclimate in Compact Urban Cores: A Study in the City Center of Thessaloniki. **Urban Sci.**, v. 5, n. 37, 2021. DOI: https://doi.org/10.3390/urbansci5020037.

MA, X.; WANG, M.; ZHAO, J.; ZHANG, L.; LIU, W. Performance of Different Urban Design Parameters in Improving Outdoor Thermal Comfort and Health in a Pedestrianized Zone. **Int. J. Environ. Res. Public Health**, v. 17, n. 2258, 2020. DOI: 10.3390/ijerph17072258.

MOHAMMED, Y.; SALMAN, A. Effect of urban geometry and green area on the formation of the urban heat island in Baghdad city. **MATEC Web of Conferences**, v. 162, 2018. DOI: https://doi.org/10.1051/matecconf/201816205025.

MUNIZ-GÄAL, L. P.; PEZZUTO, C. C.; CARVALHO, M. F. H. de; MOTA, L. T. M. Urban geometry and the microclimate of street canyons in tropical climate. **Building and Environment**, v. 169, 2020. DOI: https://doi.org/10.1016/j.buildenv.2019.106547.

NASROLLAHI, N.; GHOSOURI, A.; KHODAKARAMI, J.; TALEGHANI, M. Heat-Mitigation Strategies to Improve Pedestrian Thermal Comfort in Urban Environments: A Review. **Sustainability**, v. 12, p. 01-22, 2020. DOI: 10.3390/su122310000.

OKE, T. R.; MILLS, G.; CHRISTEN, A.; VOOGT, J. A. **Urban climates**. Cambridge: Cambridge University Press, 2017.

PAPADOPOULOU, M.; RAPHAEL, B.; SMITH, I.; SEKHAR, C. Optimal Sensor Placement for Time-Dependent Systems: Application to Wind Studies around Buildings. **J. Comput. Civ. Eng.**, 2015, 30. DOI: http://dx.doi.org/10.1061/(ASCE)CP.1943-5487.0000497.

PERINI, K.; ATA CHOKHACHIAN, A.; SEN DONG, S.; AUER, T. Modeling and simulating urban outdoor comfort: Coupling ENVI-Met and TRNSYS by grasshopper. **Energy and Buildings**, v. 152, p. 373-384, 2017. DOI: http://dx.doi.org/10.1016/j.enbuild.2017.07.061.

ROMERO, M. A. B. Correlação entre o microclima urbano e a configuração do espaço residencial de Brasília. **Fórum Patrimônio: Mudanças climáticas e o impacto das cidades**, v. 4, n. 1, p. 9-22, 2011.

SILVA, M. F. da. Estratégias bioclimáticas para seis cidades alagoanas: contribuições para a adequação da arquitetura ao clima local (Dissertação de mestrado). Universidade Federal de Alagoas, Maceió, 2019.

SILVA, M. F. da.; BARBOSA, R. V. R. Regime de ventos em cidades de diferentes regiões geográficas de Alagoas a partir de dados meteorológicos recentes. **Revista Brasileira de Climatologia**, Dourados, MS, v. 31, 2022, ISSN 2237-8642.

TORRES, S. C. **Forma e Conforto: estratégias para repensar o adensamento construtivo urbano a partir dos parâmetros urbanísticos integrados à abordagem bioclimática**. Recife, 2017. Tese (Doutorado em Desenvolvimento Urbano - Universidade Federal de Pernambuco), Universidade Federal de Pernambuco, Pernambuco, 2017.

ISSN 2318-8472, v. 12, n. 86, 2024

XU, F.; GAO, Z. Índice de área frontal: uma revisão dos métodos de cálculo e aplicação no ambiente urbano. **Building and Environment**, v. 224, 2022. DOI: https://doi.org/10.1016/j.buildenv.2022.109588.

XUE, Y.; WANG, Y.; PENG, H.; WANG, H.; SHEN, J. The impact of building configurations and anthropogenic heat on outdoor thermal comfort in high-density urban areas. **Urban Climate**, v. 22, p. 1-16, 2017. DOI: https://doi.org/10.1016/j.uclim.2017.01.003.

WEN, C-Y.; JUAN, Y-H.; YANG, A-S. Enhancement of City Breathability with Half Open Spaces in Ideal Urban Street Canyons. **Building and Environment**, 2016. DOI: http://dx.doi.org/10.1016/j.buildenv.2016.11.048.

WONG, M. S.; NICHOL, J. E.; TO, P. H.; WANG, J. A simple method for designation of urban ventilation corridors and its application to urban heat island analysis. **Build. Environ.**, v. 45, p. 1880-1889, 2010. DOI: http://dx.doi.org/10.1016/j.buildenv.2010.02.019.

YANG, H.; ZHAO, L.; BRUSE, M.; MENG, Q. Evaluation of a microclimate model for predicting the thermal behavior of different ground surfaces. **Build. Environ.**, v. 60, p. 93-104, 2013. DOI: https://doi.org/10.1016/j.buildenv.2012.11.00.