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Urban settings, socioeconomic factors and thermal comfort in São José Do Rio Preto, SP

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ABSTRACT
This study investigates the relationship between environmental comfort and urban socio-spatial settings in the city of São José do Rio Preto. The method consists of the analysis and thermal characterization of four urban areas in the city: two in areas characterized by high building standards and two in areas of special social interest. Campaigns to collect data on temperature and air humidity were carried out simultaneously, using reports from passersby about their perception and satisfaction with the thermal environment. The Physiological Equivalent Temperature (PET) climatic index was calculated, and reports on perception and satisfaction with the thermal environment were statistically analyzed in terms of the physical characteristics of the adopted urban areas. The contributions may lead to reflections on possible relationships between socioeconomic factors and urban thermal comfort conditions. Questions related to the Sky View Factor, the direction and speed of the wind, and the availability of outdoor areas are decisive for the variation of PET and user satisfaction reports on the thermal environment in the four urban areas. The analysis and discussion of this study reaffirmed the importance of considering climate issues in urban planning. To achieve this, the aim is to contribute with analyses that can help formulate proposals for future improvements.

Keywords: urban climate. Microclimatic analysis. Urban morphology. Socio-spatial relations. PET.

INTRODUCTION

Climatic conditions are not only essential but also pivotal in the issue of thermal comfort, which is defined as the state of mind expressing satisfaction with the thermal environment. Climate can be examined across various scales: global climate (macroclimate), intermediate units (mesoclimate), and smaller units (microclimate) (MENDONÇA, 2007).

At the mesoclimate scale, cities and their urban outdoor spaces significantly enhance livability and vitality, providing physical, economic, and social benefits. Moreover, they make a substantial contribution to environmental thermal issues, directly related to environmental comfort indices, as noted by researchers Lai et al. (2019).

However, socioeconomic disparities can profoundly affect landscapes in urban outdoor spaces. Gerrish and Watkins (2018) assessed 61 studies on the relationship between socio-spatial conditions and environmental quality, concluding that decisions regarding urban infrastructure can unevenly impact the local climate across territories, disproportionately affecting vulnerable populations.

The absence of urban outdoor areas can detrimentally affect urban quality (WOOLLEY, 2003; GARTLAND, 2009). The rapid and disorderly growth of cities, coupled with population increases, raises significant concerns about urban climate, especially in emerging countries in tropical regions like Brazil, where urbanization and population growth outpace those of developed countries (UN, 2018).

This scenario is exemplified by São José do Rio Preto in Brazil (Figure 1), a municipality located inland in São Paulo State. According to the Brazilian Institute of Geography and Statistics (IBGE) (2020), the municipality has experienced substantial growth in both population and urbanization. Currently, it boasts a population of 447,924 inhabitants and an urbanization rate of 93.9%, with an annual geometric growth rate for 2010-2020 of 0.94%.

Since the 1950s, São José do Rio Preto has undergone considerable development in trade and services, evolving into a regional economic hub (TEODOZIO, 2008). Consequently, it has become increasingly bustling and populated, giving rise to socio-spatial inequalities, which are reflected in the diversity of urban qualitative standards.

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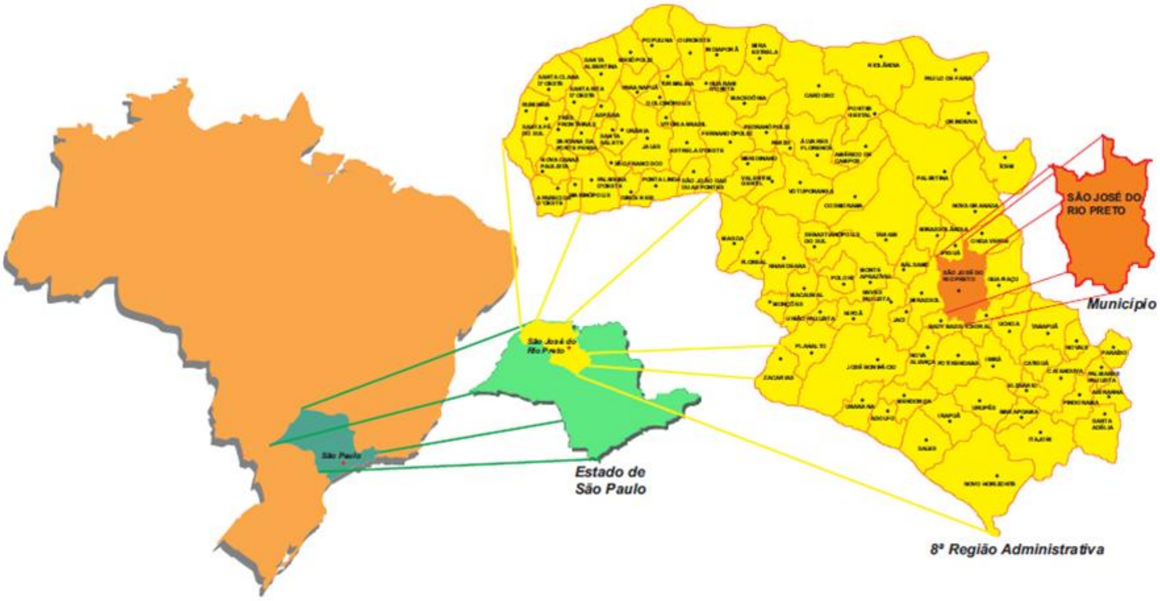
Figure 1- Location of São José do Rio Preto/SP.



Source: São José do Rio Preto economic situation, 2021.

Regarding the climate, São José do Rio Preto has a tropical climate. The summer has much more rainfall than the winter, according to the Köppen and Geiger classification, and the climate is classified as Aw. In the municipality, the average temperature is 23.4°C, and the average annual rainfall is 1465 mm. The lowest value for relative humidity was measured in August (46.33%) and the highest in March (78.98%) (CLIMATE DATA, 2022).

Although São José do Rio Preto has a high Human Development Index (HDI) of 0.797, according to the Human Development Atlas (2010), and a per capita income of R$1,169.16 (IBGE, 2010), the municipality has 0.46% of people in extreme poverty and 1.73% who are considered low income. The GINI index is 0.50, which represents a high degree of social inequality.

The current Master Plan of São José do Rio Preto (COMPLEMENTARY LAW No. 651, 2021) presents few guidelines for outdoor and conservation areas but proposes to develop an Outdoor and Conservation Area System Plan (SAV-UC in Portuguese), within 1 year of publishing the Master Plan (2021). Despite this, there is no mention of the climate issue. In general, it is extremely important that climate parameters are added to city management (Mills et al., 2010).

The lack of information on urban climate data is often a consequence of the difficulty of integration between planners and researchers (FERNANDES and MASIERO, 2019). This may be partially because of failures in translating scientific results into strategic action options and/or establishing viable implementation policies. To do this, responsible professionals such as architects, urban planners, and decision-makers should attempt this integration (DUARTE, 2015).

Parameters such as zoning, land use and occupation, direction and width of roads, height of buildings, vegetation layout, and water bodies, among others, become instruments to control urban climate change (ROSSI, 2012), and can help to create more comfortable and healthy environments.

It is therefore considered important to carry out different types of climate analysis at different points in São José do Rio Preto. Mainly because microclimatic conditions can be improved by urban design criteria and by using constructive elements and strategies (DUARTE, 2015).

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CONCEPTUAL ASPECTS

Among the thermal perception models, the most used one to evaluate the urban thermal environment is the Physiological Equivalent Temperature (PET), which is based on the thermal balance of the human body, indicating the effects of the thermal environment on parameters such as heat, cold, and comfort status. This will be the parameter used in this research.

PET uses climatic variables to estimate a person's thermal sensation. This evaluation system, which was devised by Höppe (1999), can be found in numerous studies on urban thermal comfort, such as Minella et al. (2009), Matzarakis et al. (2010), Rossi (2012), Duarte (2015), Krüger (2018), Fernandes and Masiero (2019), and Pereira et al. (2020).

The variables needed to calculate the PET index are the calculated mean radiant temperature (MRT), air temperature, wind speed, and other human variants such as the individual's age, height, weight, clothing, insulation value of clothing (CLO), and metabolism rate. According to Matzarakis (2007), the PET index can be calculated using the RayMan software.

Urban geometry also significantly impacts environmental quality (Souza et al., 2005). Urban geometry is usually quantified following parameters such as the sky view factor (SVF), height-to-width ratio (H/W), urban canyon orientation, urban fabric roughness, the relationship between permeable and impermeable areas, the proportion between built and open area, park size, and vegetation characteristics (LAI A. et al., 2017) (STEWART & OKE, 2012). In addition, the land subdivision, land regulation, occupation rate, coefficient of utilization, permeability index, minimum lot area, setbacks, definition of uses, and road infrastructure help to define the urban geometry of a location and impact the thermal quality of open spaces.

OBJECTIVE

The objective of this research is to investigate the relationship between the PET thermal comfort indices of four outside areas in the urban setting of the municipality of São José do Rio Preto, SP, considering their socioeconomic distinctions, perception and satisfaction of local visitors.

METHOD

The research was based on a selection of four representative urban clips in relation to the socioeconomic factors that formed them in areas in São José do Rio Preto/SP. That is, two in areas with a high construction standard and abundant urban infrastructure, and two in social housing areas. Thus, it was considered to investigate the relationship between thermal comfort, socioeconomic factors and the distribution of outside areas, associated with each other. To do this, the methodological steps represented in Figure 2 were established.

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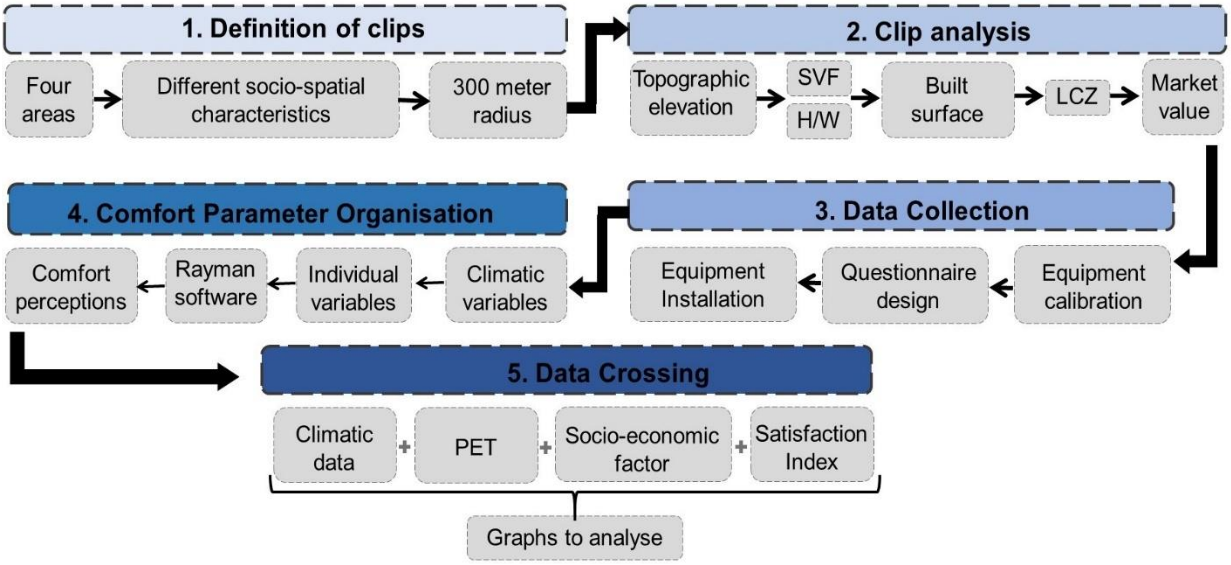
Figure 2- Research methodology.



Source: authors' own work (2022).

DEFINITION OF REPRESENTATIVE URBAN CLIPS

To delimit the clip of each study area, a 300-meter radius was standardised from the location of the air temperature measurement equipment (HOBO-U23) so that the urban fabric was representative in relation to the physical characteristics of the region to be analysed. The distance used followed the location and exposure parameters of meteorological instruments in urban areas defined by Oke (2007).

A common feature at the four points is that the main outdoor areas in the selected locations have retention basins with arboreal and undergrowth vegetation, hiking trails and leisure and sports facilities. To better illustrate this, the location of the clips was listed and initially presented below (Figure 3) with the sectorisation.

In the map, the proximity of each point to the central area can be observed, where the local council building is located, the commercial and densest area of the city (circled in green) and the area of the Municipal Reservoir park (outlined in green).

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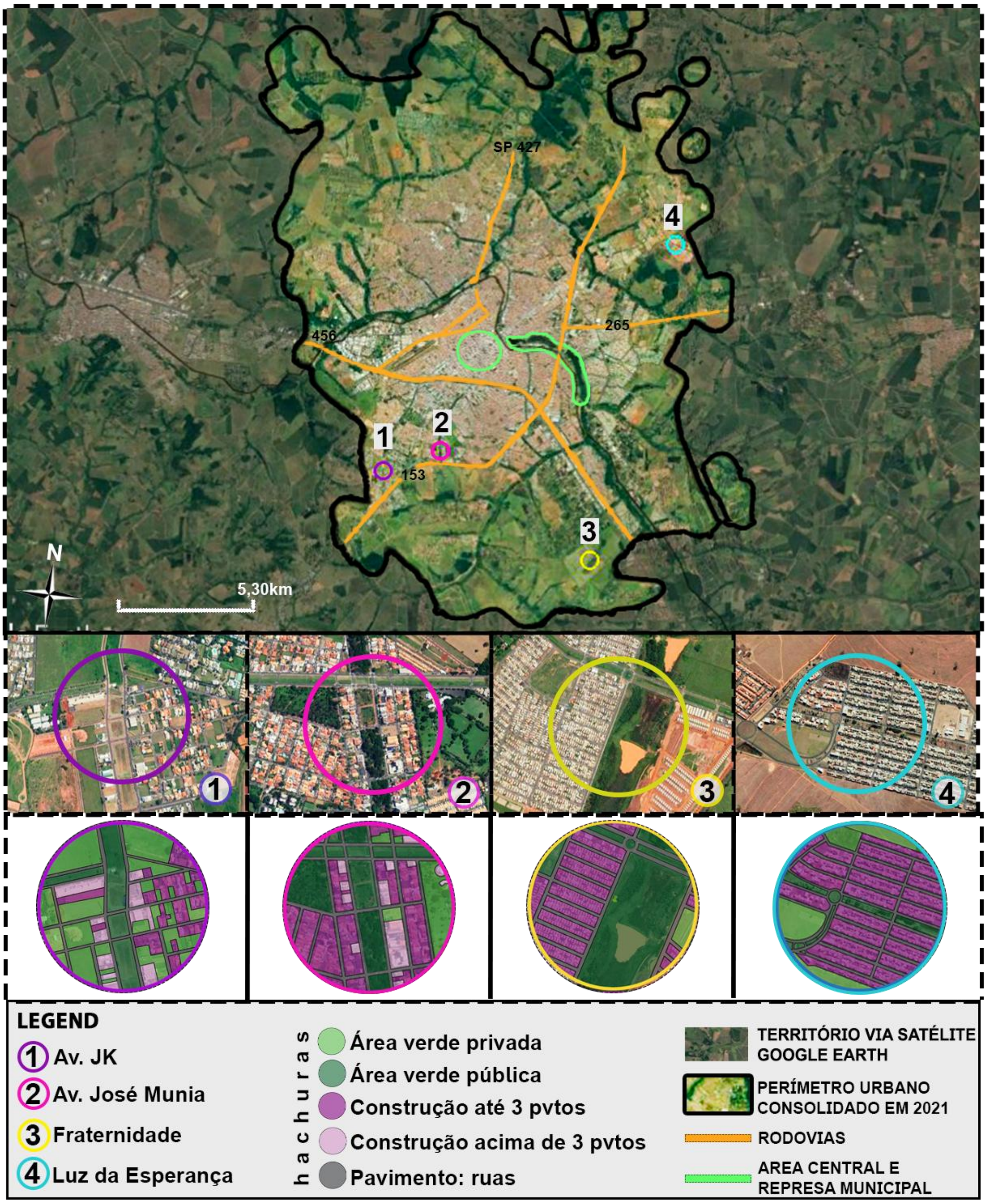
Figure 3- Location of selected clips in São José do Rio Preto and sectorisation.



Source: Google Earth (2021), adapted by the author.

PHYSICAL CHARACTERISATION AND CLIMATIC AND SOCIO-SPATIAL ANALYSIS OF SELECTED AREAS

Areas 1 and 2 are characterised by predominantly mixed-use buildings of high construction standards and urban design with abundant infrastructure, while areas 3 and 4 are characterised by

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social housing, predominantly residential use and availability conditions of green and blue infrastructure lower than areas 1 and 2.

Each clip underwent an individual morphological analysis, considering data related to the master plan, the zoning law, land use and occupation and a social analysis according to the most recent Municipal Generic Value plan (PGV, 2021) and market surveys with the real estate agents that operate in the city. In addition, the areas were also classified according to the LCZ (Local Climate Zone) system through the concept created by Stewart and Oke (2012) and a local analysis.

Table 1 describes the reference locations, the topographic elevation obtained using the Google Earth software, the height-to-width ratio (H/W) of the urban canyon, the built surface calculated from the satellite image contour in the AutoCad software ®, the average height of roughness observed at the site and its LCZ classification including a brief description with a photo and aerial view of each site.

The sky view factor (SVF) of each location was also analysed. To obtain this index, as did Labaki et al. (2012) in their research, a hemispherical photo was taken at each selected location with a Nikon camera with fisheye lenses (FishEye). The images were processed in the RayMan 1.2 software developed by the Meteorological Institute of Freiburg (MATZARAKIS et al., 2007) and the final SVF value was obtained.

Finally, the socio-spatial characterisation of the areas was also carried out based on the São José do Rio Preto Generic Value Plan (2021), which provides the market value of the square meter built for each region and a survey of commercial values in real estate agencies from the city.

For the socio-spatial characterisation and the average values of the properties in the four urban areas, a finished standard house with two bedrooms and a bathroom was considered and the data collected were: for the Moyses Miguel Haddad neighbourhood (1-LCZ 5) the standard increases in at least 3 bedrooms and 3 bathrooms, where the average value is R$800,000.00; for the Jardim Redentor neighborhood (2-LCZ 2/3A), the standard is apartments where the average price is R$300,000.00; in Residencial da Fraternidade (3-LCZ 3BA) the average value of a standard house found was R$190,000.00 and finally in residential Luz da Esperança (4-LCZ 3B), the average value found for a finished standard house was R$200,000,00.

Analysing these data, we were able to economically identify and differentiate the four points, where two of them are located in privileged areas (1-LCZ 5 and 2-LCZ 2/3A) and two of them in more remote areas and of social interest (3 -LCZ 3BA and 4-LCZ 3B), for which, respectively, the most valued and least commercially valued areas are analysed below.

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Table 1- Classification and definition of the four selected clips.

	Location	Topographic elevation	H/W	Built Area	Average Height of Roughness	LCZ	Description	Classification	Photo	Aerial View	SVF – FishEye Camera	SVF – nº	Market Value per m² built (R$)	Socio-economic situation
1	Avenida JK	559	1,36	39,05%	12	LCZ 5	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	Open midrise				0.665	549,45	High standard
2	Avenida José Munia	557	1,34	61,47%	10-12	LCZ 2/3 A	Dense mixture of medium-sized and tall buildings. Mainly paved land cover. Concrete, steel, stone, and glass building materials. It has a densely wooded urban park of deciduous and/or evergreen trees, whose cover is mainly permeable.	Compact low and mindrise with dense trees				0.565	549,45	High standard
3	Fraternidade	540	0,59	50,21%	3-5	LCZ 3BA	Dense mix of low-rise buildings (1-3 floors). Lightly wooded landscape of deciduous and evergreen trees. Land cover mainly paved with trees or urban park. Stone, brick, tile and concrete building materials.	Compact low-rise with scattered trees				0.784	208,3	Low/Medium Standard
4	Luz da Esperança	556	0,57	77,21%	3-5	LCZ 3B	Dense mix of low-rise buildings (1-3 floors). Lightly wooded landscape of deciduous and evergreen trees. Land cover mainly paved with trees or urban park. Stone, brick, tile and concrete building materials.	Compact low-rise with scattered trees				0.806	208,3	Low/Medium Standard
Referências: Google Earth; Google Maps; Software RayMan; Stweart and Oke, 2012; Prefeitura de São José do Rio Preto; dados organizados pela autora (2022).														

Source: Stewart and Oke (2012); own photos, created and adapted by the author.

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LCZ 5:

The first area analysed is located in the southeast region, in the Miguel Moisés Haddad neighbourhood, in an exclusively residential area (zone 01) surrounded by high-end horizontal residential condominiums according to the São José do Rio Preto Zoning Map (2021). The occupancy rate is 60%, the coefficient of utilization 1 and the minimum lot area is 450 m².

Despite the fact that there are pavements for pedestrians, a cycle path and extensive outdoor areas along the sub-basin of the Borá stream, the clip in question still presents a structure that is sparsely and recently wooded with occasional and sparse shade along its route. Having said that, it is a meeting point and/or passage, not only for the residents of the region, but for many other inhabitants, whether for work or leisure.

It can be observed that local council staff often maintain the outdoor areas by pruning and cleaning the place. The clip in question, from Avenida JK, will be identified in this work as number 1, as well as its classification LCZ 5 and shown in purple in the graphs and captions.

LCZ 2/3 A:

According to the São José do Rio Preto Zoning Map (2021), the second clip that was selected is located between zones 1, 2 and 10, in the southeast region, where some of the rainwater retention basins of the Canela stream can be found.

Zones 1 and 2 have an occupancy rate (OR) of 60%, coefficient of utilization (CU) 1 and a minimum lot area between 360 and 450 m² (Zoning Law No. 13,709, 2021)

It is largely wooded, it has pavements, a cycle path and urban parks between the structures. Therefore, similar to the first clip, it is also considered a privileged area, due to maintenance. The region consists of residences, clinics, gated communities and businesses.

Due to the fact that the region is formed by buildings with diverse geometry, the classification by Stewart and Oke (2012) was assigned based on the combination of the LCZ 2 + LCZ 3+ LCZ A characteristics. The urban linear park is extremely wooded and the SVF obtained was the smallest of all the analysed points, with a value of 0.565.

Regarding the caption, the clip in question, from Avenida JM, will be identified in this work as number 2, classification LCZ 2/3A and shown in pink.

LCZ 3BA:

The third location that was analysed is in Residencial da Fraternidade (popular allotment). It is classified as an area for social interest, which is located far from the centre, close to the Engenheiro Schmitt district in the period from 2015 to 2019 and having poor infrastructure.

According to the São José do Rio Preto Zoning Map (2021), the site is divided into Mixed Use of Baixa (zone 03) and Medium Density (zone 04), and on the map the main avenue of the neighbourhood is not classified as a valley floor or an area of special environmental interest, however it is located close to a rainwater retention basin in the central median of an avenue.

Zones 3 and 4 have an occupancy rate (OR) of 60% and coefficient of utilization (CU) 2 and a minimum lot area of 200 m² (Zoning Law No. 13,709, 2021).

The site does not have many trees and landscape for leisure and contemplation. Some urban facilities are precarious, such as public transport stops, health centres, schools and shops.

The rainwater retention basin areas are in the central reservations of the avenue, they have little afforestation, precarious maintenance and restricted access at some points. This clip is characterised by combining classifications (STEWART & OKE, 2012) in LCZ 3 + LCZ B + LCZ A, as it is considered a very compact area and densely populated by buildings of up to 3 floors, mostly

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on the ground floor, where afforestation appears more dispersed together with the central green area, which presents a more concentrated afforestation. The SVF obtained was 0.784, the second highest value analysed when compared to other locations.

Concerning the caption, the clip in question, from Residencial da Fraternidade, will be identified in this work by the number 3 and its classification LCZ 3BA and always shown in yellow.

LCZ 3B:

The fourth section is located in the Luz da Esperança Housing Complex (HIS subdivision), on the east side of the city, in a peripheral expansion area, therefore further from the urban centre.

In the clip, the dense mix of midrise buildings predominates, but it also presents sections of low density and predominantly commercial areas.

The occupancy rate (OR) for zones 2, 3 and 4 is 60%, the coefficient of utilization (CU) is 2 and the minimum lot area is 200 m². Zone 06 has an occupancy rate (OR) of 66% and coefficient of utilization (CU) 4 and a minimum lot area of 360 m² (Zoning Law No. 13,709, 2021).

For the analysis, the open area close to an Alto Rio Preto retention basin was also selected. The site does not have many trees, and the outdoor areas are restricted to public access. Maintenance is practically non-existent, and the soil mostly remains exposed, which causes a great deal of erosion. In addition, it has pavements around it that are commonly used for walking and paths without adequate infrastructure.

The landscape in Section 4 is similar to Section 3 (LCZ 3B), without exploring landscape and environmental use for popular leisure. Some local residents have entered the closed areas and are trying to enhance the quality by randomly planting different species and creating vegetable gardens at the site. However, waste can be observed in certain places, which shows the local population’s lack of sense of belonging and care with these outdoor areas.

This clip is characterised by combining classifications (STEWART & OKE, 2012) in LCZ 3 + LCZ B, with mostly single-story residences and few buildings of up to 3 floors. Afforestation appears as being dispersed and spread along the length. The SVF obtained was 0.806, the highest value among the analysed clips.

The Luz da Esperança Housing Complex legend is identified in this work by the number 4, and its LCZ 3B classification and is always shown in blue.

MICROCLIMATIC DATA COLLECTION AND USER SATISFACTION AND THERMAL PERCEPTION REPORTS

Each site was analyzed considering different climatic parameters depending on the morphological characteristics and urban context. Thus, we aimed to evaluate various samples in relation to socioeconomic factors and similarities regarding urban outdoor areas. To achieve this, campaigns were developed to measure air temperature, humidity, wind speed and direction. Additionally, questionnaires were distributed to users of each urban area to assess their perception and satisfaction with the thermal environment.

Safety factors and social distancing precautions due to COVID-19 were considered, given that the selected areas for analysis are open outdoor spaces. Micro meteorological data collection took place on 4 non-consecutive days: 23/11/2021 (Tuesday), 01/12/2021 (Wednesday), 21/12/2021 (Tuesday), and 22/12/2021 (Wednesday). To ensure comparability,

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climatic similarity between the analysis days was considered, such as a stable atmosphere, clear sky, and light winds, following Oke's (1982) recommendations.

Times with higher foot traffic were selected for analysis, allowing for two time points to be examined each day: morning (7 am to 8 am) and late afternoon (5 pm to 6 pm).

For data collection, HOBO Pro V2 U23-001 thermo-hygrometers were installed at a height above 1.50 m, following Oke's guidelines (2007), as depicted in Figure 4. The equipment was placed in shaded areas to minimize interference from longwave radiation in measurements, aligning with methodologies used by Labaki (2012) and Ribeiro (2019) in their analyses.

The HOBO thermohygrometer setup is illustrated in Figure 5, with item A representing the measurement sensor, item B indicating the protective film, item C as the meteorological shelter housing the sensor to shield it from direct sunlight, and item D being the USB connector linking the sensor to a computer. Data stored in the capture device were extracted using HOBOware Software, allowing for visualization through graphs or extraction into tables. In this study, data were transferred to Excel Software for further analysis and graph generation.

The sensors were programmed to start measuring at 7 am daily, recording temperature and relative humidity every 10 minutes until 8 am. Subsequently, data were collected, and the sensor was reprogrammed to start a new measurement at 5 pm, continuing every 10 minutes until 6 pm. This process was repeated for each day at each selected location.

Simultaneously, questionnaires were distributed to passersby, randomly chosen according to ISO 10551 (INTERNATIONAL STANDARD, 1995). Data collected included sex, age, weight, height, clothing, duration of residence in São José do Rio Preto, activity, time of outdoor exposure, as well as perceptions using the Sensation Real Vote (SRV) scale and thermal comfort satisfaction.

Despite the randomness in participant selection, only data from residents who had lived in São José do Rio Preto for at least 2 years and were accustomed to visiting the analyzed spaces were considered. Additionally, acclimatization was taken into account in the data analysis.

Regarding the Sky View Factor (SVF), a five-point scale was initially used as suggested by Labaki et al. (2012), ranging from -2 to 2 (very cold, cold, neither hot nor cold, hot, and very hot). However, after a test data collection in 2020, adjustments were made to include more commonly used terms and reduce the scale for "cold," which was not evident. Finally, a scale of -2 to 2 was employed: cold, cool, warm, hot, and very hot.

Questionnaires were distributed in pairs, with one person recording participant data while the other used the Digital Instrutherm TAVR - 650 anemometer and the Kimo VT200 globe thermometer. These instruments respectively measured wind speed and global temperature during questionnaire administration (LABAKI, 2012) (Figure 6).

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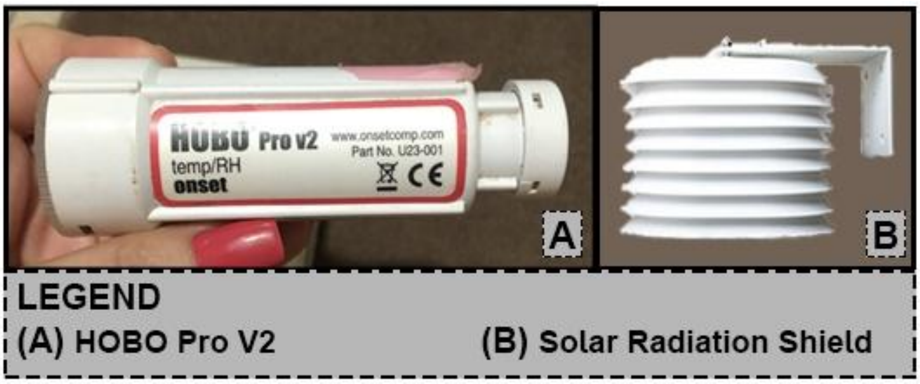
Figure 4- Positioning of the measurement equipment in the field.

Source: author

Figure 5- HOBO thermohygrometer measurement equipment used.



Source: author

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Figure 6- Measuring equipment used in the field.

Source: author.

Although some people did not answer the questionnaire, and some visitors to the region did not consider it, some places had more people that responded to the questionnaires than others, mainly point 2-LCZ 2/3 (JM). To resolve the issue of statistical bias, the smallest number of people found was considered (24 people in the 4-LCZ 3B clip) and 24 questionnaires were randomly selected from the other locations. Thus, resulting in 96 questionnaires, that is, 24 for each collection point.

PET INDEX CALCULATION, SELECTION AND ORGANISATION OF HUMAN THERMAL COMFORT PARAMETERS

The data collected by the equipment and from distributing the questionnaires were separated and characterised using the EXCEL® software, thus the other indices such as the Mean Radiant Temperature (MRT) and the Physiological Equivalent Temperature (PET) could be calculated.

The MRT was calculated from the globe temperature, collected in the field at the same time as the questionnaire was distributed, using a globe thermometer as previously described. The equation for forced convection was adopted, according to ISO 7726/1988, Equation 1.

$$tr = \left[\left(t_g + 273\right)^4 + \frac{1{,}1.10^8 . v_a^{0{,}6}}{E_g . D^{0{,}4}} . \left|t_g - t_a\right| \quad ^{1/4} . \left(t_g - t_a\right) \right]^{1/4} - 273 \quad \text{Equation 1}$$

Where:
“tg” = globe temperature,
“eg” = globe emissivity
“ta” = air temperature.

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In the RayMan software, to generate the PET index, the metabolic rate was set at 165 W/m² according to the summary table by Lamberts (2011, p.26) in accordance with ISO 7730/2005. The clothing coefficient was also fixed, because as these are outdoor areas integrated with leisure, most passers-by wore light clothes and sports shoes. Therefore, the value clo=0.5 was also used according to the table by Lamberts (2011, p.27).

In addition, for each location, the date was added in the software according to the data collection and the topographic elevation obtained by Google Earth. These data were also fixed according to each point. The other parameters added in the software were all modified and added manually according to each questionnaire that was distributed.

As an analysis parameter for the thermal perception and satisfaction data, the values according to the index indicated by Monteiro & Alucci (2010) were used, however they were calibrated for the city of São Paulo as no calibration data were found for the state of São Paulo (inland), or close to the region of the Municipality of São José do Rio Preto. The data served as a comparative basis for the data collected in the questionnaire to be crossed with the PET data and it was observed whether they are in accordance with the perception and satisfaction reported by the people in the field.

RESULTS ANALYSIS

The results analysis is mainly based on establishing relationships between the physical parameters of the four urban configurations, translated into LCZs, and their implications on the sensation and perception of urban thermal comfort.

RELATIONSHIPS BETWEEN PET, WIND AND LCZ

Using the PET data, the next step was to compare them for each selected location, therefore boxplot graphs were used to analyse them by period, Figure 7 and Figure 8. The morning period is shown in green and the end of the afternoon in orange. The clips are represented by numbers, respective colours and their LCZ classification.

For the morning period (Figure 7), when comparing the data by location, it can be seen that point 4 (LCZ 3B) differs from the others by presenting 75% of the PET data in this period below 32ºC, while the others present their data in 75% above 30ºC. In addition, the median for this point is around 27ºC, while for 1 (LCZ 5) it is 31ºC, for 2 (LCZ 2/3A) it is 32ºC and for 3 (LCZ 3BA) it is 34ºC.

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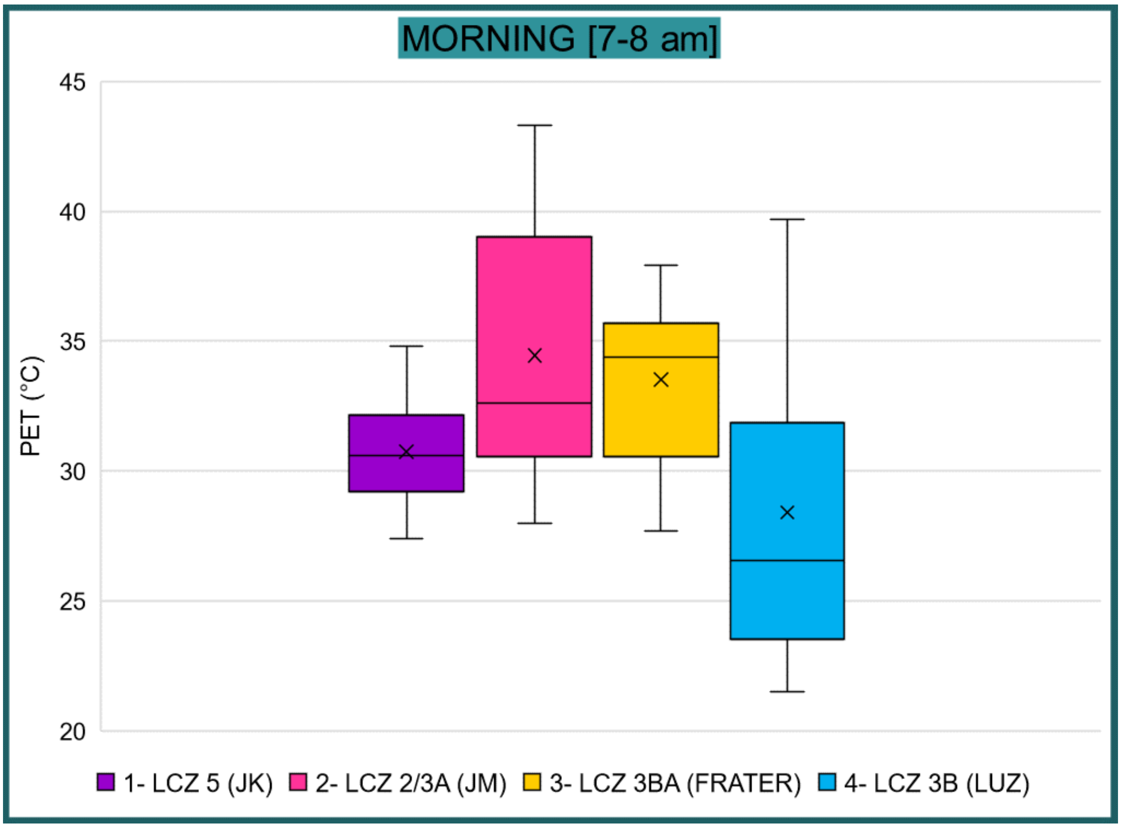
Figure 7-PET x LCZ x Morning Period Graph.



Source: author

Despite this, at site 4-LCZ 3B, the maximum is 39ºC, surpassing the maximum values presented at points 1-LCZ 5 and 3-LCZ 3BA, which are 35ºC and 37ºC, respectively. It is important to highlight that the 2-LCZ 2/3A cli presents approximately 50% of the data varying above 32ºC with the maximum reaching 44ºC. Therefore, it can be stated that other factors may stand out in relation to socioeconomic issues in the analysed climate scenarios as this clip is one of those considered of high standard.

In the afternoon, in Figure 7, the clips 2-LCZ 2/3A (pink) and 4-LCZ 3B (blue) are practically equivalent with a minimum of 31ºC in the boxplot, a median of 35ºC and a maximum of 42ºC. They differ when analysing the graph's quartiles, where 75% of the data for LCZ 2/3A is above 32ºC, while for LCZ 3B, 75% is above 34ºC, thus proving to be the worst scenario analysed.

In the graph in Figure 21 (in purple) for this afternoon period, site 1-LCZ 5 shows greater variability in scale for the PET index, as it has a minimum considerably lower than the others at 26ºC and a maximum reaching approximately 42ºC.

On the other hand, the 3-LCZ 3BA site presents the lowest maximum among the scenarios with an index of 33ºC (disregarding the outlier). The minimum for this point is 27ºC and the median 28ºC, for this scenario, 75% of the indices are below 30ºC. Therefore, it presents the lowest thermal variability throughout the analysed time.

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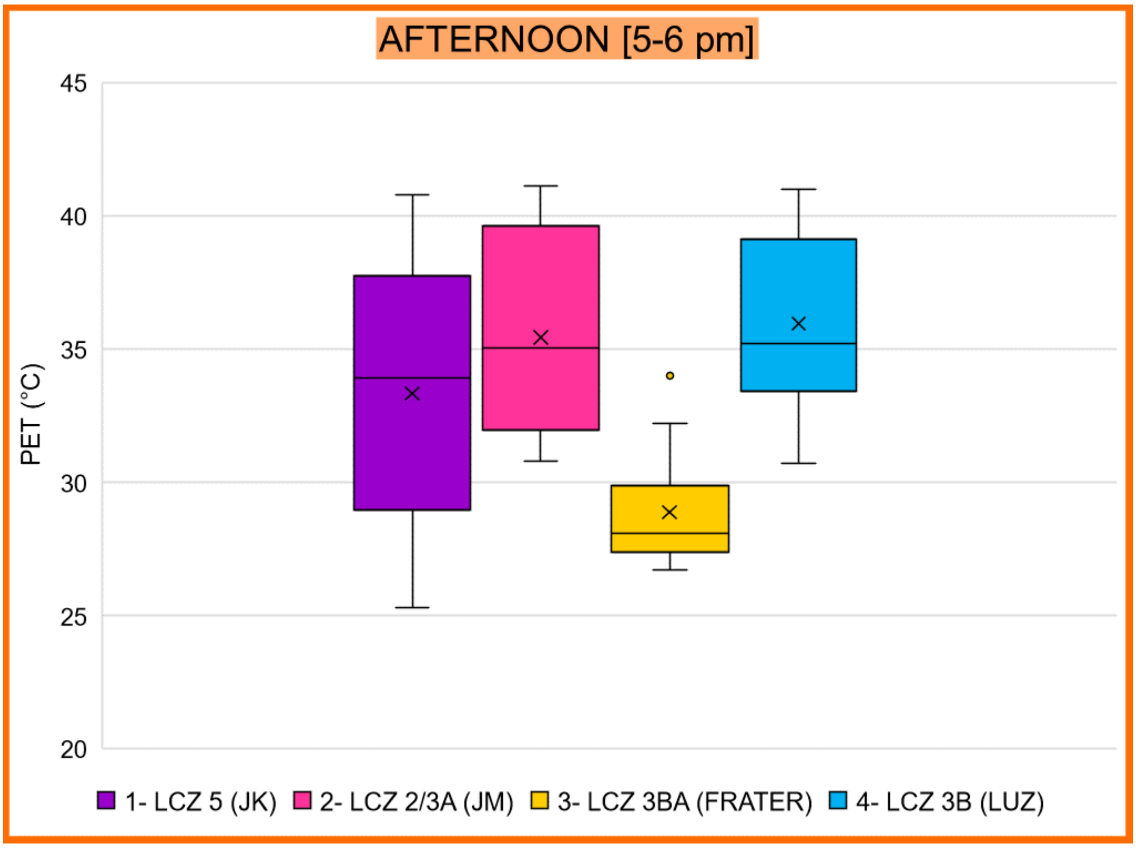
In the afternoon, the LCZ3BA area has the lowest PET indices. Despite being considered a low-income area with poorly developed infrastructure, this is fundamentally due to the action of more intense winds in this region of the city.

Figure 8-PET x LCZ x Afternoon Period Graph



Source: author

Figures 9 and 10 show the relationships between PET, LCZ and wind action. It can be observed that as the wind action increases, the PET values tend to decrease. Therefore, in this scenario, there is a lack of wind at point 4-LCZ 3B, and a slight drop in the PET index.

It should be noted that although LCZ 3BA and LCZ 3B are areas of social interest considered of low/medium construction standard, they are subject to wind action because they have few obstacles, as they are areas with social interest housing with single-story residences isolated in the lots and predominantly grassy and low vegetation.

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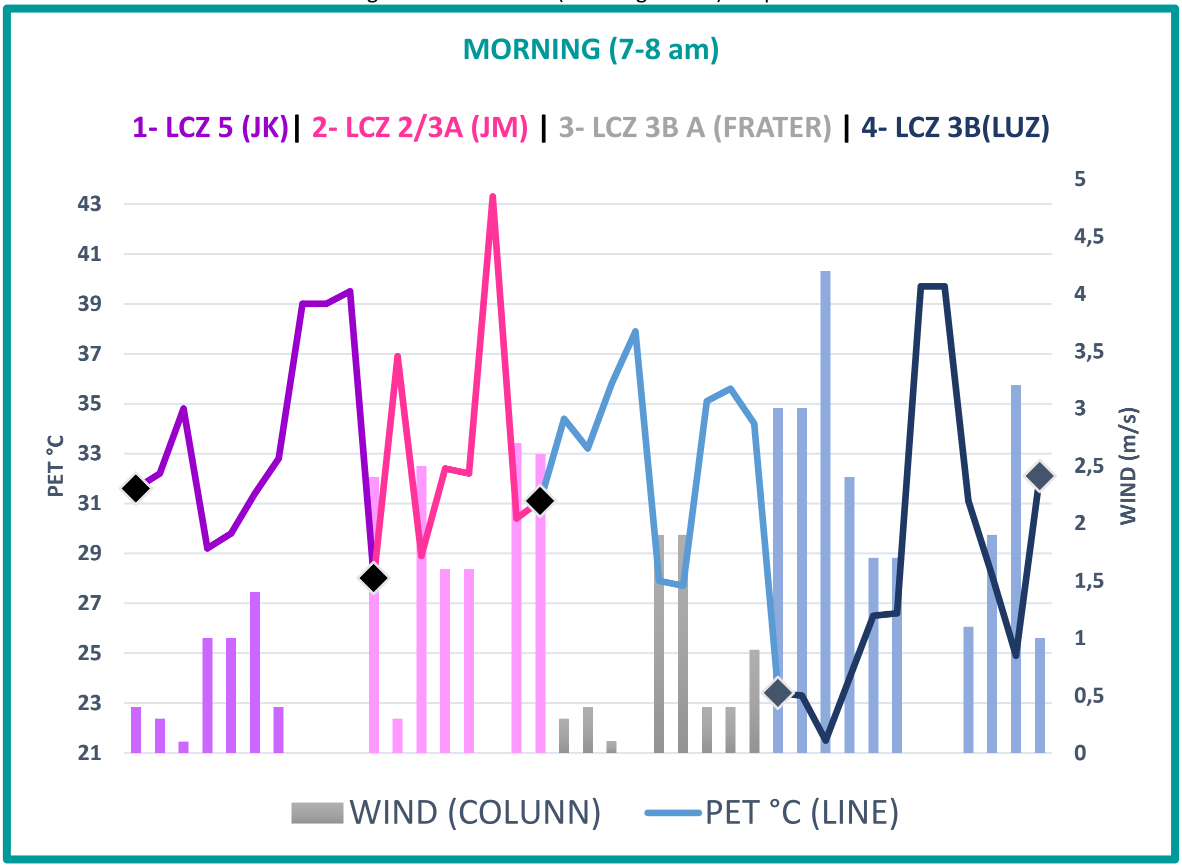
Figure 9-PET x WIND (Morning Period) Graph



Source: author

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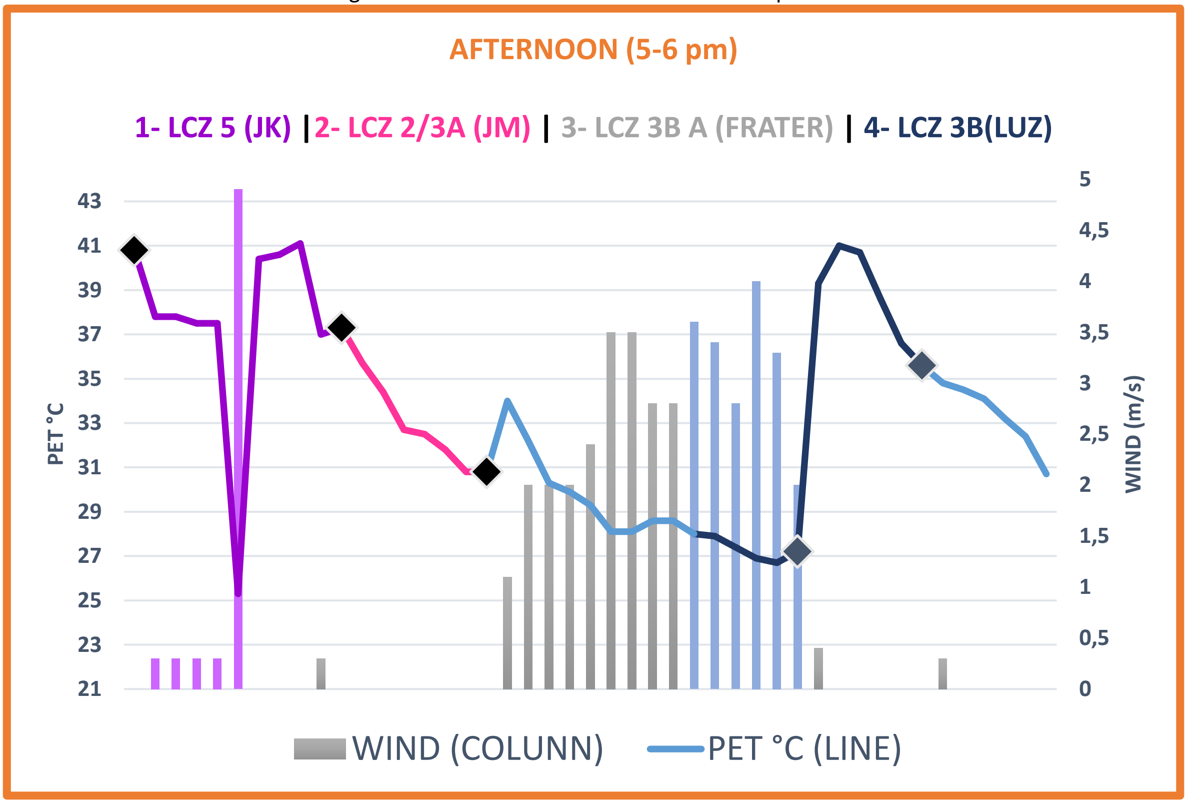
Figure 10-PET x WIND x Afternoon Period Graph.



Source: author

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Areas 1-LCZ 5 and 2-LCZ 2/3A also show the same trend in terms of wind. However, due to the fact that these are more densely populated areas, winds have less influence on PET indices than in residential areas of social interest.

For the afternoon period, the graph shown in Figure 10 strongly maintains this variation in relation to PET x Wind, as well as in the other scenarios. In the graph, for point 1-LCZ 5, there is a moment, close to 6 pm, when the wind reaches 4.9 m/s and, together with this, a sharp drop in the temperature of the PET index is observed in the place. As for site 2-LCZ 2/3A, the temperature gradually decreases, and less abruptly than at point 1, however the presence of wind is almost constant during this period.

Thus, the socioeconomic factor alone is not as preponderant as the wind and SVF. Although the cleaning and maintenance of these outdoor areas also influence the perception and sensation of thermal comfort, as analysed by Menegaldo, Parra and Masiero (2021), the wind and SVF are decisive.

These results are similar to those of Cheng et al. (2012), who, in their research for Hong Kong, obtain the results that the change in wind speed and the solar radiation conditions significantly influence the thermal sensation, especially in the summer.

THERMAL PERCEPTION AND SATISFACTION

The results for the SVF, on the five-point scale used (cold, cool, warm, hot and very hot), were presented in comparative bar graphs. Each clip is represented by its respective colour, where the lighter colour represents the morning period and the darker colour represents the afternoon period, Figures 11, 12, 13 and 14.

No location that was analysed used the first point of the SVF scale; "cold".

In area 1-LCZ 5, Figure 11, it can be observed that most of the questionnaires point to the “hot” thermal sensation, mainly in the morning, despite this clip showing less variability and the lowest maximum among all the points.

In area 1-LCZ, the perceptions "hot" and "very hot" predominate during the two periods. The manifestations of satisfaction vary in a reasonably balanced way between satisfied, dissatisfied and indifferent.

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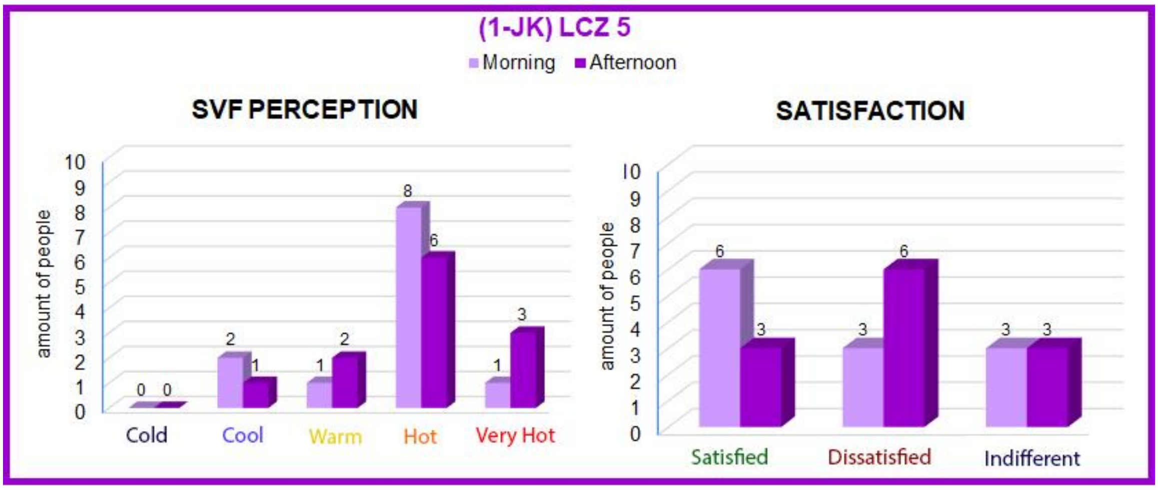
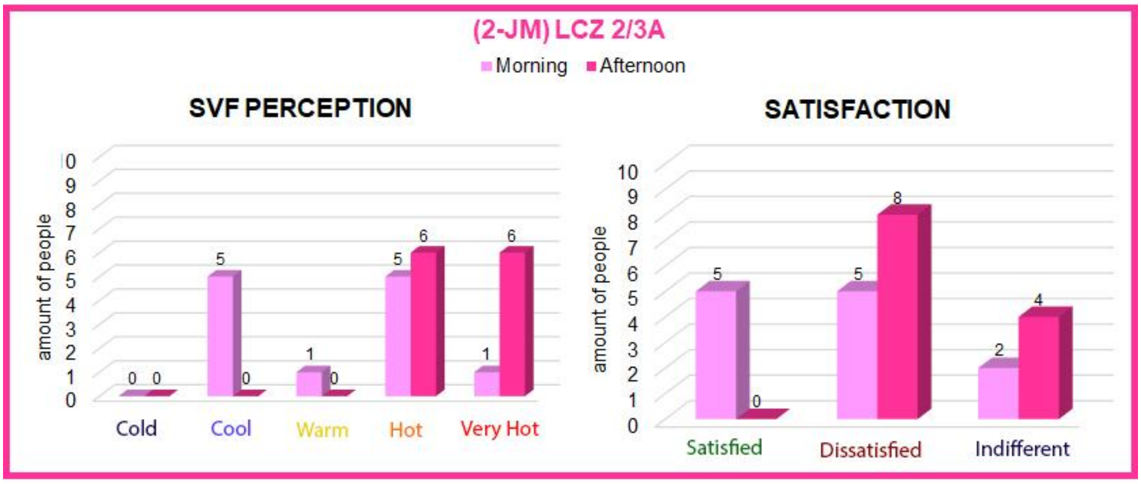
Figure 11- ASV Perception and Satisfaction for 1-LCZ5.



Source: author

The SVF for site 2-LCZ 2/3A, in the morning, presents the same number of people, classifying "cool" and "hot", as well as "satisfied" and "dissatisfied". Although this area presented high PET indexes, many said they were "satisfied" during the morning period.

Figure 12- ASV perception for 2-LCZ 2/3A.



Source: author

Despite Figure 13 recording a high perception of "hot" during the two periods, most people said they were satisfied during the afternoon. It is important to point out that the wind had a strong influence on the PET indices in this area.

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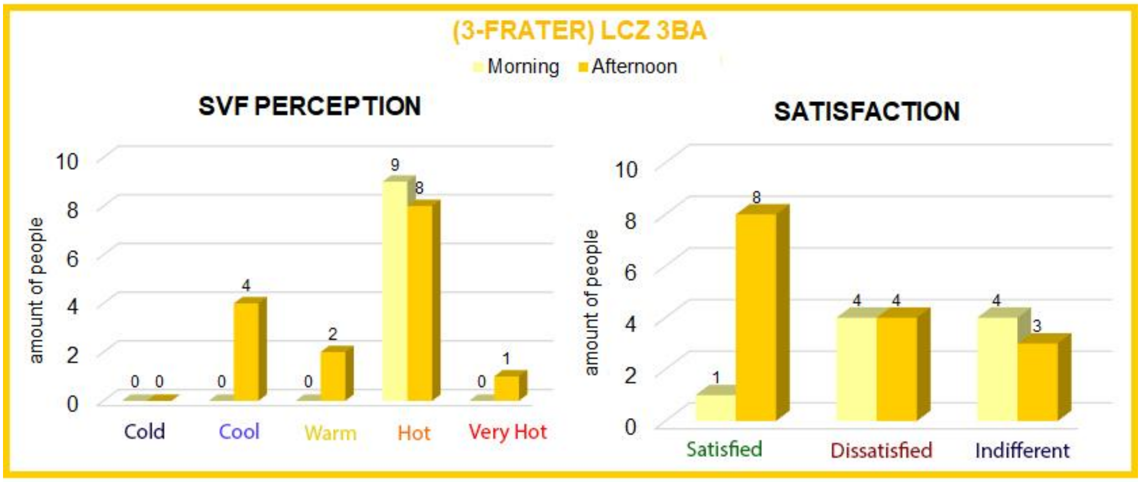
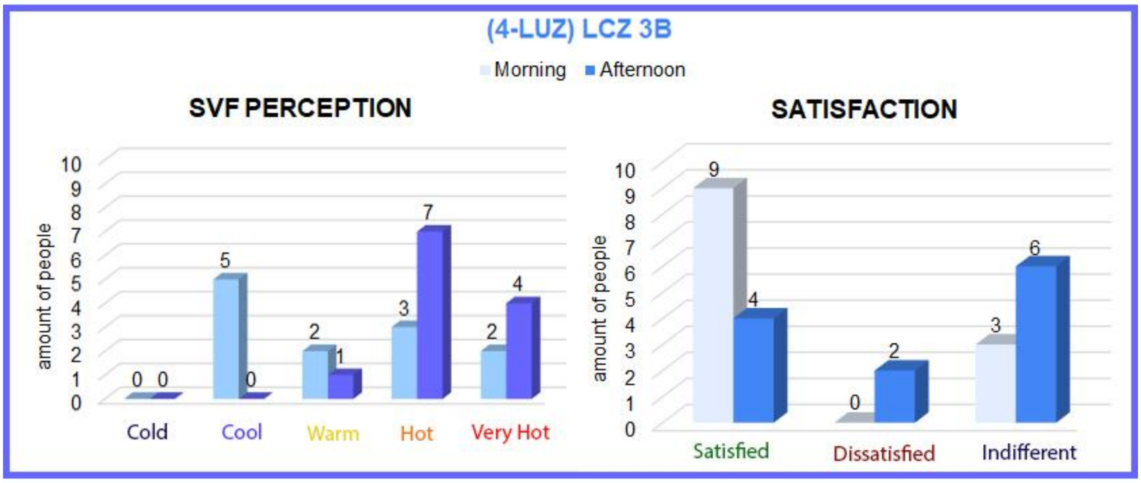
Figure 13- ASV perception for 3-LCZ 3BA.



Source: author

In area 4-LCZ 3B, most people said the environment was “fresh” and they were satisfied during the morning, Figure 14. It is important to highlight that this area was also strongly influenced by the wind.

Figure 14- SVF Perception for 4-LCZ 3B.



Source: author

To conclude the analysis regarding thermal perception, the graphs were compared to verify possible similarities in the results presented by Monteiro and Alucci (2010). The variation collected, for both periods, was between 22ºC and 43ºC. In this case, the thermal perception would be between “neutral”, “little heat” and “heat”. Although the applied PET calibration was for the city of São Paulo, the results are consistent with those of Monteiro and Alucci (2010). Even so, it is worth reinforcing the importance of calibrating the PET index for the city of São José do Rio Preto and other regions in the state of São Paulo (inland).

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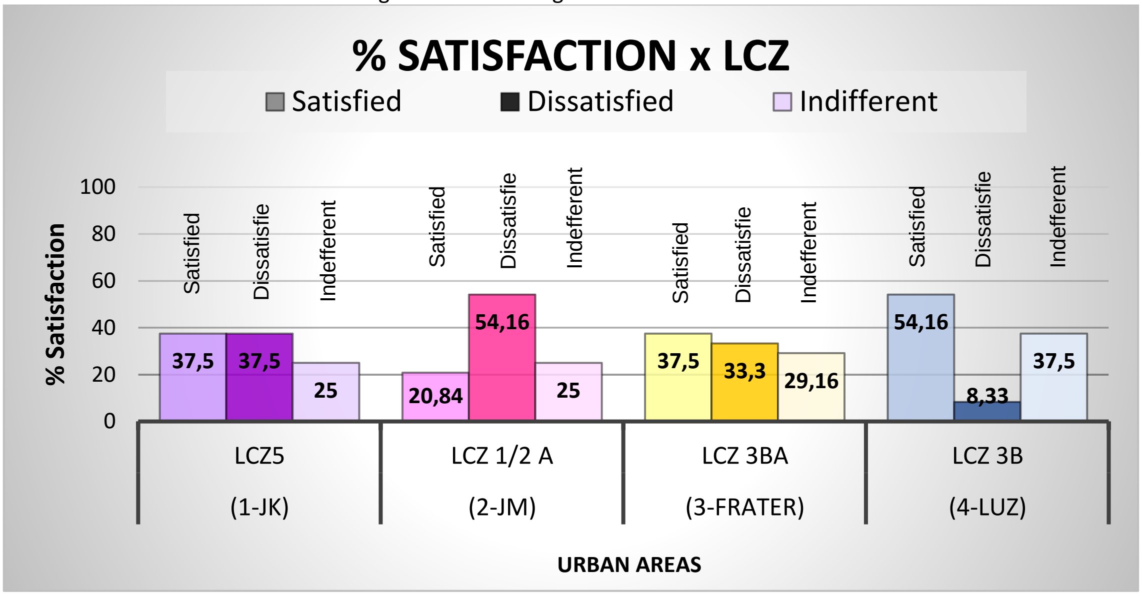
Figure 15 summarises the percentages of people's satisfaction according to the characteristics of each LCZ.

Figure 15- Percentage of satisfaction x LCZ.



Source: author

It is possible to observe a certain similarity between 1-LCZ 5 and 3-LCZ 3BA regarding the satisfied provided, since the variations for the three presented scale points, “satisfied”, “dissatisfied” and “indifferent”, are well balanced and both 37.5% of people are satisfied.

A certain similarity can be observed between clips 1-LCZ 5 and 3-LCZ 3BA regarding the satisfaction parameter as the variations for the three presented scale points, “satisfied”, “dissatisfied” and “indifferent”, are well balanced and 37.5% of people are satisfied.

Another important result in Figure 15 is the contrast between clips 2-LCZ 2/3A and 4-LCZ 3B in terms of “satisfied” and “dissatisfied”. In the boxplot PET comparison graph shown, these clips are practically equivalent in the afternoon and show the two highest peaks in the morning. Despite this, while the 2-LCZ 2/3A has 20.84% satisfied people, clip 4-LCZ 3B presents more than half of satisfaction, with 54.16%. Concerning “dissatisfied”, the 2-LCZ 2/3 A presents 54.16% and 4-LCZ 3B has only 8.33%.

Location 4-LCZ 3B also differs from the others when analysing the Satisfaction x PET graphs, for which in the three other points of analysis, satisfaction is indicated in the lowest PET temperatures and with little variability, while in this location, satisfaction is very variable, exceeding the maximum temperature in the boxplot for PET regarding dissatisfaction for the location.

This can happen even if PET indices are considered unfavourable in the region, as satisfaction levels are seen as personal and subjective.

In addition, when distributing the questionnaires at site 4-LCZ 3B located in the social interest subdivision called Luz da Esperança, two main perceptions were observed in people regarding the location: a certain scepticism regarding the real possibility of improvement and

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the refusal to “complain” about something that was achieved with so much difficulty. At times, the answers were simply “I can't complain”, so the options within the scale were repeated to reach the best answer.

Situations such as this are also reported in the research by Nikolopoua and Steemersb (2003), who analysed the forms of control perceived in the environment and the satisfaction related to the reason for being there. The researchers show how easy it is to feel uncomfortable when the reason for being there is to wait for something or someone, for example. Moreover, when people are aware of their choice to expose themselves to a certain location, they become more tolerant of the thermal environment.

These situations may demonstrate that subjective issues should also be the object of further studies on urban environmental comfort. Table 2 presents a summary of the parameters evaluated in the field, the physical characteristics of each environment, PET indices, satisfaction, perception and market value of each area.

It can be stated that the area classified as LCZ 2/3A is the one with the highest PET rates and lowest satisfaction rates with the thermal environment. It is the only clip in which most users expressed a “very hot” perception during the afternoon. It is important to point out that although LCZ 2/3A has abundant outdoor areas, a high standard of construction, careful and periodic maintenance of the leisure infrastructure, is the one with the lowest SVF (0.56), which, according to Souza et al (2007), may indicate possibilities of the occurrence of Urban Heat Islands.

On the other hand, the area classified as LCZ 3B has the highest SVF among the four areas, and consequently, it is more subject to the occurrence of winds, which favours the reduction of PET. Therefore, it has the highest user satisfaction rates with the thermal environment (54.16%), despite having the lowest quality of urban infrastructure for the leisure and maintenance of outdoor areas.

According to Pereira et al. (2021), the peripheral areas of most Brazilian cities lack adequate housing and leisure spaces. In general, there are few green spaces that ensure abundant shading. Therefore, these are areas that often expose vulnerable populations to high heat loads through ineffective urban planning processes that affect the health and comfort of residents of these areas.

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Table 2- Summary table of resulting parameters.

LOCATION		1- LCZ 5 (JK)			2- LCZ 2/3A (JM)			3- LCZ 3BA (FRATER)		4- LCZ 3B (LUZ)		
ZONING		Zone 01	Zone 10	Zone 12	Zone 01	Zone 02	Zone 10	Zone 03	Zone 04	Zone 03	Zone 04	Zone 06
OR		60%	60% - 50%	A critério GRAPOURB	60%	60%	60% - 50%	60%	60% - 50%	60%	60% - 50%	66% - 50%
UC		1	1-2		1	1	1-2	2	2-4	2	2-4	4
Minimum Lot Area		450 m^2	360 m^2		450 m^2	360 m^2	360 m^2	200 m^2	200 m^2	200 m^2	200 m^2	360 m^2
Market value built up		549,45			549,45			208,3		208,3		
Access to maintenance of outdoor areas		Protection in cycle areas, adequate cleaning and integrated to leisure.			Protection around, adequate cleaning and integrated to leisure.			Fencing, cleaning and average maintenance and not integrated into leisure.		Fencing, inadequate cleaning and maintenance and not integrated into leisure.		
SVF		0,665			0.565			0.784		0.806		
PET variation	Morning	27°C a 35°C			28°C a 43°C			28°C a 38°C		22°C a 40°C		
	Afternoon	25°C a 41°C			31°C a 42°C			27°C a 32°C		31°C a 42°C		
Perception most	Morning	Hot			Cool/Hot			Hot		Cool		
	Afternoon	Hot			Hot/Very hot			Hot		Hot		
Satisfaction		37,50%			20,84%			37,50%		54,16%		

*OR= occupancy rate; UC=utilization coefficient

Source: authors

In the case of the city of Santos, the urban reforms developed by Saturnino de Brito from the beginning of the 20th century not only embellished the landscape, but also improved the environmental quality of the central and tourist areas of the city. However, such reforms do not include peripheral neighbourhoods, where the low-income population lives (Pereira et al., 2021). It appears, in the case of São José do Rio Preto, that despite LCZ 3BA and LCZ3B being characterized as peripheral housing districts with low building density, they have many open and vegetated surfaces, which contributed to the various reports of satisfaction with the environment thermal.

In general, revegetating impermeable surfaces, establishing linear parks, promoting ventilation channels, water surfaces and other types of shading, such as canopies, awnings or built volumes, can help reduce the air temperature and thermal stress (Masiero and Souza, 2018).

FINAL CONSIDERATIONS

Therefore, it can be concluded that the socioeconomic factor was not predominant in user perception and satisfaction with the thermal environment. There are factors such as wind, shading and SVF that are essential to ensure environments that are thermally suitable for human beings, regardless of the construction pattern associated with the LCZ.

It is important to distinguish that the physical characteristics of an LCZ can be defined from the prerogatives of a master plan, from a set of constructive rules of a zoning law, from the

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proactivity of the public power in maintaining outdoor areas, or even, from the interest of investors in the real estate market in establishing quality infrastructure.

Therefore, an urban area with low socioeconomic indices, on the other hand, may present SVF, H/W ratio, roughness and soil permeability rates conducive to obtaining thermal conditions of human comfort. Despite the peripheral areas of São José do Rio Preto having conditions of urban leisure infrastructure that are far from ideal, they were sufficient for people to express a reasonable level of satisfaction with the heat.

It is noteworthy that site 2-LCZ 2/3B, considered a privileged location and high construction standard, has the worst conditions for the PET index and satisfaction. Thus, it can be concluded that factors such as SVF, soil permeability and H/W ratio predominate over the perception and satisfaction results regarding the thermal environment. The site had a higher SVF index compared to the others, which could characterise the formation of the phenomenon of urban heat islands. Therefore, an in-depth study of the site is suggested.

In the comparative analysis between Wind x PET, it was possible to observe the preponderance of the wind parameter in the PET indices and in the manifestations of perception and satisfaction regarding the thermal environment.

Despite this, the data obtained for 4-LCZ 3B, a place of social interest with a low/medium standard, were also among the worst conditions and there were many singularities regarding satisfaction, which does not rule out the predominance of other urban issues such as zoning, occupation rate and maintenance of areas, which are related to social and economic contexts.

Another important aspect to be highlighted is, although the PETs recorded in the four locations were close to 40°C in the hottest periods of the day, the satisfaction rates with the thermal environment in less economically favoured areas were higher than those obtained in more affluent areas. This is possibly due to human and subjective factors, in which people living in popular neighbourhoods often tend to be embarrassed to report their dissatisfaction, which should also be further investigated.

Finally, the results obtained in this research aim to contribute to further analyses that can help propose improvements in terms of thermal efficiency for open outdoor spaces in legislation such as the Master Plan, and thus define more egalitarian and adequate conditions for urban thermal comfort.

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