Urban Climate map proposal for small town

Mamanguape, Brazil

SILVA, CLECIANE CASSIANO[1]; VLADIMIR S. SOUZA[2]; DANIELE G. FERREIRA[2]; SIMONE Q. S. HIRASHIMA[3]; ELEONORA S. ASSIS[2;] LUTZ KATZSCHNER[4]

[1] Centro Universitário de João Pessoa – UNIPÊ;
[2] The Federal University of Minas Gerais - UFMG;
[3] Federal Center of Technological Education of Minas Gerais - CEFET-MG;
[4] Institute for Climate and Energy Concepts – INKEK

Abstract: Most Brazilian cities are considered small (87.79%) and few have studies that assess their urban climate. Thus, practical and easy-to-understand bioclimatic analysis methods are needed to help urban managers in their decision making. The main objective of this work is to develop a thematic map that represents thermally uncomfortable regions of the Center of Mamanguape, a small town in the state of Paraiba/Brazil. For this, it was used the German methodology of production of Urban Climate Maps that characterizes urban areas considering the energy balance, influenced by the aspects of thermal load and dynamic potential. The analyzed areas were identified, classified, and received a climatic valuation according to the relation in the temperature elevation and wind flow capacity, influenced by constructions, topography, vegetation, and open spaces, making use of a Geographic Information System (GIS). With the Urban Climate Map, it was observed that consolidated areas contribute negatively to the thermal comfort of the population, and that areas classified as favorable to comfort are located mainly in peripheral areas. Therefore, the preliminary results obtained can collaborate with the beginning of a climate awareness not only of public managers, but of all those involved in the production of urban space.
Keywords: Small towns, Urban Climate Map, Thermal Comfort.

1. INTRODUCTION

The application of climatology in urban planning has attracted great attention from researchers since the mid-20th century (Arnfield, 2003; Hebbert, 2014), however, it has focused mainly on medium and large cities. Few studies assess the impacts of urban characteristics of small towns (i.e., cities with < 50,000 inhabitants) on their local climate (Kopec, 1970; Cardoso, 2017).

In Brazil, the importance of small towns is reflected in the socioeconomic expression they have taken on in recent decades, as well as in the rapid territorial expansion. Estimates from the Brazilian Institute of Geography and Statistics (IBGE) show that 87.79% of cities in the country are considered small, with a population of fewer than 50,000 inhabitants (IBGE, 2021). In this context, it is essential that these cities draw up urban development plans that ensure less environmental impact and that avoid or minimize the negative effects of urban expansion on the environmental comfort of the population, recurrent in large cities.

In Brazil, it is noted that many of these cities do not have an administrative structure that has professionals specialized in the elaboration of master plans or urban climate studies. Therefore, a climate analysis methodology focused on supporting municipal decision-making must be practical and easy to understand not only by public managers but by the population in general (Eliasson, 2006).

An urban planning tool for this purpose is the Urban Climate Map (VDI 3787, 2015). In the 1970s, the idea of representing the urban climate through maps arose in Germany as a way of evaluating urban plans (Hebbert, 2014). This method has been adapted and applied in several cities around the world, including Amsterdam, Barcelona, Lisbon, Tokyo, Hong Kong, and Singapore (Ren et al, 2011). In Brazil, several studies were developed in different Brazilian regions, however, they were designed for large cities (Nery et al, 2006; Shimomura et al, 2015; Ferreira et al, 2017); Souza & Katzschner, 2018; Freitas et al, 2021; Anjos et al, 2021).

Recognizing the importance of small Brazilian cities and their role in the future of a more urbanized country, this research aims to present a case study of the application of urban climate maps methodology adapted to a region of northeastern Brazil, located in the city of Mamanguape, Paraiba state.

2. METHOD

Since the objective of this paper is to facilitate the elaboration of an urban climatic map (MCU) for small cities, it has been decided to synthesize the methodology, facilitate the obtaining of local geographic data, and employ free geographic information systems (GIS) software.

Within this context, the following data were used in this study: 1. Orthophoto chart with 5-meter spectral resolution; 2. Digital Elevation Model provided by the Brazilian Agricultural Research Corporation (Embrapa); 3. Climate data provided by the government website Projetee (2016).

Thus, the elaboration of the urban climate map for the central region of Mamanguape consisted of 04 steps: 1. data collection and processing; 2. evaluation of aspects of the urban structure in the thermal comfort of the population; 3. analysis of thermal load and dynamic potential; 4. elaboration of the Urban Climate Map.

2.1 Urban climatic map methodology

The methodology for elaborating the urban climatic maps is based on the concept of Climatopes (homogeneous spaces with similar climatic characteristics), focusing on human thermal comfort and atmospheric air quality. For this, a multi-criteria approach is used, with a qualitative and quantitative approach. Two aspects are evaluated: the thermal load and the dynamic potential.

The Thermal Load (TL) is related to the intensity and storage of heat by the city influenced by buildings, topography, and the availability of green spaces. These aspects act directly on the increase in air temperature. The Dynamic Potential (DP), in turn, is related to the possibility of wind flow through the city, considering the built density, the natural landscape and the existence of open spaces. A synthetic description of the MCU analysis structure can be seen below in Table 01.

Table 01:
MCU Analysis Layers

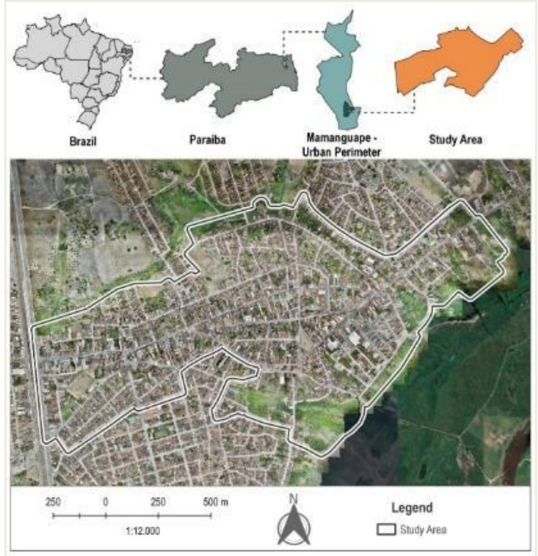
Energy balance	Urban characte. / Layer	Urban Climate Aspect	Thermal Comfort Effect
Thermal Load	Volume Construção	Armazena calor	Negative
	Altitude e elevação	Resfriame-to do ar	Positive
	Vegetação arbórea	Resfriame-to do ar	Positive
Dynamic Potential	Cobertura do solo	Obstrução dos ventos	Negative
	Paisagens Naturais	Movimento do ar frio	Positive
	Espaços abertos	Trocas de massa de ar	Positive

An orthophoto chart of the city center of the year 2019, provided by the Federal Public Ministry of Paraíba (MPF-PB), was used to extract the spatial data of the study area. The elements that make up the image were vectorized using the free software QGis v 3.10. Additionally, other spatial information was collected using the free software Google Earth Pro and on-site visits.

2.2. Study area

The study area is located within the urban perimeter of Mamanguape city (Figure 02). The town was founded in 1855 and is located 45 km from the state capital (6°50'20"S, 35°7'33"W). It is considered a small city with an estimated population of 45,385 inhabitants and a population density of 124.23 inhabit/km² (IBGE, 2021).

Figure 02:
Study Area Location



According to the Köppen-Geiger classification, the climate of Mamanguape is characterized as Aw'i type (tropical climate), that is, hot and humid with rains of fall and winter. The average annual temperature is around 27°C. The annual thermal amplitude is very small due to the low latitude, oscillating between 5° and 6°C. The average rainfall is 1,634.2 mm.

For many small Brazilian cities, wind information is not available. In this case, wind data were taken from the nearest weather station located in the city of João Pessoa (Projetee, 2022). The city's proximity to the equator provides a predominantly daily wind regime, characteristic of coastal areas. In this way, it remains throughout the year within the range corresponding to the southeast trade winds, which characteristically blow in the cooler months with greater frequency and speed. During the warmer months, its frequency is altered by easterly and northeasterly winds coming from the equatorial areas in the displacement current, towards the south of the Intertropical Convergence Zone (ITCZ). The winds assume distributions in the southeast quadrant between 150° and 180° and speeds ranging from 0 to 9m/s, with an average of 3.6m/s.

The study area analyzed is the Centro district, the oldest in the city, which is spread over an area of 1.4 km². It has a high building density, a greater concentration of services and shops, and a greater dynamic and flow of people in the city.

3. RESULTS

The spatial data vectorization process used the information contained in the orthophotochart, complemented by satellite images from the Google Earth Pro application. Over 4 weeks, 4132 polygons (buildings) were vectorized. In order to collect information on the height of the buildings, on-site visits were carried out, finding that most of the buildings have a height close to 3m, and the tallest with a height close to 12m.

The main biomes found are remnants of the Atlantic Forest, in areas of environmental protection, in addition to the Cerrado, which extends over a greater extent of the municipality, with grass and shrub species.

For the location and delimitation of water bodies, the same material and method were used for vectorization.

After processing the spatial data, the analysis layers related to the CT and PD of the MCU were elaborated, namely: 1. Building Volume; 2. Topography; 3. Green Spaces; 4. Ground cover; 5. Natural Landscapes; 6. Open spaces. Each layer was evaluated and classified according to its impact on thermal comfort based on the study developed by Souza & Kaztschner (2018) for the city of João Pessoa, a region close to the city of Mamanguape. All layers were converted to a raster format, with a spatial resolution of 30m x 30m.

Layer 01 corresponds to the relationship of building volumes with heat storage. Buildings store solar energy during the day and gradually release it at night. Depending on the amount of built-up area, the heat may not properly dissipate into the atmosphere. In the climate classification, areas with a high volume of constructions receive positive classification values for contributing significantly to the increase in air temperature and, conversely, areas with little or no construction receive value. Table 2 shows the impact on the thermal load of city areas according to the percentage of building volume and the respective valuation of climate classes on a scale of 0 (No construction), 1 (low concentration) and 2 (medium concentration).

Table 02
Description of layer 01

Thermal Load	Building Volume	Value
NONE	0%	0
LOW	1 – 4 (%)	1
MEDIUM	4 – 10 (%)	2

Layer 2 is based on the concept of adiabatic cooling of the air concerning altitude. Thus, the topography contributes to the decrease of air temperature due to changes in altitude and relief. The values assigned to the layer are negative, as they do not influence the Thermal Load, and decrease depending on the altitude variation (Table 03).

The digital elevation model file (DEM) was generated from the interpolation of dimensioned points, which consists of using known dimensions to estimate unknown values. Subsequently, this file was converted into a raster format file and reclassified according to the impact of topography on Thermal Load.

Table 03
Description of layer 02

Thermal Load	Topography (m)	Value
YES	> 50m	-1
NONE	0 – 50m	0

The evaluation of vegetation makes up layer 3. The presence of large vegetation formations (forests and woods) favors the cooling of the air temperature, contributing to the reduction of heat storage in the city.

No large area full of trees were identified in the study area, only small arboreal clusters. However, these can contribute to the localized cooling of the local temperature. Thus, negative classification values were assigned to this concerning climate classification (Table 04).

Tabele 04
Description of layer 03

Thermal Load	Vegetation	Value
YES	EXISTENT	-1
NONE	NONEXISTENT	0

The buildings have a direct impact on the flow of winds in the urban environment, that is, the higher the percentage of the occupied area, the lower the urban permeability to ventilation. This is the concept applied to layer 4.

Therefore, the vectorization of buildings was used to classify areas with the highest concentration of constructions, classifying them according to the effects caused on the dynamic potential. Areas with occupancy greater than 50% received a null classification, as they do not favor the dynamic potential, and less dense areas received negative values (Table 05).

Table 05
Description of layer 04

Dynamic Potential	Ground Cover (%)	Value
VERY FAVORABLE	0 – 30	-2
FAVORABLE	30 - 50	-1
NONE	> 50	0

In layer 5, natural landscapes that may favor the flow of winds in the urban space were considered. Thus, areas with undergrowth, fields and pastures received negative classification values. The tree clusters, on the other hand, received a null value, since, in terms of roughness against the winds, they present characteristics similar to the buildings (Table 06).

Table 06
Description of layer 05

Dynamic Potential	Natural Landscape	Value
FAVORABLE	FIELDS, PASTURES	-1
NONE	URBAN	0

In the last layer, areas close to bodies of water and open fields were taken into account, which, due to their low roughness, favor the circulation of winds, benefiting air exchanges. Therefore, the layer was elaborated from the identification of these areas.

For each space described above, a map was prepared with its classification values, called water bodies layer and open spaces layer. Subsequently, they were superimposed, using the map algebra technique (sum operation), and the Open Space Proximity Layer was generated as new classification values (Table 07).

Table 07:
Description of layer 06

Dynamic Potential	Open Spaces	Value
YES	YES	-1
NONE	NO	0

Through the GIS map algebra technique again, performed in the QGis software, the thermal load map was generated by adding the values of layers 1, 2 and 3, which resulted in a map with 5 climate classification values. Similarly, the dynamic potential map was created by superimposing layers 4, 5 and 6, resulting in six new climate classification values. In Figure 03, the structure of the MCU layers can be observed.

As can be seen in Figure 3, the central regions of the study area already have a significant concentration of areas favorable to the Thermal Load, while peripheral areas have few areas that favor the flow of winds.

Finally, for the elaboration of the Urban Climate Map (Figure 4), the map algebra technique (sum operation) was used again in the values of the CT and PD maps, resulting in 6 values of climate classification. The classified areas were evaluated according to characteristics that influence the energy balance of the study area (Table 08).

Figure 03*:*
Structure of the Urban Climate Map layers.

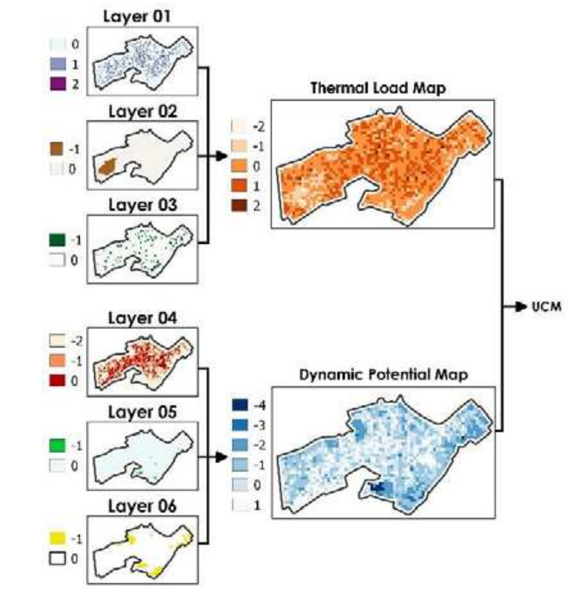


Figure 04*:*
MCU Mamanguape downtown.

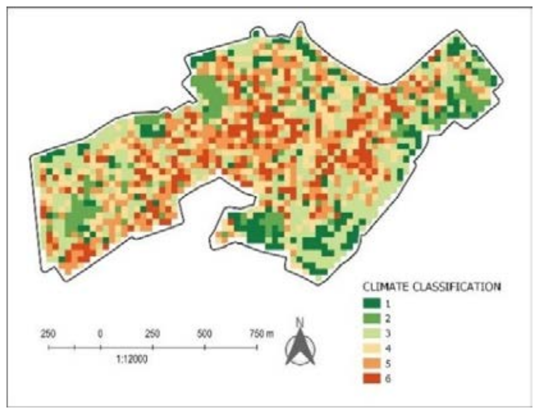


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Table 08
Description of the MCU climate classes

Class	Description	Thermal Comfort Impact
1	HIGH MITIGATION	VERY IMPORTANT FOR CLIMATE ITIGATION
2	MODERATE MITIGATION	CONSIDERABLE CLIMATE MITIGATION
3	LIGHT MITIGATION	IMPORTANT FOR WIND FLOW
4	NONE	LOW INCREASE IN TEMPERATURE
5	LIGHT ELEVATION	NO HIGH THERMAL LOADS
6	HIGHT ELEVATION	THERMAL COMFORT AFFECTED

Class 1 represents regions with high climate mitigation, that is, they benefit natural ventilation and reduce the increase in air temperature. In these regions, there is a predominance of vegetation, which in turn favors humidity and the reduction of air temperature, important for reducing the thermal load. The highlighted regions are mainly rural areas, with large extensions of pastures and water bodies, used for irrigation. There are also peripheral, poorly developed areas, with a process of expansion at the beginning and natural landscape still preserved.

Class 2 depicts areas with moderate climate mitigation, characterized by a low building density, a mix of few residential buildings and large open spaces of pastures, which benefit the dynamic potential of the area.

Regions with the presence of buildings and reduced vegetation represent class 3 (light climate mitigation), demonstrating the beginning of urban expansion to peripheral areas and the beginning of the de-characterization of the natural landscape, with the removal of existing vegetation, soil sealing and constructions that can obstruct the flow of winds.

Class 4 shows urban spaces with significant urban density, low-rise buildings, with low impact on thermal comfort, with a predominance of the use of construction materials with low thermal absorption, unpaved streets, and the presence of vegetation, which work with a thermoregulator for temperature.

Class 5 represents areas with a high building density, little vegetation, and few open spaces, impacting the rise in air temperature. They are located mainly in the central region, which have strong characteristics of the urban layout of the 19th century, with few setbacks between the buildings that do not favor the circulation of winds, causing barriers that prevent the winds from entering the urban fabric, in addition to the use of materials with high absorption capacity.

Finally, class 6 (high elevation) depicts regions with affected thermal comfort, characterized by the absence of vegetation, high density and the presence of large equipment, aspects that act as a barrier to ventilation and/or absorption and storage of radiation. These are places that present greater difficulties in intervention, as they are already consolidated areas, in addition to a greater concentration of commercial equipment.

Figure 05 presents some examples of classified areas through the MCU. As can be noted with the increase in the class value, there is a sudden reduction in vegetation and a significant increase in dense and impermeable areas.

Figure 05*:*
Examples of MCU classes.

4. CONCLUSION

Like most small Brazilian cities, the municipality of Mamanguape/PB does not have an urban planning sector, in which it could assess current climatic conditions and propose climate-conscious urban development solutions. The responsible sector, the Secretaria de Obras, focuses only on projects and the construction of buildings for the municipality.

Interventions have already been observed in the studied area. Based on the classical literature, they are known to aggravate human thermal discomfort. The removal of trees from public spaces, asphalt paving of streets and the use of low-albedo materials are recurrent strategies in the city.

In this sense, a practical and easy-to-understand method of climate analysis is urgently needed to help decision-making by public managers in Mamanguape city.

The proposal of an Urban Climate Map, based on the analysis of local physical aspects, was effective to identify and understand how these aspects act in relation to the quality of the urban environment, with the identification of areas where they already present a high thermal discomfort, result of urbanization and the expansion process of recent years. However, the measurement method presented is not fully effective, and the results need to be deepened and constantly updated.

In any case, the Urban Climate Map can collaborate with the beginning of a climate awareness among city managers, as well as professionals who deal with urban planning and design.

ACKNOWLEDGEMENTS

This work was financed in part by the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* – Brazil (CAPES) – Finance Code 001.

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