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Presence of buildings and their influence on patterns of urban microclimates: A case study in the city of Juiz de Fora, Southeast Brazil

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ABSTRACT

Several mechanisms and processes are responsible for the urban climate. A city's growth intensity and speed along with the distinct and complex materials of which it is composed, lead to multiple urban microclimates. The main objective of this research was analysing the influence of one of these factors – the buildings – in an area near the central zone of Juiz de Fora, a city in Brazil, and the patterns of microclimates associated with them. The presence of buildings might be creating thermal and barometrical distinct fields, influencing the population's quality of life. Five sampling points spatially distributed in previously designated locations were chosen, considering those that presented different characteristics in the building standards. Meteorological stations (Oregon model WNR928NX) collected air temperature, wind and air humidity data at each sampling point, during the days 12, 13, 14, 19 and 20 of August of 2014, out for a period of 10 hours in a row (from 8am to 6pm each day). Maps were made for the purpose of observing the spatial distribution patterns of the buildings, comparing the geographical location of the Points, number of pavements and 3D Shadows. The buildings had a significant effect on patterns of microclimates. A wind corridor was also found at point 2, as a result of the dimensions and disposition of the access roads and their buildings. There is a need to rethink planning laws related to the urban land use and cover of the city of Juiz de Fora, taking into consideration the effect of buildings as part of the planning process.

Key words: Urban climate; Climate mapping; Urban planning; Land use/cover.

RESUMO

Inúmeros mecanismos e processos são responsáveis pela produção de um clima urbano. A intensidade e velocidade de alteração do espaço das cidades, somada aos distintos e complexos materiais que o compõe, criam múltiplos microclimas urbanos. O objetivo do trabalho foi analisar as influências exercidas por um desses materiais, que são os edifícios, presentes em um trecho da área central da cidade de Juiz de Fora, Brasil, e a formação de microclimas. A presença de edifícios pode estar criando campos térmicos e barométricos distintos, influenciando na qualidade de vida da população que habita esta cidade. Foram escolhidos 5 pontos amostrais distribuídos espacialmente em locais previamente designados, considerando aqueles que apresentassem características distintas nos padrões de edificação. Nestes foram alocadas estações meteorológicas (modelo OREGON WNR928NX) para coleta dos elementos meteorológicos: Temperatura do ar, Ventos e Umidade do Ar, durante os dias 12, 13, 14, 19 e 20 de agosto de 2014, por um período de 10 horas seguidas (das 8h às 18h, todos os dias). Mapas foram confeccionados com fins de observar os padrões de distribuição espacial dos edifícios (“Localização geográfica dos pontos”, “Número de pavimentos” e “3D de sombras”). As edificações influenciam na formação dos microclimas na área analisada. Os mapeamentos trouxeram respostas que puderam ser apreendidas pelas mensurações dos elementos climáticos. Constatou-se a formação de um corredor de ventos no ponto 2, dada as dimensões e disposição das vias de acesso e seus edifícios. Há a necessidade de repensar as leis de planejamento de usos e coberturas do solo urbanos da cidade de Juiz de Fora, considerando as edificações em seus processos analíticos.

Palavras-Chave: Clima urbano; Mapeamento climático; Planejamento urbano; Uso/cobertura da Terra.

Introduction

The multiple ways in which cities grow are often accelerated and can lead to innumerable spatial contradictions if planned ineffectually. This characteristic creates an atmospheric dynamic on the surface – which is marked by its spatial-temporal heterogeneity of the elements – causing the loss of people's life quality. This is one of the issues on urban landscape, bringing the need to better understand the cities.

One way to better explain the urban phenomenon is by understanding its climate bias. The city's climate is a result of the interaction between the atmospheric air and the environment (Oke, 1993, 2004), in which the complexity of the urban phenomena and their environmental wealth are associated with the diversity of materials that constitute the result on the cities' microclimates structure (Monteiro, 2003).

The elements that form the cities (trees, streets, plazas, houses, buildings, lakes etc) show distinct physical-chemical characteristics that interact individually with the atmosphere. Such materials and their spatial distribution patterns, along with the city's stream (people, goods, cars), influence temperature, changing on the time-spatial rain and wind dynamics and the composition of new air pressure fields.

Brazilian geographer Carlos Augusto de Figueiredo Monteiro created the theory that there is an *Urban Climate* (Monteiro, 1976), by showing the fact that cities have a typical climate. According to Monteiro, the urban climate is the climate of the city itself, which differs from its immediate surroundings due to the very materials and structures that constitute the urban area (Monteiro, 2003). It is also able to be modelled and can be seized through channels of climate perception (Monteiro, 1976), which are: the *physical-chemical subsystem*, that encompasses air quality and atmospheric pollution, the *hydrometeorological subsystem*, related to rainfalls and the *thermodynamic subsystem*, connected to urban temperatures – these being core elements for thermal comfort studies (Monteiro, 2009).

Such theoretical-methodological propositions follow the Brazilian Climatological School which are based on the Climatology Dynamics and seek to understand the urban and atmospheric dynamics in an interconnected way. Many of these studies use the meteorological elements to define the city's climate while others are related to green areas or land cover patterns.

However, there is a lack of studies that specifically consider other urban materials, such as transportation, people and automobiles flow. There are also gaps in relation to some more specific elements of the urban areas, such as buildings.

Studies that have climatic elements and buildings as their research objects are, for the most part, from other areas of study, such as Architecture. Generally, the thermal or lighting comfort guide the architecture, whereas the climatology has been the main theme for geography (Fante et al., 2017; Ferreira, 2014; Rocha et al., 2014; Santos, et al., 2014; Freitas, 2015; Nascimento et al, 2015; Oscar Júnior e Brandão, 2015; Amorim, 2015; Silveira e Carvalho, 2016 Alves, 2017; Oliveira, et al., 2017; Armond, 2017; Assis, 2018; Castro e Mendes, 2018; Medeiros et al., 2011).

This work will focus on buildings but it is recognized that any change any part of the urban area would change the whole dynamic of a city, since the urban physical-chemical properties can guide the climatic dynamics. The type of material they are built, for example, will influence the physical properties they represent, changing the thermal fields of cities. The albedo and the emissivity of the building materials will be directly related to these particularities (Mascaró, 1990). For example, the constructed mass will be higher in built-up areas than in land covered by houses (Nascimento et al., 2015). The thermal inertia can create distinct barometric fields and favour the movement of local winds patterns, creating wind corridors. The height of the buildings and the number of storeys can also change the wind direction and speed.

The buildings act as physical barriers to radiation (Nascimento et al., 2015) regarding the amount and intensity with which the sun's rays will reach the surfaces, or also make the air changes impossible, causing the heating of a certain area. The shades caused by buildings are directly related to the thermal and lighting comfort in urban areas or the horizontal coverage within the urban canyons; such relationship is determined as the Sky View Factor (Ferreira e Fialho, et al., 2016).

In this context, in spite of the variety and complexity of urban climatic typologies, a theoretical-methodological option that has as the main focus of the study the microclimates formed by the buildings would show good elements in the modification of the microclimatic conditions of the cities. These climatic investigations would

contribute to the improvement of the life quality for the urban population, reducing the problems.

The present study had as the main objective analysing the influence of the variable Buildings on the pattern of urban microclimates, having the city of Juiz de Fora, located on the Southeast of Brazil, as the study area.

Materials and methods

The study was conducted in a section of the central area of the city of Juiz de Fora, which has

numerous buildings. The methodological option for the microclimatic study involved the field collection of data and laboratory mappings.

Area of Study

The municipality of Juiz de Fora is located in the state of Minas Gerais, in the Southeast of Brazil (figure 1). It has an area of 1,429,875 km² and a population of 516,247 inhabitants (IBGE, Censo Demográfico, 2010).

Figure 1. Location of the area of study.

The city stands out as a regional hub, attracting people from all over the region, which intensifies the flow of motor vehicles and people in the central part of the city. The centre is the urban area of the city that has the highest number of buildings, indicating the verticality of the region.

The regional climate type is the Tropical Altitude, which corresponds to a variation of the tropical climate due to the characteristics of the regional soil, transformed into resin by the Earth's coverage patterns. The city has great variations in

altitude (close to 1000m at the highest points and 670 to 750m at the bottom of the Paraibuna river valley) and a climate that presents two well defined seasons: one that runs from October to April, with higher temperatures and higher rainfall frequency, and another from May to September, colder and with a lower rainfall presence (Oliveira e Ferreira, 2017).

Field data collection

Meteorological stations were distributed to each control point to collect information on: air temperature, winds and air humidity. The choice of collection points considered those that presented different characteristics in the building standards and that could create different thermal fields. Five itinerant points and one fixed point were selected.

The choice of a fixed location point (control point) occurred to calibrate and enable the comparison between the studied sites, since it was the only one that presented the data collection in all the studied days. Such methodology was chosen due to the non availability of equipment in operation in moments concomitance.

Two portable meteorological stations of the model Oregon WNR928NX were used and the measurements were carried out for a period of 10 hours in a row (from 8am to 6pm each day). The interval between measurements was 15 minutes. Simultaneous data collection took place in two points per day.

Measurements occurred on days 12, 13, 14, 19 and 20 of August 2014. Only the sunshine period (day) was monitored, since the objective of the article was to investigate the daytime behavior of the temperature in with relationship the buildings, besides that there was not the viability and availability of equipment and people so that the two schedules (night and day) were monitored in concomitant moments. So it was possible to observe only the climatic displacements recorded during the day. The choice to study during the winter was due to the lower cloud coverage, which allows to observe the daily variation of the data.

Corrections or statistical experiments were not performed in order to calibrate the data of weather types. The data used were the real ones and the comparisons became possible because the atmospheric system acting during the studied days was the same. It was on the basis of the records found at the control point (where records were presented every day) that this methodological choice it was possible. Only the basic statistical correlation it was applied.

Atmospheric characteristics

The atmospheric system on the region during all the studied days was the Tropical Atlantic mass, which is characterised as stable and having a clear sky. As a result of being under the same air mass, it was possible to use the information collected on different days, but always analysing it

in relation to the information obtained at the fixed station.

Generation of cartographic and numerical bases

Generation of variables that were related to the influence of buildings and microclimates in urban environment were analysed. Mapping of the "Points geographic location", "number of storeys" and "3D shadows" were carried out. The maps were made on the software *ArcGIS 10* and *Google SketchUp Pro 2015*.

The geographic location information was obtained from aerial photographs provided by the city hall and used to ascertain which materials the urban environment of Juiz de Fora is made of. The "number of storeys" map was elaborated with the purpose of highlighting the roughness of the urban mesh, from the height of the properties located in each area and using the "Street View" tool of "Google Earth" for counting the buildings storeys. The "3D shadows" map represented a shading model for each control point and to accomplish it, it was carried out a three-dimensional modelling on "Google SketchUp Pro 2015". A limit of 50 meters radius was used to define the area of influence of the buildings shades and 100 meters for the other variables.

Data synthesis

Correlating the information collected on the field and the maps generated in the laboratory.

Results and discussion

Firstly, it is worth mentioning that the values presented below represent the actual daily values of the 5 days studied and not mean values per monitored period.

The broad definition of the climatic descriptions found for the city on the studied days indicated that the atmospheric pression fluctuated between 918,67 hPa and 911,21 hPa, the highest registered temperature was 25.6°C on the 19th of August and the lowest was 12.4°C on the 14th of August, and the relative humidity varied between 65% and 82%, respectively.

The main influence found between the buildings and the generation of space-time microclimates happened because of the layout variability of the transport routes the influence such factors on the occurrence of shading areas. The

formation of wind corridors favoured both increase and decrease of air temperatures, as also altered the winds direction and speed.

Point 1: this point was located on the Silva Jardim Street, almost corner with the Olegário Maciel Street, at an altitude of 705 meters (figure 2). The area was characterized by the presence of houses, which are less elevated, and some trees on the sidewalks.

Air temperatures ranged between 16.8°C and 23.1°C, relative air humidity was between 31% and 61% and most of winds were in the East (figure 3). The wind speed reached 2.6 km per hour and only on the first frame the point is not shaded.

The formation of this microclimate caused by shading was not due to the presence of high buildings (Figure 8) but because it was a narrow road where the houses around it eventually caused the shades.

Figure 2. Location of the sample point 1.

Figure 3. Results of sample point 1.

Point 2: It was allocated at altitude of 682 meters, in a place that is known for being as one of the main crossroads of the central region, which is the intersection between the Barão do Rio Branco Avenue and Itamar Franco Avenue (figure 4). Several higher buildings and a high degree of soil waterproofing were found on the surroundings of this concentrated flow of vehicles and people.

These characteristics favoured a microclimate with great heating potential, especially during the period when it was not shaded (between 17.6°C in the morning and 26.1°C in the afternoon).

The buildings may have acted as physical barriers to radiation, determining the amount and intensity in which the sun's rays hit the surfaces and may have prevented air changes, making the area remaining warm.

The relative air humidity was between 61% and 25% and the predominance of the winds were those from the South and West quadrants (S, SW and W). The highest speed of the winds was 1.6 km per hour, which can be linked to the pattern of anthropic roughness formed by the heights of the buildings, favouring the speed decrease.

Figure 4. Location of the sample point 2

Figure 5. Results of sample point 2.

Point 3: On this point, the relative air humidity varied between 35% and 68%, predominant direction of the winds was from East and maximum speed was 3, 6 km. The height and proximity of the buildings plus the difference of pressure between nearby areas may have helped the formation of a barometric field and a local wind corridor of the fastest winds, formed by the North-South axis constructions. The maximum speed (from all points) was recorded at this location.

The low temperature amplitude records (between 16.7°C and 24.2°C) was related to the

shading, which lasted almost all day and it was only lightened by solar radiation at noon. It is possible to infer that the temperatures registered on this locality have been dampened by the shadows because the streets were narrow, so the high buildings reduced the Sky View Factor.

This point was located on Antônio Carlos Street, at an altitude of 708 meters, in an area that is characterized by the representative presence of new, high buildings and a high financial standard.

Figure 6. Location of the sample point 3.

Figure 7. Results of sample point 3.

Point 4: It was located on Américo Lobo Avenue on an important region of the city, which due to its functionality for the other surrounding regions offers commerce and services. It was located at an altitude of 682 meters, shaded during almost all the schedules and there was a high flow of people and vehicles during the whole day, which could have resized the energy flow.

The point had higher temperatures (between 19.7°C and 26.8°C) even though it had the

meteorological station located near buildings with several storeys (figure 8), which means that the local flow may have exerted more influence than the shades. This different response to shading, as having this place registered as warmer, emphasizes the importance of considering the complexity of the urban climate.

The relative humidity was between 33% and 57%, the main direction of the winds was from East and its maximum speed was of 2,5 Km per hour.

Figure 8. Location of the sample point 4.

Figure 9. Results of sample point 4.

Point 5: the temperature records were between 17°C and 23.7°C, relative air relative humidity between 52% and 32% and there was no predominance on the direction of the winds. The highest wind speed record was 2.6 km per hour. There was shading only in the afternoon, precisely at the 4pm, with low obstruction of the sky view due to the small buildings. This generated a more comfortable microclimate – because the reduction of Sky View Factor could generate discomfort – either due to excessive shading or stored heat, causing a need for artificial cooling which could lead to

increase the energy consumption (Ferreira e Fialho, 2005)

This point was located at an altitude of 710 meters on Monsenhor Gustavo Freire Street, in front of the house numbered as 401. This street is itself an important interconnection path between different neighbourhoods, mainly the region that has the campus of the Federal University of Juiz de Fora, which attracts a large number of people, so the route has an intense flow of vehicles throughout the day. In contrast, the area around the point is residential (figure 10).

Figure 10. Location of the sample point 5.

Figure 11. Results of sample point 5.

Fixed point: because the fixed station was installed in a higher location, it did not have shades generated by buildings at any time of day (figure 12). The Sky View Factor was equal to one, because there were no barriers in the location that could obstruct the sky view.

If this area happens to have a higher number of buildings in the future, it may occur that the solar radiation does not directly affect the surface at any moment of the day which could cause the decrease

of air temperatures and surface luminosity, directly influencing the loss of life quality and aggravating respiratory diseases. The shading caused by buildings is directly related to thermal and lighting comfort in urban areas.

The fixed point was located on 567 Tiradentes Street, at an altitude of 709 meters and it has an arboreal vegetation area on its surroundings.

Figure 12. Results of the fixed sample point.

The data found by the analysis of coherence with the results recorded at the fixed point (figure 13) and the other five points was obtained by analysing each element and its temporal repercussion on the studied days, making it able to

identify patterns of similarity in the behaviour of climatic typologies during the days of data collection.

Figure 13. Results of the fixed sample point.

The air temperature followed a pattern that repeated during the studied days and it increased during the first 14 hours of each day – decreasing during the dusk – being 31°C the highest value recorded. That may be linked to the possibility of direct incidence of solar radiation, given the influence of Topicality (CONTI, 1989).

The relative humidity also maintained the same pattern on all days, not exceeding 60%, being higher in the morning and decreasing during the day. This pattern was inversely proportional to temperature.

The predominant direction of the wind was from the South, but the Southwest, Northwest and West quadrants were also highlighted. The wind speed was higher than 5 km per hour.

After these observations, it became possible to say that the buildings have been influencing the formation of the microclimates on the selected points, bringing answers that could be apprehended by measuring the climatic elements.

The buildings had an important influence on the definition of the recorded meteorological elements, mainly about the space-time amplitude. The formation of wind corridors on point 5 was clear, which can be justified by the spatial arrangement of the buildings there.

About the shading, points 2 and 3 were highlighted. These were the ones that showed the largest shaded area and similar daily temperature patterns. The temperature followed an expected pattern, heating in the morning and decreasing in the afternoon.

The station that had the highest statistic correlation with the fixed point was located on point 1 and the lowest correlation occurred on point 3. The highest and lowest values of temperature had negative correlation (-0.0179 and 0, 3071, respectively), while only the lows had a positive correlation (0.0633 and 0.0826). The highest correlation observed was the high relative air humidity, while the wind correlation (0.0010) can be considered as very low or non-existent. Only points 2 and 4 coincided with the direction of the winds on the fixed point.

The maximum humidity record was very similar among the collection points, allowing the conclusion that the buildings would not have as much influence on the formation and distinction of the urban microclimates in the studied city. However, the low correlation found for the minimum and maximum temperatures indicated that the various patterns of buildings around the

sampling points could be responsible for the production of their respective microclimates.

Although there are laws that help guiding the urban growth of the city of Juiz de Fora as an attempt to mitigate the effects of urbanization and disorganized concentration, there is still a high concentration of buildings in the central region. Besides this, other regions also stand out, as is the case of Grambery, Alto dos Passos and the northeast portion of São Mateus.

Those buildings, or sets of buildings, have been making the centre of the city a place of shaded areas by blocking the sun's rays. This fact, coupled with the type of material they are built and their physical properties (albedo and emissivity), are increasingly creating complexes and changeable microclimates.

The fixed point behaved very similarly during the gather data period, with temperatures varying from 19 to 30 ° C and humidity between 20 and 80%. The wind is predominantly South / Southeast on most days, except for the last day (08/20), that the predominant direction was north. Noteworthy is the first day presents relative humidity values higher, however in the next gather days already there is a decrease in these values. With respect to temperature it is possible to say that the starting point has a homogeneous behavior during all gather days, with mild temperatures in the morning and higher between 14 and 16 hours. From the records of this point it is possible to affirm that the studied region was under the same atmospheric system, since there are no significant changes between the analyzed days.

About the itinerant gather points, point 2, which presented the highest thermal amplitude and with higher temperatures. This is due to the essentially urban character of the point, with similar behavior, point 3 also presented a thermal amplitude of around 8 ° C, but there was a highlight for the wind speed, which presented higher values than in the other points, due to formation of wind runners formed by the area's prominent buildings.

With similar configurations, points 1 and 5 also have similar thermal characteristics, with a thermal amplitude between 6 and 7 ° C. The two points consist of regions with residential use patterns, surrounded by houses, although point 5 has a massive flow of cars and is at a higher altitude. On the other hand, point 1 is different from the local transit route of less flow and tree-lined road.

Finally, it is necessary to point out that although it is the most distant point of the central

region of the city, point 4 has behavior similar to points 1 and 3, located in the central portion. This similarity is due to the profile of the region, which is characterized by commercial uses, with high flow of vehicles and people. However, it is important to reflect that the propagation of the patterns seen in the central portion towards the peripheries leads to problems resulting from the imbalance of the thermal conditions. In this sense, it is important to consider the structuring of the urbanization vectors of the city, as it is necessary in the central portions.

The present paper came to reinforce the need to better interpret the urban environment due to climate effects caused by the socio-spatial inequalities (Araújo, 2015; Armond, 2017).

Choosing to analyse the study based on the buildings showed how salutary the elements of urban environments are related to the modification of microclimatic conditions. The fact that the work is theoretically and methodologically based on a Dynamic School of Climatology, which has the paradigm of the Urban Climate System as one of its guiding principles, also brought a holistic view of the environment.

A one caveat is that it can not be aver that there was generation was heat and freshness islands, and than it is necessary more comprehensive analysis. For this its important considered data collections at night, since the heat island phenomenon is schedule and better identified in the nocturnal period.

We highlight identifying heat islands was not the objective that way article since there are already other works carried out in the city that identified the occurrence of this phenomenon. In this present article it was possible to verify the influence of the buildings and their built areas, your influence in the urban climate formation in the city of Juiz de Fora and consequently your intensity in the effects of the urban climate which reach the city population.

There is a small altimetric variation between the collection points, but not enough to impact the thermal reality of the points, since the altimetric range between them does not exceed 50 meters. In this way, it can be said that the interference of the altitude factor in the climatic characterization of each point is not significant to have need to be highlighted.

Some possible interventions to be carried out for order to mitigate the impacts that urban microclimatic changes would bring to the population are related to the possibilities for quality improvement. Because it is a densely urbanized area,

with buildings and houses of different heights, uses and materials, it would become impractical we the propose to alter the structures of these pavements.

However, some more critical points such as those of number 2 and 3 that ware more vertical, have a larger shaded area and contribute to producing of wind flow. One possible way of intervening in these points would be to create mechanisms for future urban plans, to take into account the current demand for improvements to verticalization in the city.

Final Considerations

The results of this study confirmed that the most shaded places were not those with the lowest temperature values but point 1 and that the pattern of a wind corridor on point 5 was clear. The initial hypothesis of the study that the buildings influenced the urban microclimates of the city of Juiz de Fora, was confirmed. The experimental sample, even if small (5 days) allowed an initial diagnosis to be performed. The work showed concise results that allowed us to infer relations between the buildings and the patterns of urban microclimates in the city of Juiz de Fora. This will contribute to a dynamic understanding of the urban area as it was constructed from the correlation of several variables, especially in Brazil where the growth of medium-sized cities as important regional centres has been increasing in recent years and demanding that they should be better planned.

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