Intra-urban Ventilation Conditions and Interactions between Urban Morphology and Climate Variables

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ABSTRACT: This work presents some results of a new methodology applied in the analysis of the interaction between the urban shape and the climate [1], based both in the study of the wind flow [2] and a urban climate system theory [3]. Through wind tunnel experiments, microclimatic variables survey in João Pessoa City and statistical analysis, it was find out that the correlation between the urban shape and the air temperature depends strongly on the intra-urban ventilation (velocity and direction), and at the same time, mainly on the urban grid, the rugosity and permeability of the urban form.

Keywords: urban climate variables, statistical correlations.

1. INTRODUCTION

Urban climate is defined in this paper as a synthesis of the relationship of the interaction between natural and urban elements. It is a **system** with the following characteristics**: open** - as a subject to the incoming and outgoing flow of energy; **unique** - applied to the city; **complex** - given the variety and intensity of the relationships between these various elements; **progressive** - as it adapts to urban and climate dynamics and, **self-regulating –** because it has a response to human feedback [3].

Recent studies have demonstrated how urban planning modifies ventilation, race the boundary layer atmospheric limit and reduce the surface wind velocity, which increases according to the level of surface rugosity [4]. Assis [5] & Sakamoto [6] found that ventilation affects the air temperature behaviour of certain urban areas. Different air temperatures in different city locations can cause internal air to circulate from warmer to cooler areas, better evidenced during light winds. Serra [7] and Assis [5] demonstrated that a low correlation between urban landscape and air temperature in coastal cities is caused by the area's abundant and more intense ventilation with the usual flow of "Aliseos" winds. However, other studies of coastal cities like Salvador [8], João Pessoa and Rio de Janeiro [9] [10] demonstrate the relationship between ventilation and landscape elements (direction, dimensions, spatial building layout) is more complex, setting ventilation patterns which, consequently, are responsible for urban area thermal patterns.

The majority of urban climate studies did not measure the wind direction and velocity at the place, instead, only the air temperature and relative air humidity. The studies that did take these measurements, used only field measurements which are not sufficient, because they lacked a controlled wind velocity and direction before entering the city and did not consider their change to the intra-urban ventilation.

Within this context and with the object of reducing measurement errors, this paper presents the results of the Brazilian city of João Pessoa´s climate study using Carvalho´s [1] methods for the analysis of the relationship between landscape and climate. Carvalho used microclimatic measurements, experiments using an aerodynamic tunnel, and correlation and linear regression analysis.

2. CASE STUDY DESCRIPTION

This study was performed in a section of the Brazilian city of João Pessoa, between the Atlantic Ocean on the east side and the River Jaguaribe on the west side, north of Sen. Rui Carneiro Ave. and R. Helena Maria Lima St., and José Américo de Almeida on the south side. It is an extension of the Tambaú and Cabo Branco neighbourhoods, with an approximate area of 563.000m^2 divided into 758 lots, almost fully in use.

The selected area is located in the *Zona Adensável Prioritária* Zone, according to the General City Map of João Pessoa [11], with calculated population density of 150 inhabitants/hectare, and maximum land use index[1] of 4.0. However, this index does not meet the by-law standards given the predominance of one or two story buildings.

A large section of the area of the study is under building height template restrictions. This section is called "Orla Marítima" (Beach Zone) and corresponds to a linear 500m section measured from the beach

[1] Land use index (UI) is a parameter that relates the building's construct area (C) and the land area (B): UI = C/B Land occupancy rate (OR) is a parameter that relates the building's horizontal projection (A) and the land area (B): OR = A/B x 100.

avenue to the interior of the continent. The height template of this section is on a scale from 12,90m minimum for the first line of lots, on the beach avenue, up to a maximum of 35m. It is a residential neighbourhood with an array of shops, services, hotels, B&B's, bars and restaurants.

3. METHOD

The study was divided into eight stages. It started by collecting field data, mapping the area of study using 1:5000 scale reduction, including use and occupancy of the land, building height, topography, land occupancy rate, land use index drawn in CAD.

The map served as a basis for designing a reduced model of the location for testing in the atmospheric boundary layer aerodynamic tunnel using sand erosion technique [12]. The tests were done according to the Silva´s [2] defined ventilation standards set at 150° wind direction, predominant at the location of the study. The test-survey identified erosion points were then plotted onto the same scale as that of the first stage. Sand erosion figures are composed of several isolines, each corresponding to an external velocity.

Microclimatic measurements points were selected based on the map and the sand erosion figures fulfilling the following criteria:

- number of points compatible with the time and instruments available;
- point pairs should be constituted by points with similar use and occupancy, differentiating those from ventilation conditions;
- each pair of points should include the distance from the sea range, different types of use and land use.

The confirmation of each point was done via *in loco* field trips. These field trips enabled the researcher to observe details that had been excluded from the lay-outs, such as traffic and pedestrian influx, trees, construction surface colours and materials. Thus, four pairs of points were selected (Fig.1). The characteristics of these four pairs of points can be seen plotted in Table 1. These characteristics were written down on standard filing cards so that they could be used for future reference and analysis.

Table 1: Characteristics of the measurement points

Point	Dist (m)	OR(%)	UI	SVF(%)	P
A1	350	42,7	1,5	60,2	Asphalt
A2	350	43,8	1,7	61,1	Asphalt
B1	290	54,3	1,3	71,24	Stone
B2	290	51,5	0,7	66,94	Stone
C1	550	46,9	1,0	70,02	Asphalt
C2	550	46,3	1,1	69,36	Asphalt
D1	650	42,1	1,6	62,04	Stone
D2	650	37,9	1,9	59,16	Stone

Captions: Dist – Distance from the sea; OR – land occupancy rate; UI – land use index; SVF – sky view factor; P – type of street pavement.

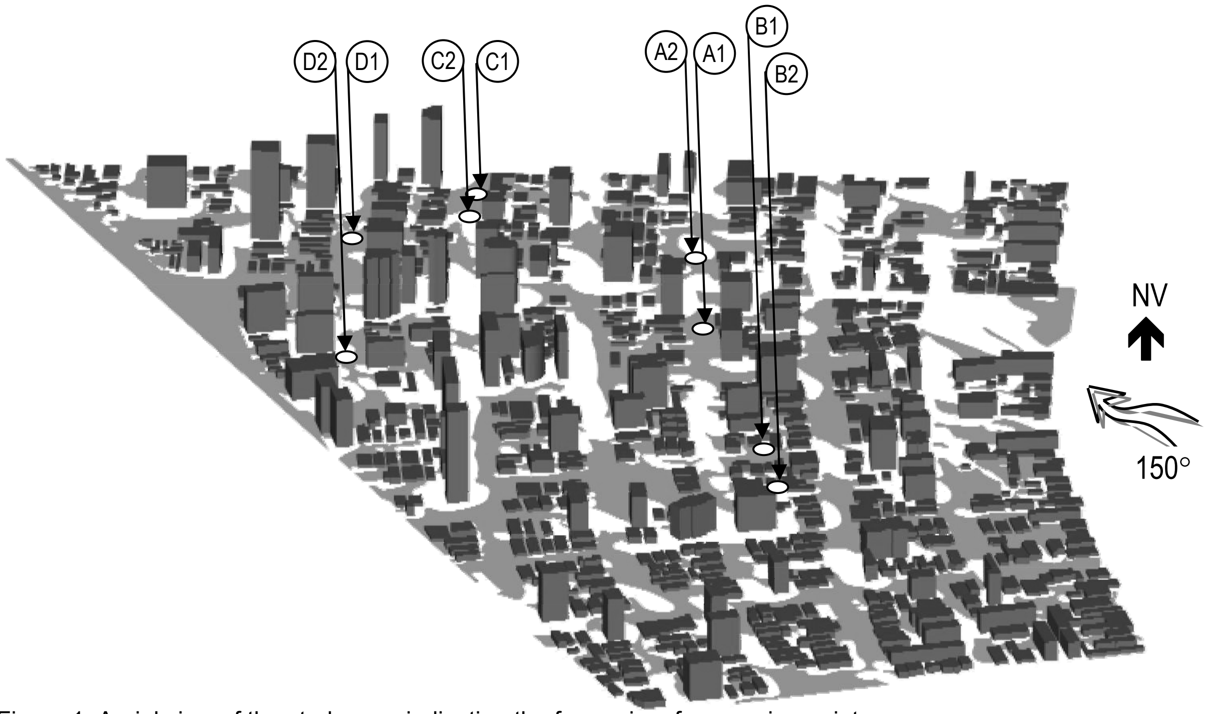

Figure 1: Aerial view of the study area indicating the four pairs of measuring points.

The wind velocity average and wind predominant direction, relative air humidity, solar radiation, and nebulosity fraction were measured for each point.

Measurements were taken during 28 consecutive days, from 8 a.m. to 9 p.m., from 2 p.m. to 3 p.m., and from 8 p.m. to 9 p.m. in a transect using a car. Measurement time averaged 10 minutes per pair of points measured, taking a total of 60 minutes to make it through the transect.

Measurements were taken at a height of 1.5 metres. Two labs were set-up to take these measurements. Each with two air temperature and relative air humidity dataloggers, two portable anemometers, two wind direction indicators, one pyranometer and two portable radio communications systems.

Field data collected were plotted onto graphs for future multiple correlation and linear regression analysis using the software SPSS [14]. The Pearson method was used for simple correlation analysis while *Stepwise* was used for multiple correlations and regression analysis.

4. RESULTS

When it was compared the data collected of the field measurements to the measurements of the lab station and to synoptic data it was verified a significant change in wind velocity and direction during the study. During the first period (11/03 – 11/18), predominated those originating from the southeast quadrant, whereas during the second time period the predominant winds flew from the east and northeast.

This change reflects the arrival of the warmest months (November and March respectively). At these periods the wind frequency changes as a result of the east and northeast winds flowing in from the equatorial regions as the wind currents move south and towards the *Zona de Convergência Tropical Interna*. At that time a warm air mass blocking and weakening the wind flowing from the Atlantic Ocean.

Due to these conditions, the relationship between climate and city planning follow different patterns as a result of the ventilation conditions. This can be identified in the wind velocity pattern and in the air temperature in the interior of the city. It was also possible to note that the wind speed reached its peak and the air temperature decreased to its lowest point when the wind originates from the southeast.

The multiple and simple correlation and linear regression analysis enabled the identification of the urban morphological variables. A significant correlation between these variables and the air temperature was identified as a function of the wind direction.

The measurement time interval was selected according to Silva's [2] and Carvalho's [13] studies results. Therefore, measurements were taken during the month of November, in the summer due to low rainfall, higher frequency of fastest (predominantly) southeast wind velocity and due to lowest levels of light winds (winds with a speed of less than 1.2 m/s).

The simple correlation coefficient is represented by the letter "r". The multiple correlation coefficients will be represented by the letter "R". The correlations will be considered true when they have a level of significance 0.01 and/or 0.05. The value of the level-p represents a decreasing index of the of result reliability. It represents the probability of error in accepting the result as valid, in other words, a value "representative of the population".

The results still show the determination coefficient "R^2" which was obtained from the multiple regression analysis. This coefficient explains how a set of dependent variables determine the pattern of the independent variable (the air temperature in this paper).

4.1 In the morning

In the morning, and when southeast winds predominate, the air temperature increased as it flowed away from the sea (r = 0.48 e p = 0.000) and slowed down in the areas of greater occupancy rate (r = - 0.41 e p = 0.000) (Fig. 2).

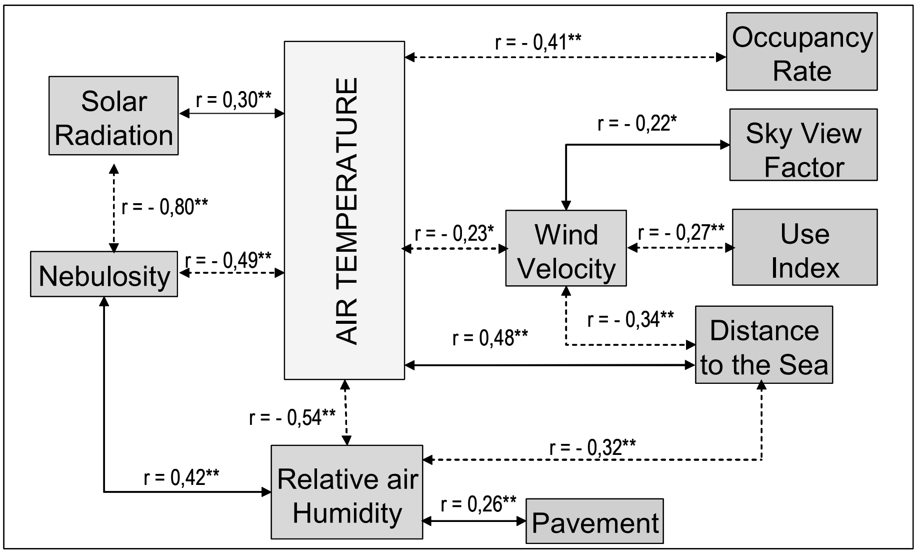

Figure 2: Correlation system between climate variables and urban landscape in the morning, with southeast winds. CAPTION: Pearson's correlation, * Significant correlation at 0.05 and ** significant correlation at 0.01.

There was also a correlation between the wind speed (r = - 0.23 e p = 0.017), relative air humidity, solar radiation (r = 0.30 e p = 0.002) and with nebulosity conditions ((r = - 0.49 e p = 0.000). The last two variables caused the co-linearity effect, to such an extent that solar radiation was excluded from the explanation of the air temperature variations model. Therefore, the model is formed by the variables: relative air humidity, occupancy rate, wind velocity, land use index, nebulosity fraction and distance to the sea, with a determination coefficient of R^2 = 59.3% and multiple correlation coefficient of R = 0.77.

In this wind direction there is a low correlation between the other climate variables and landscape elements. The wind velocity increased in the higher sky view factors areas and decreased in the areas of greatest land use index, especially in the points furthest away from the sea. And, the relative air humidity also decreased.

With east and northeast (Fig. 3) winds, a great number of variables had a significant correlation with the air temperature (Fig. 3), with a correlation peak at solar radiation (r = 0,674), followed by correlations with to relative air humidity (r = - 0,634) and with weather conditions (r = - 0,524).

The *stepwise* regression analysis produced the explanatory model of the air temperature variations constituted by the variables: relative air humidity, solar radiation, land occupancy rate, sky view factor, and wind speed variables. Together, they explain 71.1% of the temperature variation, making up a model that has a correlation with the air temperature R = 0.84.

The correlation between the air temperature and other variables was low; however, the significance values show that these variables should be considered co-responsible for the change in temperature variation.

It is important to highlight when analyzing the relationship between the variables that the temperature tended to increase at points of greatest exposure to solar radiation (greater sky view factors). Consequently, at those points the relative air humidity tended to decrease, contrary to the most protected points (greater land use).

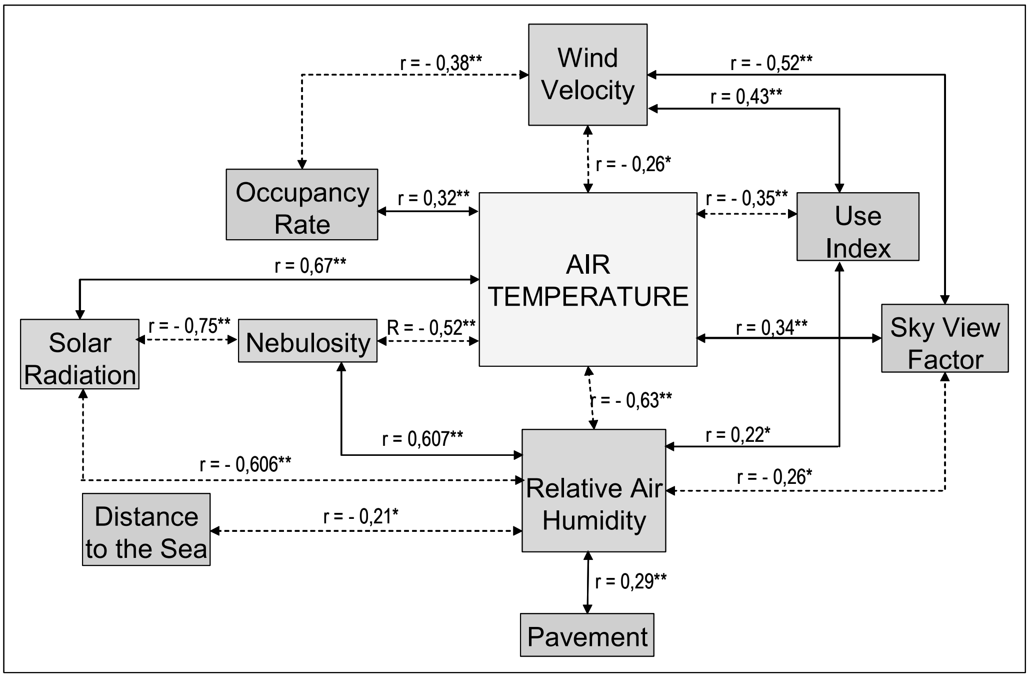

Figure 3: The correlation system between climate variables and urban landscape in the morning, with east and northeast winds. CAPTIONS: *Idem* Figure 2.

4.2 In the afternoon

In the afternoon, with southeast winds, the variable wind velocity maintained a greater correlation with the air temperature (r = - 0.446 e p = 0.00), suggesting that temperature tends to decrease as the wind velocity increases (Fig.4). However, the type of pavement was the variable that had the greatest correlation with the temperature (r = 0,721), suggesting that the temperature remained at its peak at the points located in asphalted roads.

The explanatory model of variations included seven out of nine variables considered, excluding only solar radiation and relative air humidity, which caused the multicollinearity effect, besides the nebulosity fraction. The type of pavement, nebulosity, wind velocity, rate of land use, land occupancy rate, distance from the sea, and sky view factor make up the explanatory model of temperature variation with R^2= 78,9% e R = 0,89.

With east and northeast winds, the sky view factor (r = 0,540) and wind velocity (r = - 0,517), followed by the land use index (r = - 0,415), were the variables that offered the highest correlation with the air temperature (Fig.5). The other variables maintained low correlation; however, the significant levels show that these variables contribute to a certain degree to the variations of temperature patterns.

In this case, the explanatory model of temperature variations was composed of: sky view factor, wind velocity, type of pavement and nebulosity, with R^2 = 67.3% e R = 0.45.

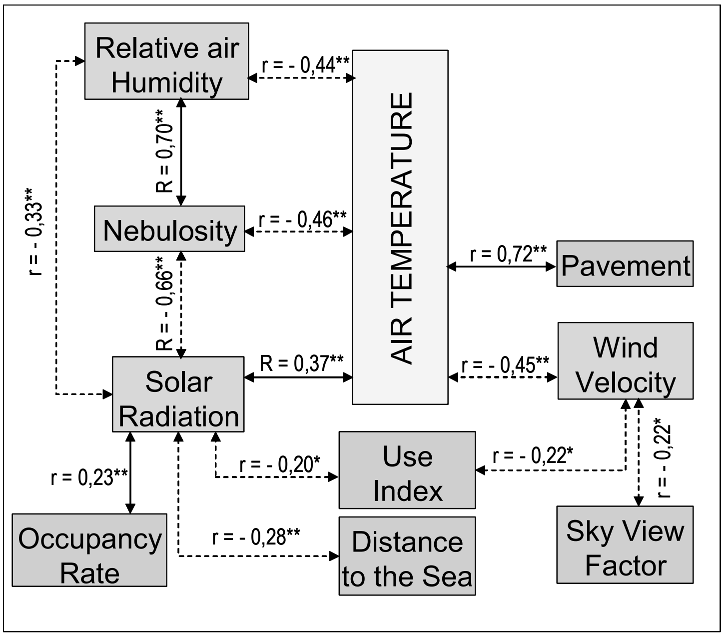

Figure 4: The correlation system between climate variables and urban landscape in the afternoon with southeast winds. CAPTIONS: *Idem* Figure 2.

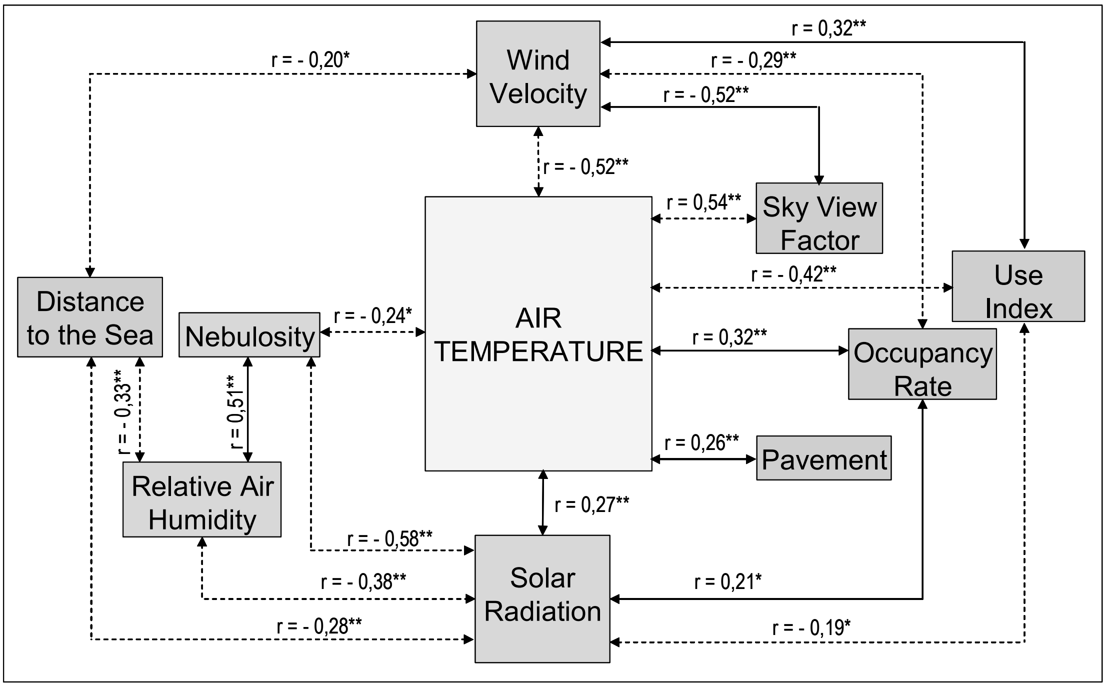

Figure 5: The correlation system between the urban climate variables and urban landscape in the afternoon with east and northeast winds. CAPTION: *Idem* Figure 2.

4.3 At night

No significant correlation was identified between the air temperature and southeast winds at night possibly due to the small difference in the temperature values between measured points which was verified during the full measurement period.

With east and northeast winds, the correlations identified were low; however, with significance (Fig. 6). The nebulosity parameter (r=0,494 e p=0,000), the wind velocity (r= -0,464 e p=0,000) and sky view factor (r=0,443 e p=0,000) were the variables that had the highest correlation with the air temperature.

Given the co-linearity effect caused by the wind velocity and sky view factor, only the nebulosity and wind velocity remained part of the explanatory model for the air temperature variations, with R^2 = 49.3% e R = 0.70.

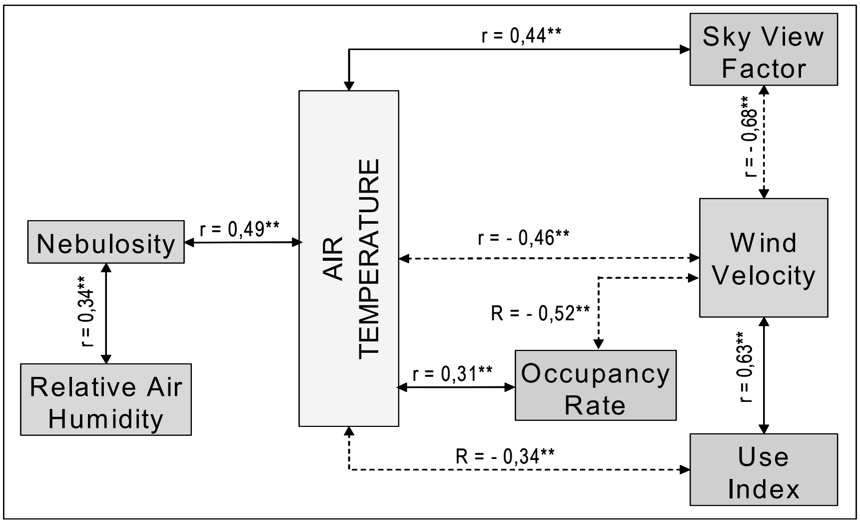

Figure 6: The correlation system between the climate variables and urban landscape at night with east and northeast winds. CAPTION: *Idem* Figure 2.

5. CONCLUSIONS

The results of this paper show that although the correlation between the elements of urban landscape and air temperature have been low in the majority of the observed cases, the city planning model adopted in this area of study has significantly altered the thermal pattern in the urban landscape, generating significant differences in air temperature, relative air humidity and wind velocity between the points measured, specially during the daytime.

The results found in this study support the hypothesis that up to a certain limit, and at adequate distances, the verticalisation of buildings contributes towards the reduction of temperature, because it increases street shadows and, in some instances, cause wind velocity to increase.

The correlation coefficient between the wind velocity and distance from the sea indicate a slight tendency of the wind velocity to decrease as winds reach the urban grid. This tendency is attributed to the rugosity of the surface and is accentuated by building height template scale.

Thus, it is necessary to reformulate the urban by-laws of João Pessoa, considering that thermal discomfort can increase if the construction density reaches their peak, according to the applicable current by-laws.

REFERENCES

[1] H.J.M. de Carvalho, Metodologia para a análise das interações entre a forma urbana e o clima: aplicação a uma cidade brasileira de clima litorâneo com baixa latitude. Rio de Janeiro: PROURB/FAU/ UFRJ, 2006. (Ph.D. Thesis in Urbanism).

[2] F.A.G. da Silva, O vento como ferramenta no desenho do ambiente construído; uma aplicação ao Nordeste do Brasil. São Paulo: FAUUSP, 1999. (Ph.D. Thesis in Architecture and Urbanism).

[3] C.A. de F. Monteiro, Teoria e clima urbano. São Paulo: FFLCH-USP, 1975. (Tese, Livre-Docência em Geografia).

[4] T.J. Chandler, Urban climatology and its relevance to urban design. WMO – Nº 438, Geneva: 1976.

[5] E.S. de Assis, Impactos da forma urbana na mudança climática; método para previsão do comportamento térmico e melhoria de desempenho do ambiente urbano. São Paulo: FAUUSP, 2000. (Ph.D. Thesis in Architecture and Urbanism).

[6] Sakamoto, Luiza L. S. Relações entre a temperatura do ar e a configuração do céu na área central da metrópole paulistana: análise de dois episódios diários. São Paulo: FFLCH/USP, 1994. (MSc. Dissertation in Geography).

[7] G.G. Serra, O espaço natural e a forma urbana. São Paulo: Nobel, 1984.

[8] A.H.L. Sampaio, Correlações entre uso do solo ilhas de calor no ambiente urbano: o caso de Salvador. São Paulo: FFLCH/USP, 1981. (MSc. Dissertation in Geography).

[9] O.D. Corbella and S. Yannas, Em busca de uma arquitetura sustentável para os trópicos. Rio de Janeiro: Revan, 2003.

[10] C.A. de Souza e Silva, Critérios para aquisição e análise de dados bioclimáticos urbanos em espaços abertos visando o conforto ambiental. Rio de Janeiro: PROURB/FAU/UFRJ, 2004. (MSc. Dissertation in Urbanism).

[11] A.R. Janeiro Borges and J.A.G. Saraiva, Erosion technique for assessing ground level winds. Lisboa: Laboratório Nacional de Engenharia Civil, 1981.

[12] H.J.M. de Carvalho, Parâmetros climatológicos para o estudo do balanço termo-energético de edificações da cidade de João Pessoa – PB. Natal: UFRN, 2001. (MSc. Dissertation in Architecture and Urbanism).

[13] SPSS, version 11.5 (Copyright©SPSS, Inc. 1989-2002).

[14] Plano Diretor de João Pessoa. Prefeitura Municipal de João Pessoa, 1992.