Thermal comfort in open spaces: A study in the northeast of Brazil

A.D.L. Costa and L.C. Labaki
School of Civil Engineering, Architecture and Urban Design, University of Campinas, Brazil

V.M. Dantas de Araújo
Federal University of Rio Grande do Norte, Brazil

ABSTRACT

This paper describes a study, developed in the district of Petropolis in the city of Natal, Brazil. The aim of the study was to investigate the influences of city urban form in the climate and its correlation with the thermal sensation of the users of open spaces. The method consists of drawing maps of the study area (based on Katzschner, 1997) including topography, building height, land use, green areas, soil pavement, as well as measurement of the environmental variables: air temperature, relative humidity, direction and wind speed, for a comparative study. Besides, local users of the district were interviewed about their thermal sensations in the open space. For statistical analysis, data were collected at ten points, eight within the district and two in climatological stations outside the district, in three periods (in 2000 and 2002), in four consecutive days for each measurement (from Sunday to Wednesday). The hours with lowest and highest temperatures in the city were chosen for measurement - 6:00 a.m. and 1:00 pm, respectively. At the same time interviews were carried out with users of the open spaces, totaling 171 valid formularies. The urban form showed a rather leveled topography, great diversity of land use and building height, with an area mostly occupied with high buildings, very little green area and soil almost completely impermeable. The statistical analysis showed high temperature and humidity levels. The wind direction is predominantly Southeast with extremely variable speed. It was observed that this district is hotter and less ventilated than outside; besides, most users said that they felt uncomfortable in the local environmental conditions. The results of the analysis generated a zoning for the district with recommendations for soil occupation, as well as some discussion about the comfort parameters, including the proposal of limiting temperature and humidity regions for the thermal comfort in the open spaces.

1. INTRODUCTION

The process of urbanization is a daily activity that occurs by anthropic action, through changes of the natural ecosystem imposed by human activities, such as removal of the native vegetation, alteration of topography, impermeability of the soil, by paving process, or construction of complex structures such as vertical and/or horizontal buildings.

It causes environmental changes at different levels, which damage especially the air quality and the climate, thus affecting life quality of the population.

A rise in air temperature is the most important evidence of these climatic alterations. This fact has been object of study by urban climatologists and has attracted the attention of the urban population since they are either active or passive agent of these changes.

The urban climate is also characterized by the decrease in humidity, an increase in nebulosity, heavy rain as well as a decrease in the wind speed, plus an increase in the turbulence. This study is a bioclimatic analysis of the way that urban form influences the city climate changes. The results were used for a comparative research of the thermal sensation of the users of open spaces, to identify the affected areas in relation to the climate, and to generate limits to outdoor thermal comfort, thus contributing to

the planning of an urban management more adequate to the studied city.

The city of Natal is located at the Eastern coast of the Rio Grande do Norte State bordered by the Atlantic Ocean, in the northeast of Brazil. (Fig. 1). The climate is hot and humid, with little alterations in the topography, and an altitude of about 18m.

Like many other medium size cities, Natal is undergoing an accelerated urban development, characterized by the building of vertical structures in some districts, and by an expansion of its urban network towards the neighboring cities (Araújo et al., 2000).

The research was developed in the district of Petrópolis, which has a consolidated occupation. Among other reasons, it was selected for this study because it was originally planned, in the beginning of the last century, taking into consideration environmental aspects of comfort (Fig. 2).

Figure 1: Natal in the Northeast of Brazil.

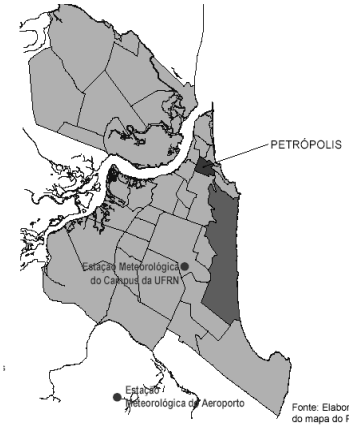

Figure 2: Petrópolis localization in Natal/RN and the climatological stations.

Presently, despite the primary concern of providing comfort to its inhabitants, the district is exposed to many environmental problems, including the increase of impermeable areas, lack of green public and private areas, increase of areas exposed to radiation (as a result of the crescent verticalization), and exhaustion of the roadway.

2. METHODOLOGY

The works of Katzschner (1997) and Oliveira (1988) were the basis to the methodology developed; this one suggests a physical analysis and mapping of the topography of the district, building height, land use, green areas and type of pavement, by superposition and identification of sites for measurements of environmental variables, such as air temperature and humidity, wind speed and direction.

For the statistical analysis data were collected simultaneously at ten different points with different physical characteristics relating the aspects of the urban form under study. Eight of them were in the district of Petrópolis and two in climatological stations, during three different periods (August/2000, January/2002 and June/2002), for four consecutive days for each period (from Sunday to Wednesday), at the hours of lowest and highest temperatures in the city, at 6:00am and 1:00pm, respectively, according to Araújo et al., (1998) (Fig. 3).

Four digital thermo-hygro-anemometers were used for the measurements. Simultaneously questionnaires were distributed to the passers-by

Figure 3: Measurement sites within the District of Petrópolis.

who were asked about their thermal sensation, attaining a total of 171 valid forms. The questionnaires were applied in the last two periods of measurement.

3. PRESENTATION AND ANALYSIS OF THE RESULTS

3.1 The physical environmental component

To design the maps, updated by *in loco* visits the software Arc View was applied. Observing and analyzing the factors that have influenced the climate changes, such as the situation and the size of the city regarding the region, density of the built area, the pavement, the height of the buildings, the direction and width of the streets, the subdivision of plots used for construction, it was verified that a large part of the District is between 30m and 40m above the sea level, thus forming a large plain. This fact represents an aspect that predisposes the urban site to better climate conditions, mainly concerning ventilation. Besides, its scheme, like a "chess game", facilitates the wind flow, since it is appropriately oriented towards the predominant ventilation.

There are still some vacant plots in the area, although most of the constructions in the district are family houses and apartment buildings. The district functions as a residential area, for business, services and public and private institutions. The change in land use has been frequent: unifamiliar houses are substituted by multifamiliar/commercial high buildings, which contributes to increase heat emission, density and the anthropic activities.

There is a great diversity of buildings height in Petrópolis. There are one-story houses as well as buildings with more than 20 floors. It is one of the most verticalized districts in the city, overloading mainly the road infrastructure, which lacks parking spaces. In the North part of the district there is a verticalized area, characterized by luxury residential buildings.

Most of the land is impermeable due either to pavement or to buildings. Another important aspect is that all the roads and streets of the district received pavement, consequently they are impermeable to rain water and also emits heat. It was also noticed the lack of vegetation and the existing ones are found in the center of the streets dividing it into two lanes. In the plots with high buildings the existence of green areas is very rare.

3.2 Statistical Study

Initially an adjustment of the daily curves of the behavior was carried out, based on Araújo et al., (1998), which by means of mathematical formula allowed that hourly values of temperatures were obtained, through maximum and minimum values collected for each day of measurements.

Data collected from the forms were also substituted by numerical values, so that various corresponding scales were adopted. The statistical analysis was made using the software Statistica, with the help of the Statistical Consultancy of the Department of Statistics of University - UFRN.

According to the analysis, the parameters: Period, Site, Day and Hour, separately, have a significant effect on the air temperature and relative humidity, while the interactions "Period vs. Site", "Period vs. Hour", "Period vs. Day" have an effect on the answers variables. However, the interactions "Site x Hour", "Site x Day", "Hour x Day" have no significant effect on the answer variables.

The air temperature in the District ranges from 26,7ºC to 28,2ºC, although higher temperatures have been recorded. The average temperature is about 27,6ºC. Relative humidity is always high, an average of 74%; the wind flows predominantly from Southeast, and the wind speed is rather variable (between 0,14 m/s and 2,99 m/s).

When comparing data from the district and the two meteorological stations, both located in less urbanized areas, the district of Petrópolis is warmer than the stations, as shown in Table 1. This table also indicates that the area of the airport is rather warmer than the area of the University Campus, maybe because of its impermeable type of pavement.

Analyzing the questionnaires it was observed that 46,2% of the interviewed were male and 53% female, indicating a well-balanced sample although this was not the purpose of the research.

Most of the interviewed were between 25 and 34 years old (31%), followed by the peer group immediately under this (18 – 24 years old), corresponding to 22,2%, and those immediately

Table 3: Thermal sensation vs. associated sensations.

ASSOCIATED SENSATIONS			
SENSATION	N	%	ASSOCIATED SENSATIONS
VERY COLD (07 subjects)	6	86	Need to hunched
	1	14	Unbearable Thermal condition
COLD (33 subjects)	16	48	Need to hunched
	21	64	Tolerable thermal condition
COMFORTABLE (49 subjects)	25	51	No sweating
	42	86	No need to use a fan,
	43	88	No need to hunched
	29	59	Comfortable thermal condition
WARM (21 subjects)	13	62	Little need to use a fan
	19	90	Little sweating
	14	67	Tolerable thermal condition
VERY WARM (04 subjects)	3	75	Need to hunched
	2	50	Very much sweating
	3	75	Unbearable thermal condition

above (35 – 44 years old), corresponding to 21,6%.

From the whole group, 26,3% was classified as thin, 57,3% with normal weight and 16,4% as fat (overweight). Most of them were sitting (46,85%), followed by those who developed a light activity (19,3%), walking (15,2%) and standing still (14%). Concerning the clothes, different types of combination were observed, most of them were adequate to the climate at that moment.

Table 2 presents the thermal sensation for all interviews.

To find out the factor that influenced these answers, a multiple regression analysis was carried out in which the answer "sensation" was influenced by the regression factors: age, sex, metabolism, clothing and physical characteristics (under weight, normal and overweight). It was verified that among these factors, the ones with most influence was the metabolic rate (activity) and the physical characteristics, and those ones with less influence were the clothing and age. Important correlations were not found between the measurement site and "sensation" as well as site, period, day and "sensation".

Table 2: Thermal sensation.

THERMAL SENSATION	NUMBER OF SUBJECTS.	%
Very cold	7	4,1
Cold	35	20,5
Comfortable	75	43,9
Warm	39	22,8
Very warm	15	8,7
TOTAL	171	100

Regarding the data of the second period of survey (total of 114 people) it was possible to carry out another type of analysis relating the associated sensations. Table 3 shows that in most cases there was consistency between the thermal sensation and the supposed associated sensations for each of them.

Concerning the parameters of thermal comfort study the results show that neither the Physiological Equivalent Temperature (PET) neither the Standard Effective Temperature (SET) can be considered equal to the average of the records regardless the hour of measurement (Table 4), although they can be considered equal between themselves.

The Predicted Mean Vote (PMV) and the Predict Percentage of Dissatisfied (PPD) were also studied. The first one ranged from -1.8 to 2.9, from cold to very warm; causing uncomfortable thermal sensation due to heat. The average (taking into consideration all the subjects) is about 1.3, that shows discomfort due warm.

PPD analysis shows that most interviewed were uncomfortable with the thermal environmental conditions, since these parameters are a sum of the percentage of the interviewed subjects who were not feeling comfortable, and this number corresponds to 56,1% of the sample, since 43,9% felt comfortable under the thermal conditions studied.

4. CONCLUSIONS

The study proposes alternatives that can minimize the environmental impacts already caused by urbanization and to avoid (worsen) existing problems such as an increase of air temperature.

Petrópolis was divided in two types of areas, according to the methodology of Katzschner (1997). Areas to be improved (that represents

Table 4: Thermal comfort index.

ALL THE SENSATIONS			
Parameters	6h	13h	Average
Average Temperature	25,1^{0}C	30,4^{0}C	27,5^{0}C
SET	24,1^{0}C	28,8^{0}C	26,2^{0}C
PET	23,9^{0}C	29,6^{0}C	26,5^{0}C

Table 5: Limits of thermal comfort.

ENVIRONMENTAL VARIABLES	COMFORT RANGE
Temperature	From 24,2^{0}C to 30,4^{0}C
Humidity	From 67% to 89%

the greatest part) regarding vegetation, permeability to wind and density were indicated; including an area to be observed because of the great number of vacant lots and the number of institutions that make the road network denser; and finally it was suggested that some areas should be *protected* (a small area) due to their importance for urban ventilation according to Figure 4.

It was possible to determine a range of thermal comfort for the air temperature as well as for the relative humidity, by the statistical analysis (Table 5).

Unfortunately significant interval of the wind speed could not be accurately determined, since the data show great variation (from 0,14m/s to 2,99m/s). But the main direction of the wind is approximately 177 degrees, in the Southeast quadrant.

It is important to stress that both wind speed and direction are very susceptible to variation. The wind speed is influenced by many factors, and the wind direction is locally affected by natural and artificial obstacles, consequently it is suggested to avoid the adoption of a fixed pattern. So, observation *in loco* should be done whenever one of these variables is to be used.

A proposal to support some modification in this district as a whole is described below:

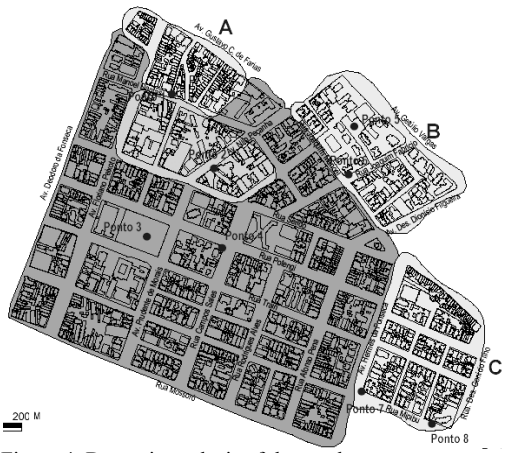

Figure 4: Dynamic analysis of the result map.

- incentive to diversification of land use;
- clearance between the buildings, in order to allow adequate ventilation and the penetration of diffuse sunlight indoors;
- planned landscape;
- compulsory maintenance of impermeable area within the plots;
- awareness of the approval of new developments in the district and impact on thermal comfort of the population;
- development and consolidation of programs of environmental education.

Based on these suggestions, the need to provide the district of Petrópolis and the city of Natal with a better quality environment is of the utmost importance. Avoiding an uncontrolled growing process, which would affect the city's attractions that should be kept by its population, can help to attain this objective.

The Government as well as the organizations of the city population has an important role in caring about the urban environment.

REFERENCES

Araújo, E.H.S., et al., 1998. Dias típicos para o projeto térmico de edificações em Natal – Rn. Natal: EDUFRN.

Araújo, E.H.S., et al., 2000. Forma Urbana e climatologia em Natal-RN. Encontro Nacional de Tecnologia no Ambiente Construído, 8, Salvador. Anais... Salvador: FAUFBA, ANTAC, p.1282-1289.

de Oliveira, P.M., 1998. Cidade apropriada ao clima: a forma urbana como instrumento de controle do clima urbano, Brasília. Dissertação (Mestrado) – Instituto de Arquitetura e Urbanismo da Universidade de Brasília.

Katzschner, L., 1997. Urban climate studies as tools for urban planning and architecture. IV Encontro Nacional de Conforto no Ambiente Construído, Salvador, 1997. Anais... Salvador: FAUFBA, ANTAC, p. 49-58.