Urban thermal behavior

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ABSTRACT: The climatic characteristics in an urban area often differ from the regional pattern. This particularity, the urban climate, results from the alterations on atmosphere produced by urbanization. This paper aims to evaluate the influence of urban compactness on the thermal behaviour of urban fractions, considering the reception of solar radiation as a weighting factor of the urban characteristics. For the analysis of the urban-rural thermal differences, measurement points were selected in two urban fractions of a Brazilian medium sized city, Sorocaba (SP). Thermal differences among them and the urban area were analysed. Besides, the thermal amplitude of these points was verified. The methodological steps followed three phases: (1) delimitation and characterization of the study area; (2) data collection; (3) cross-examination of data and analysis of the results. Two urban fractions were selected by their distinct configuration in relation to their urban compactness. Both are situated in Sorocaba (SP), which is a city in the southeast of the State of São Paulo, Brazil. According to the described results it is evident the directly proportional relationship between compression and potential heat receiving from a specific area. Thus, the more compact the surroundings, the higher the thermal differences between urban and rural area.
Keywords: Urban climate, thermal urban comfort, urban planning.

INTRODUCTION

Nowadays the world population lives mainly in urban areas, usually submitted to accelerate and unbalanced growth. The Brazilian urban population increased from 81.25% in 2000 to 84.25% in 2010 [1]. In 1960 the rural population was still predominant, but already in 1970 the census pointed out that 56% of the populations were living in urban areas [2]. The high migration level together with a vegetative growth caused a boom on urban sprawl.

This urbanization process without planning actions resulted in modified environments, which were influenced by human activities and caused a large transformation on the natural sites. One of the significant changes caused by built-up areas on the natural landscape is the modification of local climatic conditions.

The climatic pattern of urbanized areas is distinct from the surroundings rural areas, due to the interference they play in the energy balance induced by their exposition to solar radiation and wind. Therefore the urban climate is defined as a change on local climate due to urbanization, which means that the climate on cities differs from regional patterns.
Urban climate is influenced by urban geometry, building density, landscape use and occupation, vegetation, materials, and others [3, 4, 5, 6.].

Negative effects of the thermal behavior of cities may be mitigated by urban planning tools. To achieve this goal the decision agents must understand the climatic impacts and their causes [7]. The results and the knowledge generated by scientific research are not usually applied on urban planning due to conflicts of interests, communication problems, economic issues and lack of knowledge [8].

Apart from the existence of many studies [9, 10, 11, 12, 13, 14.] in this field, the generalization of the urban thermal behavior is still a difficult task, because of the complexity of the variables involved on this process. Studies, evaluations and standardized methodologies should be taken into account in order to create efficient tools to help on urban planning and management.

OBJECTIVE

This paper aims to evaluate the influence of urban compactness on the thermal behavior of urban fractions, considering the reception of solar radiation as a weighting factor of the urban characteristics.

METHODOLOGY

For the analysis of the urban-rural thermal differences, measurement points were selected in two urban fractions of a Brazilian medium sized city, Sorocaba (SP). Thermal differences among them and the urban area were analyzed. Besides, the thermal amplitude of these points was verified. The methodological steps followed three phases: (1) delimitation and characterization of the study area; (2) data collection; (3) cross-examination of data and analysis of the results.

Studying area

Two urban fractions were selected by their distinct configuration in relation to their urban compactness. Both are situated in Sorocaba (SP), which is a city in the southeast of the State of São Paulo, Brazil. Distant 90 km from the State capital, the geographical coordinates of Sorocaba are: 23º 30' South latitude and 47º 27' West longitude. The topography of the area is wavy, where altitudes vary from 1028 to 539m, with an average of 632 m above sea level. According to the Brazilian Institute of Geography and Statistics [1], the city has 586.625 inhabitants. Based on Köppen classification [15], which considers thermal and pluviometrical monthly data, categorizes this climate as tropical of altitude (Cwa) with dry winters and hot summers. The main wind directions come from the southeast.

The first selected area A has residential predominance of use with relatively homogeneous heights of buildings. Most part of the buildings is 1 to 2 pavements-high though presenting buildings of 4 pavements too. As an old neighborhood close to the city center, it has a complete urban infrastructure and few vacant lots.

Area B is a valuable area of the city, in which the Municipality Administration is located. The area is classified as institutional predominant use, but the real estate market is causing changes to its use in the last years.

Schools, universities, forums, condominiums of residential use, hotels, restaurants and others are also found in area B. The building heights are heterogeneous, containing buildings of 14 pavements as well as vacant land and 2 pavement-high buildings located in large lots.

Both areas location are highlighted on Figure 1.

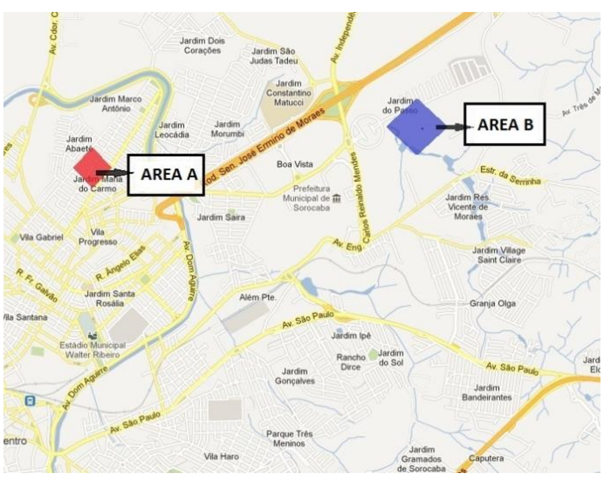

Figure 1 – Map representing part of the city of Sorocaba-SP, containing the studying areas A and B.
Font: adapted from Google Earth.

Measurements and instruments

Data collection of temperature was carried out by applying HOBO Pro Series data-loggers.

At the same urban area two data-loggers were placed on two different heights. This criterion intended to verify the thermal behavior of the specific point in relation to the difference on the scales.

Point A1 of area A corresponded to the instruments at 2 meters height, while point A2 represented a 5 meters height measure (figure 2). Points B1 and B2 area B have the same logic, being 2 and 5 meters above the ground, respectively (figure 3).

Measurements on both areas were processed in autumn, each one-hour, in stable days from 29 April to 05 May.

Figure 2 – Aerial photograph with location of points in area A.
Font: adapted from Google Earth.

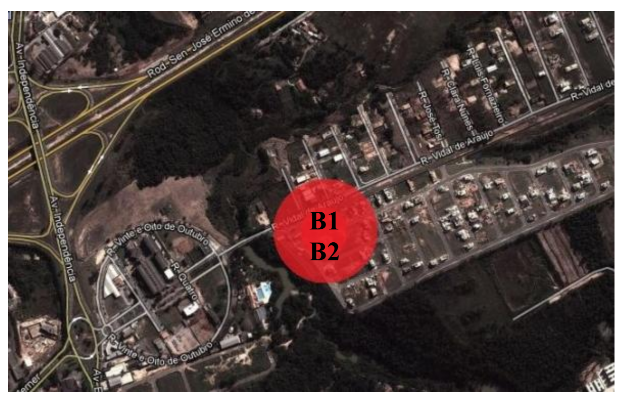

Figure 3- Aerial photograph with location of points in area B.
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Analysis Method

The thermal differences of each measurement point were compared to the rural values of temperature collected by the official local meteorological station (INMET – National Institute of Meteorology). This last one is a station located in an area with rural characteristics in the campus of FATEC (Faculdade de Tecnologia). The hourly temperatures were also compared among the points. The characterization and classification of the urban configuration of each urban fraction for the cross-examination with the thermal information was calculated on the basis of the projection of the vertical surfaces of the urban blocks surrounding the points of measurements. This calculation estimated the total radiation received by the vertical surface of the blocks surrounding the measurement points, based on the theoretical reception of solar radiation of an orientation in relation to North. In this case, the surfaces considered on the calculation were within a distance of 60 meters from the measurement points.

So, an urban index was proposed. This was an index of Potential Reception of Radiation. Equation (1) describes the calculation of this index:

$$\mathbf{Ipr} = \frac{(ASx * Rad.\ x) + (ASx * Rad.\ y) + (ASx * Rad...)}{100} \quad (1)$$

Ipr= Index of potential reception of radiation
ASx = superficial area of orientation x (m^2)
Rad. x = estimated radiation for the specific orientation x (w/m^2)

The heights of buildings were estimated, considering a height of 4 meters for one-floor building and 4 meters of height for each floor of a building.

RESULTS AND ANALYSIS

At first the thermal differences between A1 and A2 were compared, meaning the difference of temperature at 2 and 5 meters from the ground. Figure 4 indicates that for all periods the urban temperatures are higher than the rural temperatures. At point A1 this difference varies from 1.32°C to 5.34°C. At point A2 this differences varies from 1.25°C to 2.84°C. The highest point (A2) developed lower thermal differences, indicating the highest stability of air temperature at this height.

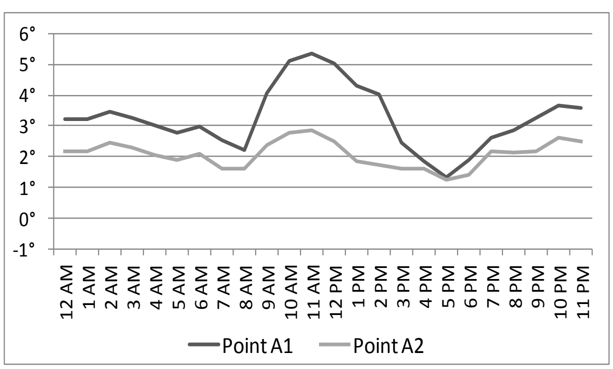

Figure 4 – Differences between the average temperatures of A1 and A2 and the temperatures of the rural meteorological station.

For area B, the comparison of points B1 and B2 is demonstrated in Figure 5. For some periods of analysis the difference was negative, meaning that the urban area presented temperatures lower than the rural area. At point B1, the negative difference occurred between 7 and 9 p.m. and varied from -0.14°C to -0.79°C. After this period the urban area presented warmer temperatures than the rural area. At point B2 this negative difference occurred between 7 and 8 p.m., varying from -0.09 °C to 0.25 °C.

The average thermal differences at B1 were -0.79°C, while this average at point B2 was 0.25°C and 3.21°C. Therefore, B2 represents a stable thermal behavior with the lowest amplitude**.**

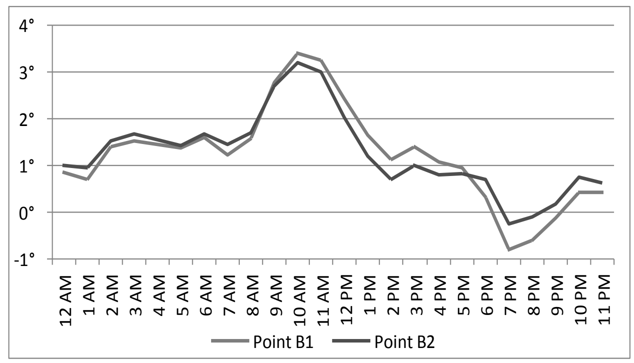

Figure 5 – Differences between average temperatures of B1 and B2 and the temperatures of the rural meteorological station.

In Figure 6 the average difference observed between point A1 and the rural area is about 3,25°C, reaching absolute values of 5,34°C at 11 a.m. At point B1 the average thermal difference was 1,23°C. The largest difference reached at this point was 3,24°C. This behavior reveals point B1 has temperatures closer to the rural area than point A does.

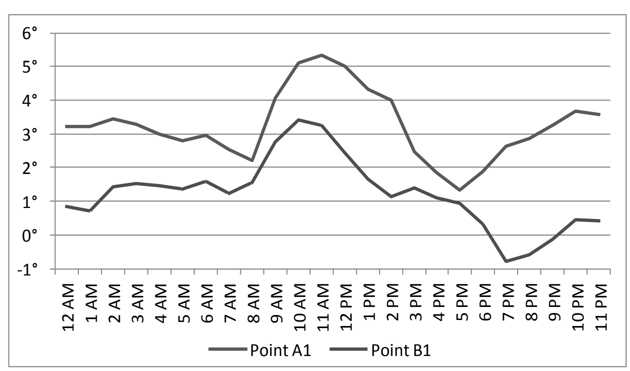

Figure 6 – Difference between average temperatures of point A1 and B1 and the rural meteorological station.

For night time, from 6 p.m. to 7 a.m. the thermal differences are presented in Figure 7. At point A1 this difference increase until 10 p.m., and then decrease gradually until 7 a.m. Point B1 has a different pattern. From 7 p.m. to 9 p.m. the temperatures are lower than the rural values, then reversing this situation, and the rural area becoming colder than point B1. This thermal difference decrease from 3 a.m. until 5 a.m. with a punctual increase at 6 a.m. From this time on, the thermal differences become to decrease again. This variation may be related to the nocturnal ventilation, because it is the lowest compacted area and the wind blows more freely. Nonetheless, it is remarkable that the thermal pattern of the urban points differs from the rural area and between each other.

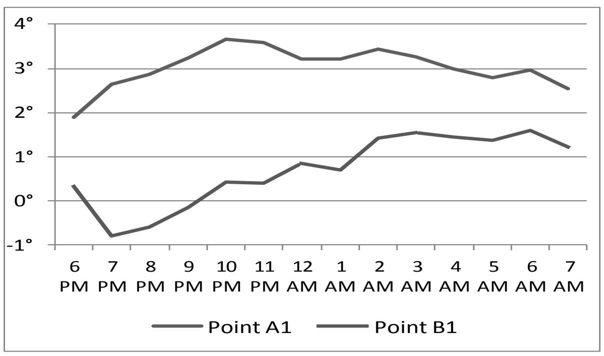

Figure 7 – Differences between average nocturnal temperature of points A1 and B1 and the rural meteorological station.

The Figure 8 presents the daily average temperature differences between points A2 and B2 and the rural area. At point A2 occurs a higher thermal difference during most of the day, except from 8 a.m. to 11 a.m. when this difference is larger at point B2. This probably occurs by the higher solar access in this area that is less dense compared to the area A. Due to the greater urban compactation, the point A2 has higher thermal differences in the other periods, averaging 2.08° C, while the point B2 has a daily average of 1.27º C.

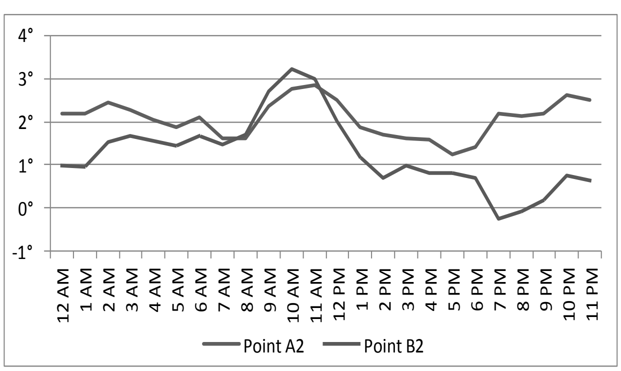

Figure 8 - Difference between average temperatures of point A2 and B2 and the rural meteorological station.

The thermal differences for the night time (6 p.m. to 7 a.m.) at points A2 e B2 are shown in figure 9. At point A2 the thermal differences increase until 11 p.m. and gradually decrease until 7 a.m. At point B2 the thermal behavior is different. The differences in urban-rural temperature decrease until 7 p.m. and gradually increase until 6 a.m. approaching the differences presented by point A2.

Both points, from 9 p.m., show higher temperatures than rural area, showing that there is heat retention by urban surfaces during the night. So urban area does not cools at the same rate that the rural area. For the same reason area A, more densified, has higher thermal differences than area B in relation to rural area.

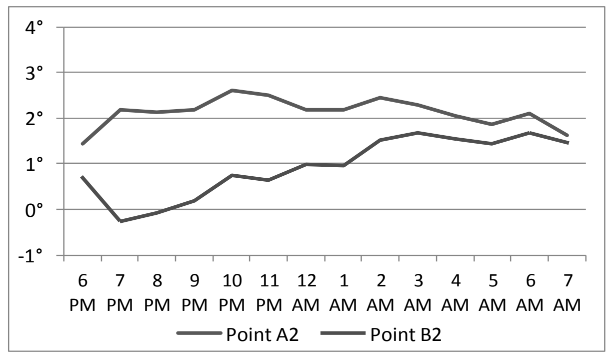

Figure 9 - Differences between average nocturnal temperature of points A2 and B2 and the rural meteorological station.

As in the previous analysis, where it was confronted the same location points, but installed at different heights, comparison between A1xB1 and A2xB2 demonstrated that the points where equipments were installed at 5 meters (A2 and B2) showed greater stability in thermal behavior. Therefore these points were chosen for the thermal behavior analysis of the two areas as a function of urban characteristics.

The characterization of the two urban fractions was done by the weighting potential heat receiving of each urban block adjacent to the data collection points. The calculation was made on the basis of the estimated radiation receiving by the urban blocks faces turned to the measurement points.

Table 1 presents the results obtained by the application of equation (1), presented in the methodology.

Table 1 - Sum of surface areas and surrounding radiation (KW/day) estimated according to the orientation of surfaces.

	∑ surrounding surfaces area (m²)	Estimated Radiation (KW/day)
Area A	3,983	17,830
Area B	2,718	11,756

For area A, represented by the point A2, it was estimated higher radiation receiving (17,830 KW/day) than for area B, represented by point B2 (11,756 KW/day). Therefore, at point A2 the potential heat reception is approximately 34% higher than at point B2. The average temperature differences obtained in points A2 (2.08°C) and B2 (1.27°C) were compared and it was found that the difference in point A2 is 39% higher than at point B2.

The sum of the areas of surfaces facing points A1 and A2 is higher than the sum of the surface areas turned to points B1 and B2. This result demonstrates that there is higher compaction in the area A.

According to the described results it is evident the directly proportional relationship between compression and potential heat receiving from a specific area. Thus, the more compact the surroundings, the higher the thermal differences between urban and rural area.

CONCLUSION

The thermal behavior of both urban fractions differs between themselves and in relation to the studied rural area. In the four measurement points were observed higher air temperatures than those from rural area, in most periods of the day. This is evidence of the influence of urbanization on local climate.

This study demonstrates that the higher (5m) data collection points (A2 and B2), in relation to the ground level, were better indicators of urban-rural thermal differentiation.

The index of potential radiation receiving (I*pr*) proposed by this research has been proved valid. Fraction A has been classified as more compact due to higher incoming radiation. It has higher thermal differences than fraction B in relation to rural area. Therefore, the difference in the thermal field of the two fractions is possibly due to the influence of urban compaction.

It can be observed that the climate changes resulting from urbanization are significant and these changes are consequences of a range of factors associated with each other. Therefore, the thermal behaviour of the urban grid is under direct influence of the complex set of urban structure.

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