CLIMATE MAP AS AN INSTRUMENT FOR URBAN PLANNING

Ruskin Fernandes Marinho de Freitas[*]
Jaucele de Fátima Ferreira Alves de Azerêdo[*]
Laís Teixeira de Carvalho[**]
Renato Freitas da Costa[*]

[*]Universidade Federal de Pernambuco, Departamento de Arquitetura e Urbanismo, Recife, PE, Brazil
[**]Architect and urbanist, Recife, PE, Brazil

Abstract

There has been a significant increase in studies on climatic mapping linked to urban planning, with the spatialized distribution of urban microclimates, in order to guide municipal actions, aiming at environmental comfort. In this research, various climatic studies have been reviewed so as to develop maps for climate analysis and to draw up recommendations on the use and occupation of land. Climatic classification was adapted for topoclimates, through the overlapping of layers and by attributing heat accumulation values to the base layers. In the city of Recife, fourteen microclimates were identified, categorized into coastal, plain and hillside macrozones. The neighborhoods of Boa Vista and Soledade presented eight microclimates, synthetized into three classes of heat accumulation, which were predominantly high, chiefly in areas of densification, and verticalization. The recommendations aim to assist in urban management, so as to act more precisely in the critical areas, and thereby, as a result of reviewing the urban parameters, provide guidelines for more effective projects on both urban and architectural scales.

Keywords

Urban climate; Environmental Comfort; Urban Planning; Climate Map; Recife.

ARTIGOS
AMBIENTE, GESTÃO E DESENVOLVIMENTO

MAPA CLIMÁTICO COMO INSTRUMENTO PARA O PLANEJAMENTO URBANO

*Ruskin Fernandes Marinho de Freitas**
*Jaucele de Fátima Ferreira Alves de Azerêdo**
*Laís Teixeira de Carvalho***
*Renato Freitas da Costa**

*Universidade Federal de Pernambuco, Departamento de Arquitetura e Urbanismo, Recife ,PE, Brasil
**Arquiteta e urbanista, Recife, PE, Brasil

Resumo

Observa-se um aumento global de estudos sobre mapeamento climático atrelados ao planejamento urbano, espacializando os microclimas urbanos, para orientar ações municipais, visando ao conforto ambiental. Nesta pesquisa, revisaram-se estudos climáticos diversos para elaborar mapas de análise climática e recomendações quanto ao uso e à ocupação do solo. Adaptou-se a técnica de classificação climática por topoclimas, a partir da sobreposição de camadas e com a atribuição de valores de acúmulo de calor para as camadas-base. No município de Recife, foram identificados catorze microclimas, distribuídos em macrozonas litorânea, de planície e de morros. Os bairros Boa Vista e Soledade apresentaram oito microclimas, sintetizados em três classes de acúmulo de calor, predominantemente alto, sobretudo em áreas adensadas e verticalizadas. As recomendações têm o propósito de contribuir com a gestão urbana, tendo em vista uma atuação mais precisa sobre as áreas críticas, promovendo, como resultado da revisão de parâmetros urbanísticos, diretrizes para a adequação de projetos em escalas urbana e arquitetônica.

Palavras-chave

Clima Urbano; Conforto Ambiental; Planejamento Urbano; Mapa Climático; Recife.

CLIMATE MAP AS AN INSTRUMENT FOR URBAN PLANNING

Ruskin Fernandes Marinho de Freitas
Jaucele de Fátima Ferreira Alves de Azerêdo
Laís Teixeira de Carvalho
Renato Freitas da Costa

Introduction

The process of urbanization, in its most basic sense, a result of the transition from a natural environment to an urban environment, is a phenomenon that dates back to the formation of the first cities, and which has been the object of study for several different disciplines at different historical moments. By concentrating people, buildings and activities, the city has become a factor in the (trans)formation of urban climates, an issue that has also permeated the history of cities and that has gained emphasis in each period of great transformations. Currently, when addressing urban planning there is an unquestionable need to discuss climate change, on both a local and a global scale.

The Industrial Revolution, dating from the second half of the eighteenth century, played an important role in the process of accelerating the growth of cities, initially bringing about a huge exodus from rural areas to urban areas, in the pursuit of job opportunities and, consequently, a better quality of life. Since that time, cities have become transformed and have expanded, through the need to fall in line with health demands, through the development of infrastructure networks and through the great urban transformations of the post-war periods, during the twentieth century (BENÉVOLO, 1991, pp. 29-48).

In accordance with Reis (2006, p. 21): "During the second half of the twentieth century, across all continents, there was a prominent increase in the urbanization indexes".[1] This process triggered both the spread of cities, overrunning areas,

1. This and all non-English citations hereafter have been translated by the authors.

which until that time had been natural or rural, and the densification of previously established centers, thereby causing modifications to the form of the city, in the way its inhabitants live and also in its functioning, for example, generating and accumulating heat, to different degrees, in accordance with the characteristics of each region. Permanence, transformation, growth, development, degradation, and innovation began to alternate and exist alongside one another, increasingly requiring greater attention from urban planning.

Technological innovations have enabled improvements in the forms of organizing work and have modified the pre-existent dynamics in many sectors of society. Most of the world's population, which corresponds to 55%, lives in urban areas (UNITED NATIONS, 2019a, p.1). According to the *World Population Prospects 2019: Highlights* (UNITED NATIONS, 2019b, p.1), the population projection for 2019 was 7.7 billion with a growth to approximately 8.5 billion, in 2020, 9.7 billion in 2050 and 10.9 billion in 2100.

In order to support this population growth, the space in the urban environment needs to be constantly undergoing changes. Souza (2010, p. 19) and Ribeiro (2013, p. 15) highlighted the influence of political, economic, and social interests as being catalysts of change. This normally brings about an increase in the urban structure, which then becomes more extensive and/or denser, thereby enabling the nature of the spatial activities of certain environments to become fragmented. Hence, this promotes a variety of land uses on the urban soil, in order to meet the required demands.

The consequences of population growth in the cities tend to entail problems, such as excessive building densification, increases in the price of land, prioritizing motor vehicles with the creation of parking spaces, the collapse of infrastructure systems, spatial and social segregation, and environmental degradation, with a decrease or complete removal of green areas and open spaces, which are then replaced with edifications and paths that interconnect them (FREITAS, 2008, p. 16; RIBEIRO, 2013, p. 15). By combining the growing population, primarily in the big cities, with a lack of surfaces free of urbanization, it may be substantiated that if the current processes of land use and occupancy continue, without due concern for environmental characteristics, there will be a tendency towards environmental saturation (AZERÊDO, 2017, p. 32), which may cause irreversible damage, on both local and regional scales.

In the urbanization process, generally associated with building densification and environmental degradation, anthropic action is presented as being responsible for transforming the natural landscape into an urban landscape. The modifications that cause damage to the environmental conditions, in relation to their geographical, ecological and morphological aspects, characterize environmental discomfort, a condition that needs to be avoided when promoting the (re)structuring of a city. Freitas (2008, p.17) stated that "the equilibrium between gains and losses begins to constitute a dilemma for urbanists, especially legislators, in defining urbanistic parameters, which are responsible for the production of urban space and for the configuration of the landscape".

The relationship between urban form and urban climate, which has always accompanied discussion on the urbanization process, still constitutes a relevant theme, and, indeed, it is essential that it continues on the current agenda. As long as cities continue to grow and, now, with the evidence of climate changes, one of the causes of which is anthropic action, it is extremely important that urban planning considers the escalation of environmental problems, beginning with climate.

In accordance with the Intergovernmental Panel of Climate Changes (IPCC, 2018, p. 7), "Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels" and that it "is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate".[2]

The Brazilian Panel of Climate Changes (PBMC), even more emphatically, has indicated cities as being the focus of anthropogenic factors for climate changes: "Climatic uncertainties and dynamic urbanization tendencies present cities in development with new, unknown challenges of planning" (PBMC, 2016, p. 24). Cities are still presented as a field of study and of applying solutions for the mitigation and adaptation to climate changes, not only as an ensemble – the urban – but also in each city, considering that the global begins in the local. The resilience of cities to global climate changes begins by studying urban climates, i.e., on a local scale, as a reference for urban planning.

Understanding the concept of urban climate stems from a general understanding of the concept of climate, defined by Mendonça (2012, p. 29) as a synthesis of the atmospheric weather variations in a series of data over a period of thirty years. Therefore, urban climate is the result of the transformations that have occurred over its extended surface, in its topography, the land use and the sealing of soil, as well as in the extension and density of the existent vegetation, both in the urban form and in its proportional relationship between the built-up areas and the free, open spaces (SOUZA, 2010, p. 19; RIBEIRO, 2013, p. 15). This causes modifications in the dynamics of the atmospheric surfaces, interfering in the thermal balance and thereby generating new microclimates.

---

2. N.B. - For the direct citations, the original English version of the IPCC Report was used. Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_Low_Res.pdf. Viewed on: February 10, 2021.

Changes in the natural characteristics implies the occurrence of modifications related to increased precipitation and air temperatures, as well as a reduction in the relative air humidity and changes in the direction and velocity of winds. This constitutes a set of information that Romero (1988, p. 19) nominates as climatic elements. The occurrence of phenomena such as temperature inversions and heat islands are also addressed. It is therefore necessary to understand the elements that constitute a city, together with its geographic characteristics, in order to improve the quality of urban life, which presupposes better conditions of habitation and, primarily, greater environmental comfort for its users. Comfort may be explained, according to Freitas (2008, p. 251), as a "state of well-being, experienced in time and space, in which environmental, morphological and economic conditioners provide physical and psychological satisfaction".

Climatology involves thermo-hygrometric indicators, through studies on comfort perceptions, heat islands, mitigation islands and temperature inversions; chemical physics, with regard to observing the air dynamics in the city; and hydrometeors, through urban rainfall regimes and the resulting impacts (MASCARÓ, 1996, p. 34; MONTEIRO, 2003, p. 178). These three strands of study may be used on which to base decisions relating to urban planning, though the use of techniques, such as mathematical modelling, remote sensing, meteorological balloon surveys, measuring through automatic or conventional meteorological stations, as well as the empirical registering of data, either linked or not to climatic mapping.

It is evident that emphasis must be given to climatic and microclimatic assessments in urban planning studies. Considering that climatic maps spatialize the contrasts between a diversity of microclimates, so as to relate the different elements of which they are composed, they undoubtedly may function, in a given region, as one of the instruments to be considered. This aims to contribute to and provide a basis for decisions made by the entities involved in the process of urban planning, herein understood as a field that:

> [...] integrates a diversity of disciplinary knowledge (economy, geography and sociology, amongst others) and essentially contemplates the decision making related to the management and creation of plans, programs and projects – including, but not necessarily, those of an architectural nature. Hence, this context requires a 'competence for planning and managing'. (ROVATI, 2013, p. 33).

1. Climate maps and urban planning

Climate maps are graphic representations of the spatial, behavioral diversity of climate variables in a particular place. They synthetize information regarding distinct morphological and environmental aspects, involving different climatic elements, and the products of various methodologies and techniques that may be used for the study of urban climate, which, in isolation, do not contribute to the act of urban planning. Satellite images, for example, are of fundamental importance in order to discover surface temperatures and their contribution to environmental warming in areas with large dimensions. However, due to the image scale, it is the surface data which is taken into account. On the other hand, in order to obtain real knowledge on areas closer to the scale of the pedestrian user, with the aim of observing the contribution of natural materials, minerals, organics and anthropic, it is of greater relevance to analyze urban morphology. This also involves local measurements of the surface temperatures of each material that composes the space, along with the measurement of the air temperature, the relative air humidity and ventilation, the conditions of which are not registered by satellite images.

The maps under discussion may be structured through the principle of a geographic information system (GIS), which, through computational resources and procedures, enables the representation and analysis of the phenomena that occur in space. Thus, GIS is part of a set of methodologies attributed to geotechnologies, since it encompasses spatial analysis.

The collection and processing of data, therefore, constitutes a multidisciplinary task, since spatial data refer to the topography, vegetation, road system, constructions and all the other elements that define the urban structure. The main climatic data are air temperature, surface temperature, relative air humidity and wind regimes. Thus, this represents a tool that simultaneously embraces physiographical, climatical, morphological and urbanistic aspects.

The set of climatic and spatial data defines the basis for constructing a climatic analysis map, with the acquisition of products for the macroscale, the mesoscale, and the local scale. The basemaps in which positive values are attributed for the accumulation of heat generate the thermal load map, and the basemaps with negative values generate the dynamic potential map. The union of both produces the climatic analysis map, aimed at climatic orientation, the classes of which are synthetized so as to produce a map of recommendations, for guidance on urban planning and management, through the presentation of guidelines, which are relevant to the encountered situations (NG *et al.*, 2012, pp. 26-27).

Because the nature of urban spaces is in a constant process of transformation, it is necessary to update the database periodically since information regarding urban surfaces and the precision of the indications recommended by the preservation and intervention guidelines tend to become obsolete. It should be highlighted, however, that the methodological procedure (overlapping layers) is constantly being adapted, since this may be modified in accordance with the climatic/geographic contexts.

Climatic maps may be made available to the public, and act as a tool for consultation and final decision-making, and may be concomitantly used by different population groups, such as geographers, urbanists, public authorities, civil construction entrepreneurs and the civilian population. By contributing to the ordering and the appropriateness of land use and occupation in a municipality, this tool fulfils the demands related to environmental comfort, primarily from a thermal perspective, thereby avoiding environmental degradation and protecting both the urban and natural areas.

The Environmental Meteorological Working Group from the German Meteorological Society conducted a pioneering study that integrated climatic maps with urban planning (SOUZA, 2010, p. 27), developed in the German cities of Stuttgart and Kassel, between 1970 and 1980, aiming to mitigate air pollution, correlating knowledge on climate and clean air with land use and occupation, on a municipal level, so as to ensure, not only the well-being of the population, but also improved health conditions and a reduction in the consumption of electric energy.

As a result of these studies, the *Urban Planning Climate Manual* was produced, a document directed towards the authorities and necessary for planning German cities (ASSIS; MACHADO, 2017, p. 188). As a consequence, it became the basis for the production of studies in Europe, Asia and America. Figure 1 presents examples of climatic analysis maps.

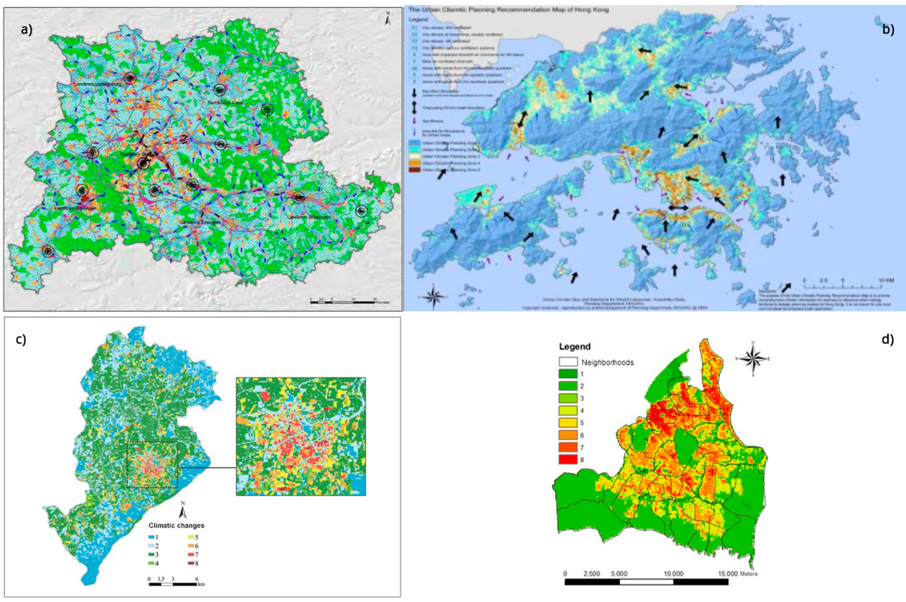

Figure 1. Climate analysis maps for Stuttgart (a), Hong Kong (b), Belo Horizonte (c) and João Pessoa (d)

Source: Adapted from: (a) Baumüller (2008, p. 153); (b) Ng *et al.* (2012, p. 470); (c) Assis and Machado (2017, p. 266); (d) Ribeiro; Braz; Silva (2013, p. 9).

The climate map for the city of **Stuttgart** was developed due to concerns over the increasing occurrences of heat islands and air pollution and health indexes, caused by the population growth and urban spatial expansion. Updates by Baumüller (2008) for the Climate Atlas added the need for sustainable spatial development. Elements of the urban structure and climate, in the most recent version, have been subdivided into three groups: basemaps; result maps and analysis maps. The basemaps group addressed the perspective on a municipal level for the geomorphological aspects of the region; the result maps group investigated the behavior of the meteorological aspects at certain times of the day or year and, lastly, the analysis maps group presented prospective studies, climate analysis and recommendation maps (BAUMÜLLER, 2008, p.7).

The climate analysis map was divided into eleven topoclimate classes, according to the main land uses: water bodies, open fields, forests and green areas presented mitigating effects; garden cities exerted little influence; periphery, city, urban nucleus, railway stations, industries and enterprises had negative effects. With regard to the recommendations map, three classes referred to open spaces, with more sensitivity in relation to the changes in land use, due to the high climatic impact that may be caused. The settlement classes indicated the prioritization of adding green areas and reducing the constructed volumes so as to diminish the climatic and health impacts (BAUMÜLLER, 2008, pp. 148-158).

In Asia, the climatic map of **Hong Kong**, produced by Ng *et al.* (2012), was begun in 2006, motivated by the need to increase the ventilation flow, because of the dense urban structure, which was vertical and surrounded by mountainous terrain. In this case, the German methodology was simplified, equating base layers with the physical aspects of the urban structure and attributing values that corresponded to the physiological equivalent temperature (PET), based on the thermal balance model, in which 1°C represents a whole number. Thus, the positive values constituted the thermal load map, and the negatives, that with dynamic potential.

The analysis map synthetizes the city into eight topoclimatic classes: classes 1 and 2 refer to the mitigating effects, class 3 has a neutral impact and the others are related to warming effects (NG *et al.*, 2012, pp. 171-173). The climatic classes were grouped into sensitivity zones, with recommendations for interventions in the urban structure – negative effect zones would undergo remediation actions, and positive effect zones either preservation or improvement actions (NG *et al.*, 2012, pp. 211-213).

In the Brazilian scenario, the *City Statute* (BRASIL, 2001) establishes general guidelines for urban policy, and defines instruments for ordering and controlling land use. Particularly outstanding are the guidelines that aim to "guarantee the right to sustainable cities" and to the "spatial distribution of the population and economic activities of the Municipality and the territory within its area of influence, in order to avoid and correct the distortions of urban growth and its negative effects within the environment". Law No. 6,766 (BRASIL, 1979) concerns the subdivision of urban land. Article 3 states that: "The subdivision of land will only be permitted for urban purposes in urban zones, for urban expansion or specific urbanization, as defined by the master plan or approved by municipal law".

Thus, within the local scope, the master plan is presented as the main instrument of territorial ordering used by the public authorities and is responsible for regulating and ordering land use, aiming at safety, well-being and environmental balance. However, this instrument does not always directly encompass aspects related to environmental comfort, urban climate, heat island phenomena, wind flows and atmospheric pollution. Aiming to provide such a need, climatic map studies have been developed for the state capitals: Belo Horizonte (MG), João Pessoa (PB), Maceió (AL), Salvador (BA) and São Paulo (SP), with the latter being the pioneering case.

The **São Paulo** map began in 1999, as a part of a project entitled *Environmental Atlas of the Municipality*. Tarifa and Armani (2000 apud SOUZA, 2010, p. 39) produced a study using cards of natural and urban climatic units, based on the principle that climate must be analyzed according to its interactions with the productive elements of space. There were three distinct levels of analysis: the metropolitan area; the topoclimatic units, the differences of which are associated with the current land; and the microclimate, associated with the quality of habitation and living. The data analyses aimed to understand the surface interactions and the atmosphere between the climatic scales, thereby identifying the areas with the highest air temperature and atmospheric pollution.

For the **Belo Horizonte** map, Assis, Ferreira and Katzschner (2017) complemented previous studies on the roughness of the municipality, aiming to analyze the consequences of urbanization on the wind regimes and other climatic factors. The methodological procedure involved the spatial analysis of topoclimates, whose analogue areas were grouped through elements of energy balance of the urban surface (ASSIS; FERREIRA; KATZSCHNER, 2017, p. 261). According to these authors, the climate analysis map presented eight topoclimate classes. Classes 1 and 2 presented a negative thermal load with a good dynamic potential due to factors such as altitude and adiabatic cooling. Classes 3 to 8 indicated a progressive impact on the climate, referring to an increase in the thermal load and to a decrease in the dynamic potential.

The **João Pessoa** map, produced by Souza (2010) and updated by Ribeiro (2013), underwent changes regarding the constituent base layers. The assessment of the topography and natural landscapes was removed since it was either inexpressive or insufficient (RIBEIRO, 2013, p. 71), and the layer in the proximities of the water bodies was subdivided into hillsides and open spaces, aiming to identify the places in which the wind flow was benefited (RIBEIRO, 2013, pp. 75-78). Next, a spatial analysis of the topoclimates was developed, with the construction of intermediary maps of the thermal load and the dynamic potential. Thermohygrometric measurements were also taken. The climate analysis map contained eight classes – classes 1 and 2 contributed to the mitigating effects of the climate with temperature reduction; class 3 offered a neutral impact; and classes 4 to 8 presented the progressive increase of the negative impacts related to the heat accumulation, with the last characterizing the heat island phenomenon. The update also registered a decrease in the areas of classes 1 and 2 and an increase in the areas of classes 6 to 8.

2. Objective

Since the climatic map is an important tool for urban planning and management, the aim was to develop a climate analysis map and to suggest recommendations, with guidelines to help with the quality and appropriateness of urbanism projects, paying particular attention to the municipality and the neighborhood scales. The specific empirical reference was the city of Recife and the central neighborhoods of Boa Vista and Soledade, which present a diversity of urban contexts, a great flux of pedestrians and vehicles, commercial areas and historical zones.

3. Object of study

Recife, the state capital of Pernambuco (Figure 2), is located on the Brazilian northeastern coast, on an estuarine plain surrounded by hills. According to the IBGE[3] – *Cities and States* (viewed in 2020) , the estimated population of the municipality in 2019 was 1,645,727, distributed across a 218,843 km^2 area, with a density of 7,520.13 hab./km^2.

According to the Master Plan of the Municipality of Recife (RECIFE, 2008), the entire municipal area is classified as an urban zone and, indeed, although there are macrozones of constructed environments and natural environments, they refer to the predominant aspects, with no rural zone, nor urban expansion zone. Thus, the area of the object of study includes the entire municipality of Recife.

3. IBGE - The Brazilian Institute of Geography and Statistics.

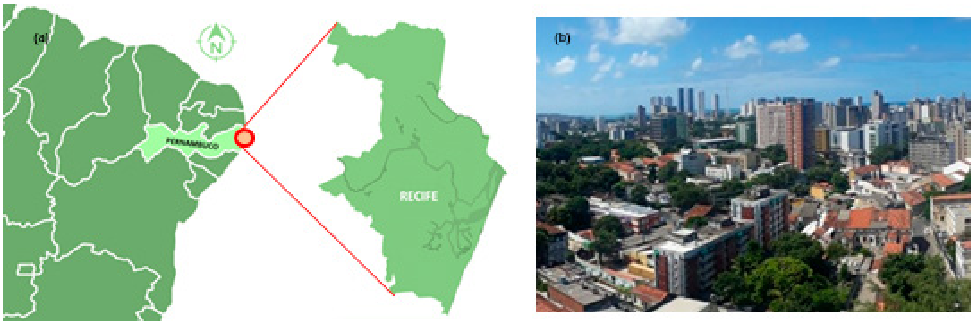

Figure 2. Localization of the municipality of Recife: (a) Location of Recife in the state of Pernambuco and in the Northeastern region; (b) Panoramic view of Boa Vista, in Recife.

Source: Maps adapted from Google Maps, 2018; Photograph by Ruskin Freitas, 2019.

In the climate map of Brazil (IBGE, 2002), Recife is inserted into the hot, humid tropical zone, characterized by two well-defined seasons, one dry and one rainy (summer and winter, respectively), high levels of air temperature and relative air humidity (above 25°C and 70%, respectively), with slight variations of temperature during the day and predominant winds from the Southeast (FROTA; SCHIFFER, 2001, p. 45). According to the Climatological Standard Normals, from 1981 to 2010, available from the National Institute of Meteorology (Inmet), in Recife, the mean annual air temperature is 25.9°C, with a relative air humidity of 78.3%, a wind velocity of 2.9 m/s and precipitation of 2,263.4 mm. For architecture and urbanism, priority should be given to appropriateness regarding climatic conditioners, in the pursuit of environmental comfort, shading and crossed ventilation strategies.

4. Methodology

The method of this work, of a hypothetico-deductive nature, is based on mathematical rigor and on rationale, in which theories and hypotheses may be confirmed through the development of rationale (SPOSITO, 2004, pp. 30-32). The quantitative and qualitative approach is based on the evident formation of urban climate, due to the different environmental units and the different forms of occupation. Climatic and morphological data were analyzed with the aim of constructing a reference base in order to contribute to urban planning.

The methodological procedures began with a documentary survey of satellite images from the Google Earth program in order to georeference the pre-existent cartographic bases within the municipality, acquired from the digital environment of the City Hall, in the shapefile (SHP) format, in agreement with the spatial data referring to the urban structure. Such layers are the topographic quotas, water resources, the projection areas of edification, the limits of the lots and blocks and the road system. Maps were also used referring to the spatialized distribution of vegetation in Recife, developed in previous research studies. The maps were systematized in line with the GIS model, in the QGIS 2.18 computational program.

The construction of the climatic map followed the German methodology and the adaptation used in João Pessoa, by attributing a classification system to each topoclimate in the analogue regions and prioritizing the qualitative and quantitative aspects of the wind flows and thermal comfort, due to the high temperatures and corresponding with the strategies required by the local climate.

Thus, an overlap procedure of the base-layer maps was adopted. The aspects of thermal load and dynamic potential were considered with respect to their general effects, without attributing values to the construction phase of the base layers, which represent the physical characteristics of the municipality of Recife. The base layers used were vegetation cover, topography, proximity to water masses, soil coverage and building density (Figure 3). For all the layers, there was no simplification on any of the layers of the analyzed areas for grids that group urban spaces into limits of 100 x 100, 30 x 30, 15 x 15 or 1 x 1, thereby approaching the scenario as precisely as possible.

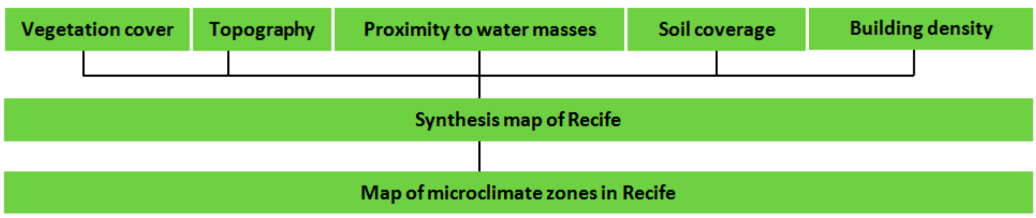

Figure 3. Flowchart of the methodological procedure for Recife, from the construction of the base layers.
Source: Produced by Ruskin Freitas and Laís Carvalho, 2020.

4.1 Layer 1: vegetation cover

The vegetation cover layer takes into account all the urban afforestation found in public open spaces, such as parks and squares, and in private open spaces, such as backyards.

The survey was undertaken by the authors, based on the polygon drawings of the vegetation cover obtained through satellite images, and was classified as being a small area of vegetation cover, when presenting a value of between 250 m^2 and 999 m^2; a medium area with a value between 1,000 m^2 and 10,000 m^2, and a large area when grouped into areas greater than 10.000 m^2, observing the quantity of recesses and overhangs. The dimensions of the surface area of thick vegetation contributes to mitigating the temperature and to increasing the humidity as a result of the adiabatic cooling effect, thereby contributing to the effects of climate mitigation. This contribution has already been tried and tested by several authors, amongst them, Azerêdo (2017).

In Recife, the largest concentrations of vegetation cover are highlighted to the west and northwest, and in the reserved areas of environmental protection (Figure 4). Altogether, vegetation covers an area corresponding to 35.37% of the municipality, of which the most afforested neighborhoods, such as Guabiraba, Pau Ferro, Dois Irmãos and Várzea, present levels of over 72% of forested surfaces, while areas in the urban central neighborhoods, such as Bairro de Recife, Santo Antônio and São José, present less than 1%.

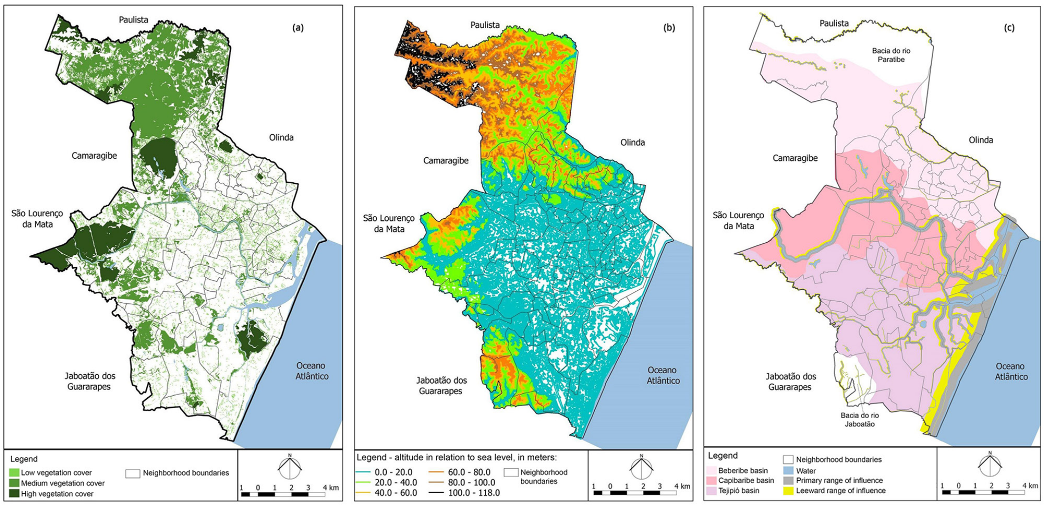

Figure 4. The Municipality of Recife: (a) vegetation cover; (b) topography and (c) proximity to water masses.

Source: (a) Adapted from Lacam/DAU/UFPE, 2016; (b) Produced by Laís Carvalho; and (c) City Hall of Recife. Adapted by Laís Carvalho, 2018.

4.2 Layer 2: topography

The topography layer aims to analyze the decrease in air temperature (the higher the layer) and the wind regimes, whereby the hillside regions may promote either an increase in the flows or act as barriers. Romero (1988, p. 26) indicated 1°C drop for each 200 meters above sea level, which contributes to the mitigating effects of the dynamic potential.

In Recife, the higher regions are concentrated towards the north and southwest, with a variation in heights of between 40 and 80 meters. The Guarabira neighborhood, in the extreme northwest, presents heights of over 100 meters, reaching a maximum peak of 118 meters. For the regions above 100 meters, there is a temperature decrease of 0.5°C, whereby the beneficial effects are maintained, especially in the as yet unoccupied areas, due to the existence of groupings of vegetation cover (Figure 4).

4.3 Layer 3: water masses

Areas occupied with water masses constitute open spaces that enable wind circulation, positively benefiting the adjacent regions with the mitigation of temperature and an increase in the humidity and thermal equilibrium (ROMERO, 1988, p. 28). Ng et al (2012, p. 111) highlighted how sea breezes reach two ranges of influence in the interior of the continents: the first, with greater intensity, up to the first 70 meters, and the second, with a lesser intensity, of between 71 and 140 meters (Figure 4).

In Recife, the existent water basins were defined, with equal emphasis on the complementary influence of the water masses with the use of Law No. 12.651/2012, referring to the Forest Code (BRASIL, 2012), which associates the limits attributed to the protection zones of water flows, lakes and lagoons as the zones of influence. For areas close to the Atlantic ocean, the Capibaribe River, and the Apipucos weir, amongst others, ranges of between 30 and 500 meters were established, depending on both the water extension and volume, with an extra extended range of influence, on the leeward side of the water masses, of the same distance, in conformity with the direction of the predominant winds. Various studies, including those for the city of Recife, such as that by Barros and Lombardo (2013), have been based on the attribution of these influence ranges.

4.4 Layer 4: building density

Urban regions with the highest building density and the highest degree of verticalization (Figure 5) implies greater heat storage, due to the capacity of buildings to store heat and to release it at night, modifying the air exchanges and the urban thermal plume (ROMERO, 1988, p. 36), thereby increasing the temperature and reducing humidity. The geometry of edifications configures changes in wind behavior in urban areas, changing the local microclimate with an increase in the effect of friction on the wind flows, which results in a greater air displacement and, consequently, a decrease in its velocity, also contributing to an increase in temperature (COSTA, 2003, pp. 31-32; SOUSA, 2014, p. 50). The sum of these factors potentializes the heat island effects and contributes to an increase in the thermal load.

Figure 5. The Municipality of Recife: (a) Map indicating the high density in the Municipality of Recife municipality; (b) The verticalization in Boa Viagem, Recife.
Source: Adapted from City Hall of Recife, 2019; Photograph by Ruskin Freitas, 2019.

Density and verticalization maps were produced for the municipality of Recife, since these aspects bring about different effects. Verticalization with distancing and a diversity of height is a positive factor for bioclimatism in hot, humid, tropical weather. What stood out were the dense hilly zones, to the northwest, which have no verticalization, and the small, but extremely verticalized areas, next to the Capibaribe River, and the large, dense, verticalized areas, which make up the coastal neighborhoods, towards the southeast of the municipality.

4.5 Layer 5: soil coverage

The soil coverage layer considers the amount of natural or exposed soil within the municipality, highlighting its effects in mitigating temperature for the unsealed areas, with buildings and paving, since the retained heat is easily cleared. Due to the scale of the map, permeable areas greater than 250 m^2 were considered, without distinguishing between open fields, parks and squares. For the unsealed areas, no distinction was made between materials. Thus, the neighborhoods to the north and west of the municipality are highlighted, with 77% to 97% of its surface areas composed of natural soil, while in the central neighborhoods, levels recorded in these areas were less than 2%.

4.6 Map of the microclimate zones in Recife

The climatic map for the capital of Pernambuco (Figure 6) establishes three macrozones, in accordance with the environmental units defined by the Secretariat of Planning and Environment of Recife SEPLAM/PCR (1993): the coastal macrozone, which constitutes the group of neighborhoods bordering the Atlantic ocean; the coastal plain macrozone, occupying the second largest area, resulting from the union between the land breaks in the hillside areas down to the low estuary, with no elevations or barriers that decrease or modify the velocity of the winds; and thirdly, the hillside macrozone, which occupies more than 58% of municipal land, to the north, west and southwest, presenting the mildest microclimate, due to higher areas of land and the presence of dense vegetation.

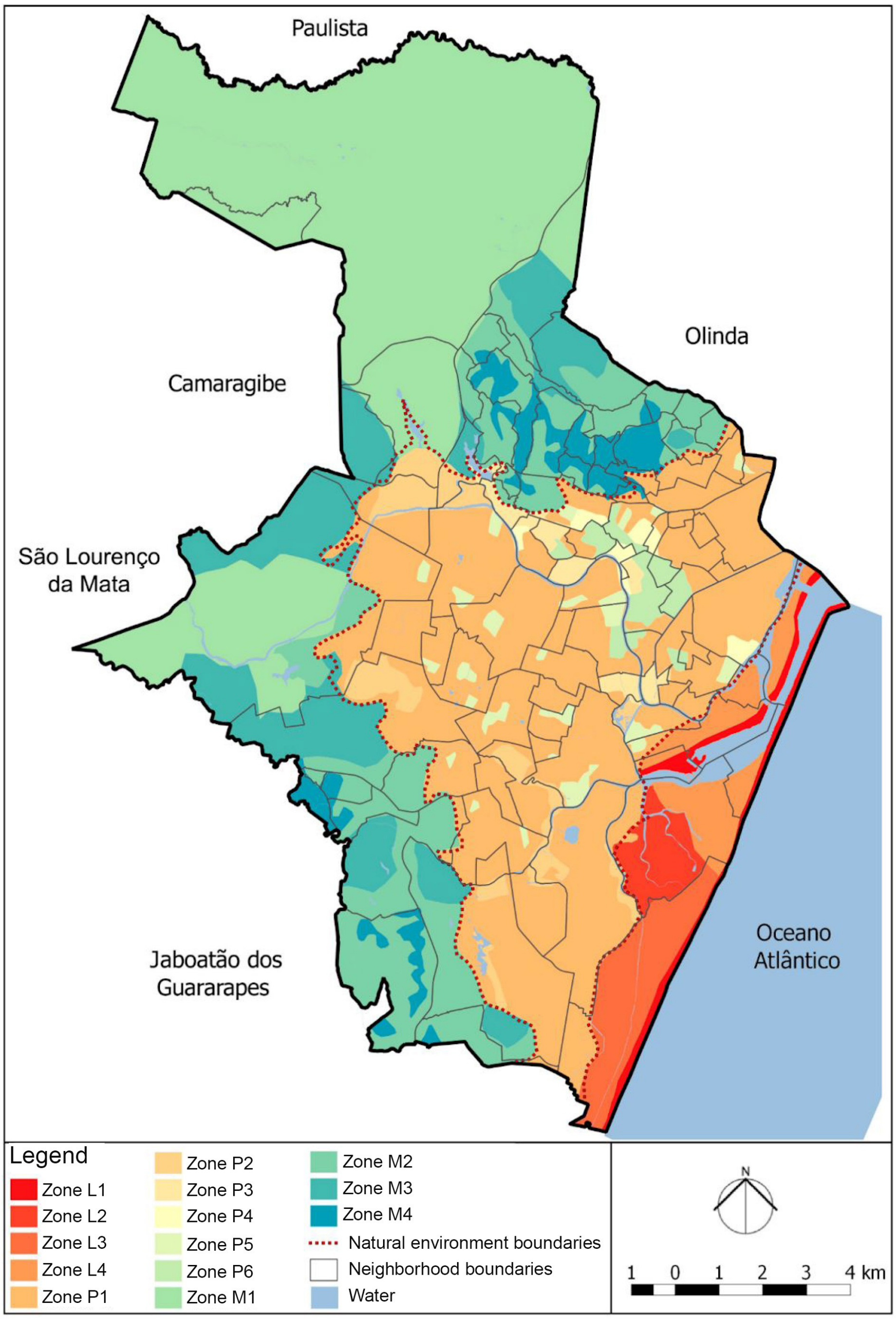

Figure 6. Map of the fourteen microclimate zones in Recife.

Source: Produced by Ruskin Freitas and Laís Carvalho, 2018.

All the following subdivisions, for Recife and for the Boa Vista and Soledade neighborhoods, were produced by the authors of this study, based on the analyses developed in the presented references.

The coastal microclimates were subdivided into four classes, from L1 to L4. In classes L1 and L2, the microclimates are milder due to the influence of the wind flows and maritimity, added to the presence of natural soil and a small area of vegetation cover. However, classes L3 and L4 present contrary effects due to a reduction in the sparce existent vegetation layer and the high building density, respectively, horizontal and vertical, thereby causing the formation of wind barriers and the heating of urban enclosures, especially for class L4.

In turn, the coastal plain microclimates are subdivided into six classes, from P1 to P6. These reflect the progressive increase in both density and verticalization, together with the removal of vegetation. Class P1 occupies most of the coastal plain and, as with class P2, is characterized by low and medium building density, although there is a progressive increase, respectively, of low and medium vegetation cover. Classes P3 and P4 cover the vertical areas of low and medium density, with a progressive increase of vegetation. Classes P5 and P6 highlight the high density areas, with a gradual increase of verticalization. Particularly outstanding in the specific case of this microclimate are the losses of vegetation cover together with the channelization and landfills of water bodies, thereby reducing the mitigating effects.

The hillside microclimates are subdivided into classes M1 to M4, which present distinct situations, from the non-urbanized localities to areas with high levels of occupancy, even without verticality. Class M1 presents the mildest microclimate due to an occupancy of low building density and to the large area of vegetation cover. Class M2 spatializes the areas with a reduction of vegetation and M3 and M4 encompass areas with medium building densification, with a gradual increase of vegetation.

The fourteen zones of the map with the environmental units were synthetized into a final map, of microclimate zoning (Figure 7), with eight urban climatic classes. Each class presents a specific assessment and recommendation according to the impacts caused in the urban climate.

- **Class 1 – Medium climate mitigation.** Air humidification and cooling, due to the large areas of vegetation and to the proximity of water masses, increasing the relative air humidity and decreasing the air temperature. The integral protection of these areas is recommended.
- **Class 2 – Low climate mitigation.** Air renovation and circulation due to the presence of forested areas, woodlands and fields, smaller areas of

vegetation in comparison to the previous class. The preservation of this region, along with low building densification is recommended.

- **Class 3 – Neutral impact.** Presents no significant climate changes due to the low building densification and to the existence of open spaces and areas with vegetation. Maintaining wind permeability is recommended, should densification occur.
- **Class 4 – Very low heat accumulation.** Very few changes in relation to the levels of climatic variables due to an increase in building density and to a decrease in vegetation cover. It is recommended that the wind permeability be maintained along with the preservation of areas with vegetation cover, should an increase in density occur.
- **Class 5 – Low heat accumulation**. A few changes in relation to the levels of climatic variables due to an increase in building density and to a decrease in vegetation cover, with the possibility of verticalization in some localities. It is recommended that a system of green areas and free open spaces should be incorporated.
- **Class 6 – Medium heat accumulation.** Changes in the levels of climatic variables due to an increase in building density, a decrease in vegetation cover, soil sealing and a decrease of wind flows. Recommendations for this class are wind permeability, the incorporation of a system of green areas and free open spaces, as well as an increase in the natural soil rate in the urban environment.
- **Class 7 – High heat accumulation.** Intense changes in the levels of climatic variables, as a result of an increase in building density, verticalization, a decrease in vegetation cover, soil sealing and a decrease in wind flows. Recommendations for this class are wind permeability, the incorporation of a system of green areas and free open spaces, as well as an increase in the natural soil rate in the urban environment.
- **Class 8 – Very high heat accumulation.** Intense changes in the levels of climatic variables, with the possible formation of heat islands, due to an increase in building density, verticalization (except for some popular settlements), a decrease in vegetation cover, soil sealing and a decrease in wind flows. Recommendations for this class are wind permeability, the incorporation of a system of green areas and free open spaces, as well as an increase in the natural soil rate in the urban environment.

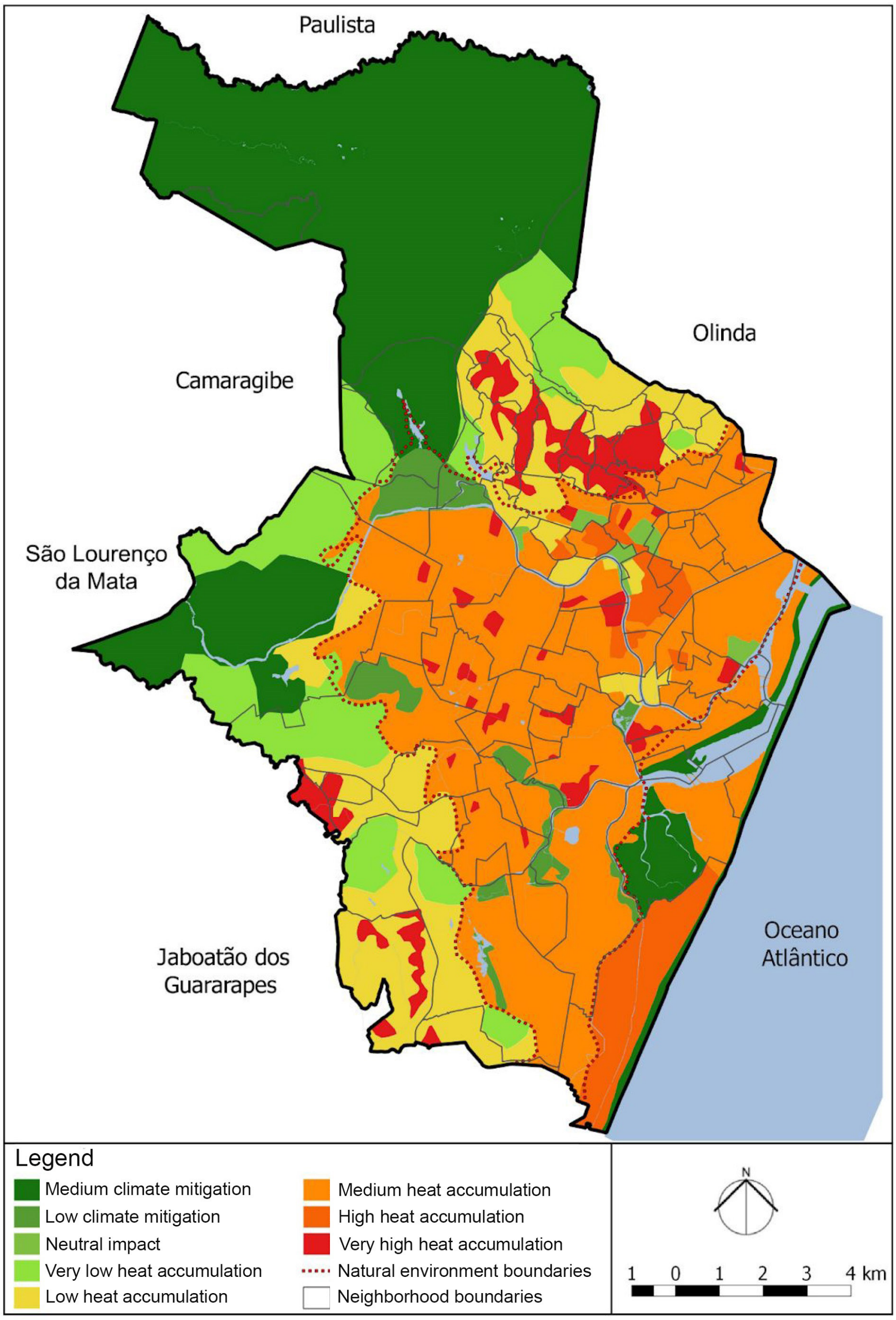

Figure 7. Map of the eight microclimate zones in Recife.
Source: Produced by Ruskin Freitas and Laís Carvalho, 2018.

4.7 Methodological procedures for Boa Vista and Soledade neighborhoods

The documentary research of the satellite images and cartographic bases was reused to produce the maps for Boa Vista and Soledade. Thus, the five base layers were maintained in order to create the microzoning map for the climatic analysis. In this phase, values were attributed to the physical aspects, even though the reality of the municipality demanded an adaptation of the German climatopes methodology of the analogue areas considering the conditions from the automatic weather station.

The atmospheric data of the municipality of Recife is registered by the Inmet automatic weather station AWS301, situated next to the natural zone, in the district of Curado. The location where the data are registered is characterized by a large clearing of natural soil to enable wind permeability, surrounded by dense Atlantic Forest, which implies lower air temperatures and higher levels of air humidity, when compared with the urban zones.

From there, values attributed to the base layers were only of positive numbers, characterizing heat accumulation.

The reference for defining the degrees of heat accumulation was taken from both previous and on-going research in the municipality, attributing the classes of heat accumulation according to the environmental, morphological and functional characteristics of each urban enclosure.

The layers of topography, vegetation cover, water masses, soil coverage and building density, together with wind permeability, sun exposure, volumetry dynamics and land use, were the factors for analysis, all of which present heat accumulation classes of 0.25°C, 0.5°C and 0.75°C. The four last factors, despite not being mapped, were nonetheless considered for the descriptive analysis.

Thus, the total heat accumulation must attain a maximum value of 6°C, in agreement with that which is registered for the urban areas of Recife. For the final classification, 0°C was attributed to neutral accumulation, 0.25°C to 0.75°C to very low accumulation, 1°C to 1.5°C to low accumulation, 1.75°C to 3.5°C to medium accumulation, 3.75°C to 4.75°C to high accumulation and 5°C to 6°C to very high accumulation.

4.7.1 Layer 1: topography

The topography layer for the local level of the Boa Vista and Soledade neighborhoods presents no height variation of over 5 meters, with no expressive values of change regarding heat accumulation. This was disregarded for the production of the final map.

4.7.2 Layer 2: vegetation cover

The classes of heat accumulation are based on the concentration levels of vegetation cover. While the large areas of vegetation cover and the immediate surroundings presented an accumulation of 0°C, they are not contained within the analyzed area. The medium area of vegetation cover corresponds to the lowest extensions of vegetation, under 4%, presenting an accumulation of 0.25°C. In the small area of vegetation cover, which is equivalent to 18.3% in the Soledade neighborhood and 12.8% in Boa Vista, and the accumulation was 0.5°C. On the neighborhood scale, a fourth class was created, corresponding to very small areas of vegetation cover, which occurs at around 30% in Soledade and in less than 4% in Boa Vista, leading to a heat accumulation of 0.75°C.

4.7.3 Layer 3: water masses

The Capibaribe River, along the edges of Aurora Street, and the Derby Tacaruna water channel, along Agamenon Magalhães Avenue, are the only water masses present in the cross-section of Boa Vista and Soledade. The areas immediately surrounding the water masses present a heat accumulation of 0.25°C, while the area in the extension range caused by the direction of the predominant winds presented an accumulation of 0.5°C. In the other areas, the accumulation was 0.75°C.

4.7.4 Layer 4: soil coverage

The areas defined as permeable soil presented a heat accumulation of between 0 and 0.25°C, in less than 7.2% of the extension of the Boa Vista neighborhood and 6.6% of Soledade. The porous impermeable soil, despite not being registered on the map, was observed, and contributed to the descriptive analysis, with an accumulation of 0.5°C. The impermeable areas presented an accumulation of 0.75°C, occupying almost the entire cross-section.

4.7.5 Layer 5: building density

In the area of Boa Vista and Soledade, a grouping grid was established of the urban spaces with dimensions of 100m x 100m, configuring the territorial area of a hectare (10.000m^2).

The built-up areas, multiplied by the mean height that they represent, defined the interval of the densities. A low building density covers a range from 0 to 2,500 m^2/ha, with a heat accumulation of 0.25°C; a medium density of between 2,501 m^2/ha and 8,000 m^2/ha, with an accumulation of 0.5°C; and a high density, with values of above 8,000 m^2/ha and an accumulation of 0.75°C. Most areas of the neighborhoods were understood as being in the high density layer, in the central areas and to the east of the spatial cross-section.

The overlap of the base layers presented a total of 22 microclimates, synthetized to twelve and, then, to eight, with three being placed into the macrozone of low building density (B1, B2 and B3), three into the medium density (M1, M3 and M3) and two into the high density (A1 and A2).

4.7.6 Map of microclimate zones in the Boa Vista and Soledade neighborhoods

A microzone map was produced for Boa Vista and Soledade (Figure 8), based on the three classes of building density.

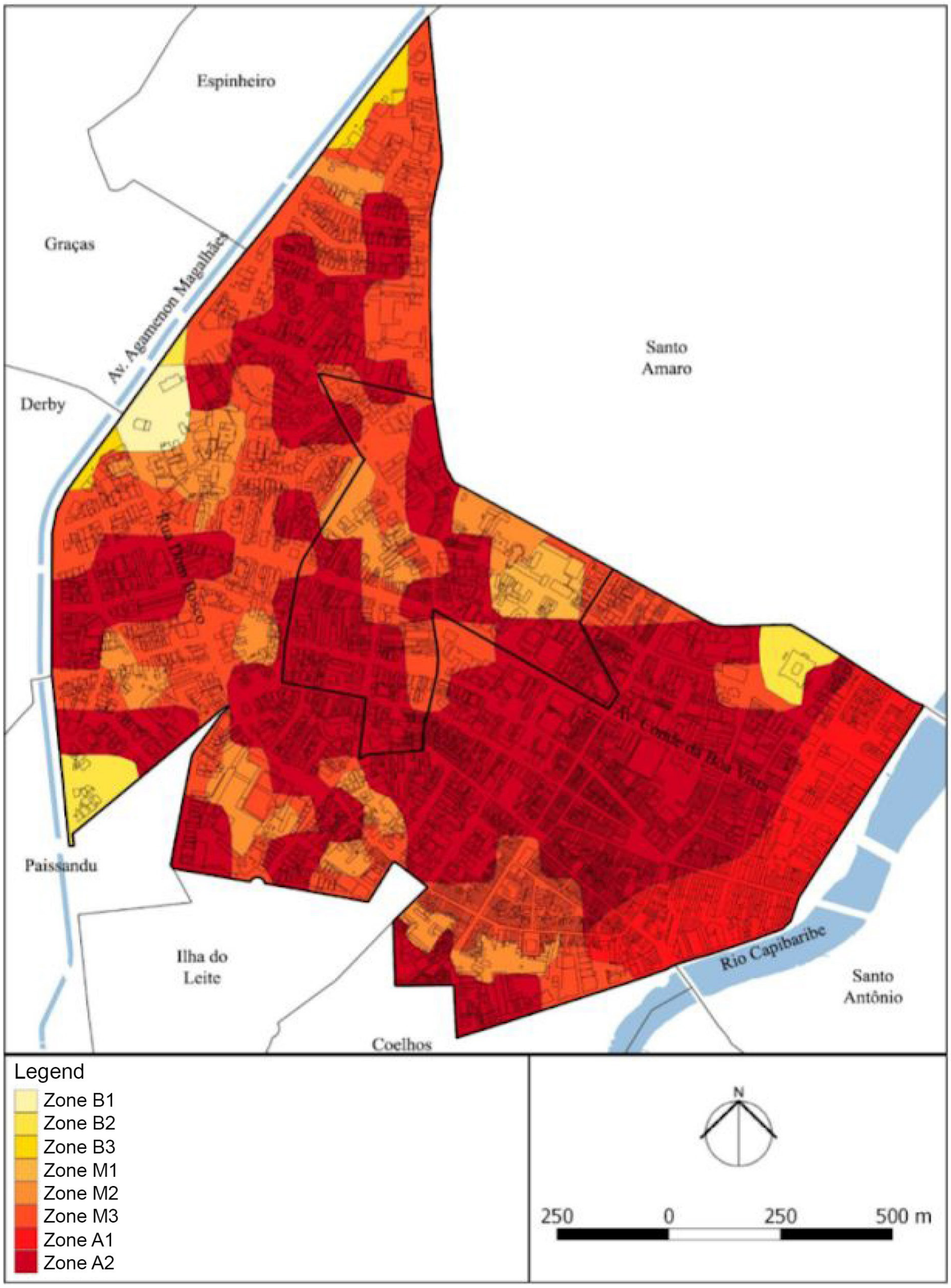

Figure 8. Map of the microzones in the Boa Vista and Soledade neighborhoods.
Source: Produced by Ruskin Freitas and Laís Carvalho, 2018.

The zones with a low building density are located on the limits of the neighborhoods, far from the Capibaribe River, and present small and medium areas of trees and permeable soil, due to the free spaces inside the lots, and the distancing between the buildings, which enables wind permeability. The areas with trees mitigate the negative effects of sun exposure. High flows of people and vehicles occur only around the proximities of Agamenon Magalhães Avenue.

The zones with a medium building density are located to the west, north and southeast of the area, which are mostly at a distance from the water masses, marked by the existence of some high buildings, by a predominance of soil sealing in public spaces and by small areas with trees inside the lots. In some places, there is a channelization of winds.

The zones with a high building density are in the oldest part of the neighborhoods, near the Capibaribe River. The vegetation is almost nonexistent and there is a predominance of sealed soil, with land use being dedicated to trade and services, which results in a high flow of people and vehicles. The low exposure to the sun inside the lots and the difficulty for wind permeability are due to the verticalization.

Taking these data as a reference, the next phase was undertaken to produce the heat accumulation map in the microclimates of Boa Vista and Soledade (Figure 9), considering that each class of heat accumulation corresponds, respectively, to one climatic class. Some recommendations were made, which are presented below, aiming to minimize heat accumulation in the urban climate.

- **Class 6 – Medium heat accumulation (between 1.75°C and 3.5°C).** It is recommended that open mitigating areas should be created, with natural soil and vegetation, in order to enable wind permeability; an urban system of planted tree needs to be created to connect the areas with trees; there should be a greater distance between the buildings, to favor ventilation and to increase the surface area of natural soil.
- **Class 7 – High heat accumulation (between 3.75°C and 4.75°C).** The recommendations for the previous class are maintained, with the addition of the need for a detailed study in the historical areas so as to preserve the buildings and recover their backyards.
- **Class 8 – Very high heat accumulation (between 5°C and 6°C).** The very high densification renders the recommendation of distancing very difficult, considering that the edifications have already been built and are firmly established. Taking advantage of the zones where the sidewalks

are wider, there is a recommendation to add natural soil areas, as well as implementing tree-planted public areas, in order to decrease exposure to the sun and to increase shading on the roads.

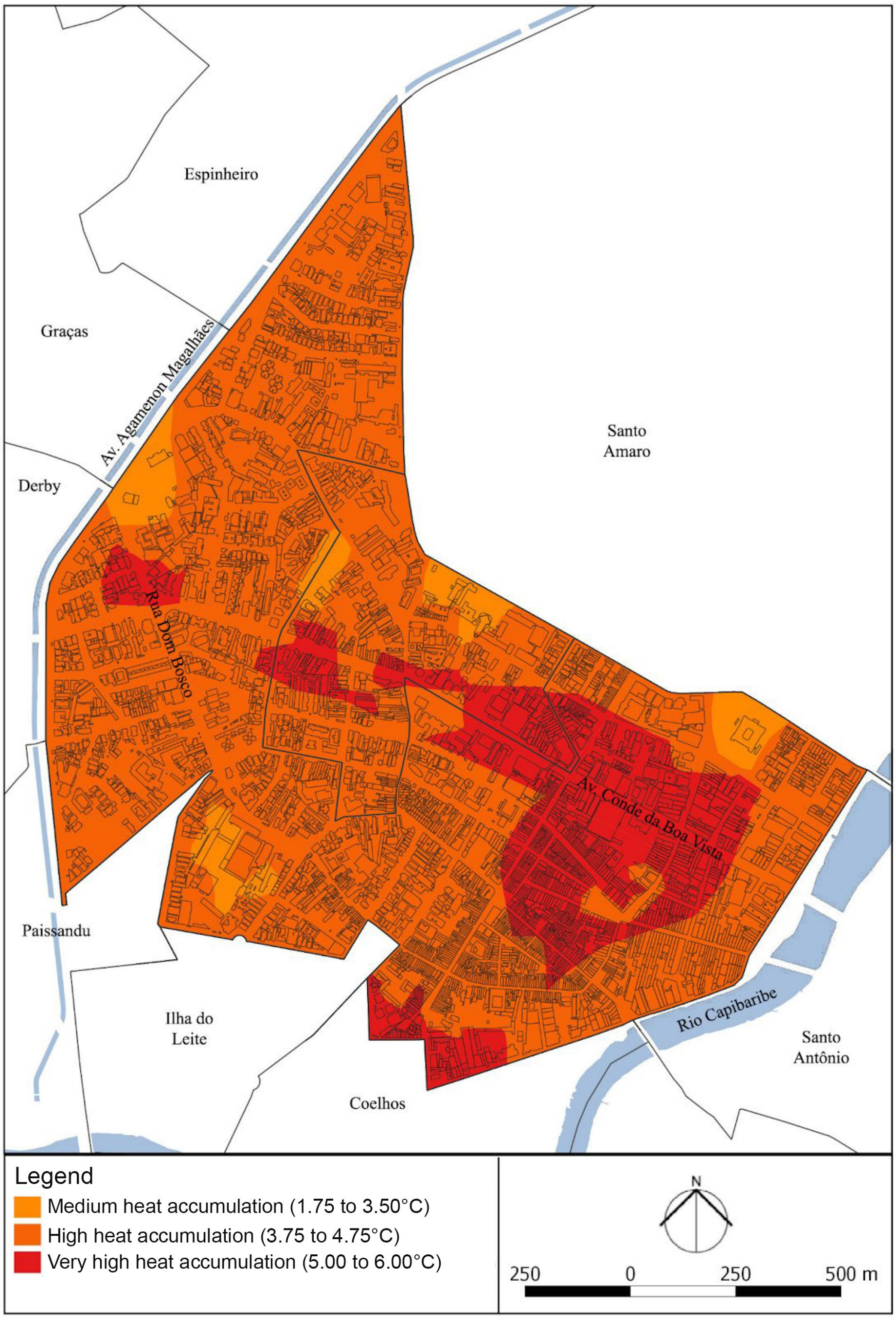

Figure 9. Heat accumulation map of the microclimates in Boa Vista and Soledade.
Source: Produced by Ruskin Freitas and Laís Carvalho, 2018.

Final considerations

The creation of climatic analysis maps involves the use of several different references, such as the temperatures provided by satellite images or by field monitoring, and does not in itself constitute the result of one of these techniques, but the analysis of a result achieved through the application of various techniques. The constructed maps, together with the recommendations, have aimed to analyze aspects of heat accumulation caused within the urban climate and to suggest more appropriate urbanism projects, in order to provide a better quality of life for the users. The registered spatial and meteorological data contributed to the construction of five base layers, referring to the topography, the building density, the vegetation cover, the soil coverage and the water masses, and included the attribution of general notions on thermal load and dynamic potential, according to the type of impact caused.

The climatic analysis map for Recife defined fourteen microclimates in three macrozones, subdivided into: coastal, with four microclimates, coastal plain, with six microclimates, and hillsides, with a further four microclimates. The main characteristics of the units were: a greater wind influence in the costal macrozone and in the hillside areas to the windward side and in the unoccupied areas, thereby constituting the climatic classes of medium mitigation. The coastal plain and coastal macrozones with a higher building density, verticalization and little vegetation presented the greatest impacts of heat accumulation. There is a possibility that the zones with heat accumulation microclimates may expand, due to the urban practices valorized by the real estate market and permitted by legislation.

For Boa Vista and Soledade, the climatic classification by topoclimates of the analogue areas needed to be adapted, with the exclusive attribution of positive values, in relation to heat accumulation. Eight microclimates were determined and synthetized into three classes of heat accumulation, from medium to very high (1.75°C to 6°C), with a predominance of high heat accumulation (3.75°C to 4.75°C). This has resulted because of their distance from the water masses, little vegetation, a high building densification and decreased wind flows. The mild areas are isolated within points of open spaces, such as squares and the lots of institutional buildings. Heat islands are present in the verticalized central region, with a high building density and greater commercial activity, concentrating high flows of people and vehicles.

This study represents an important contribution towards understanding what influences urban transformations with regard to the quality of life in cities. Furthermore, the resulting recommendations may be used to improve microclimates, particularly by technicians and administrators, since these agents may monitor the critical regions and act more quickly, due to the facility of communicating with the other social actors, thereby making urban planning and urban management more efficient. The creation of maps for Recife and some of its neighborhoods, as presented herein for Boa Vista and Soledade, is also an incentive to continue with this research into other neighborhoods of the city, as well as other municipalities, observing the specificities of each location.

We trust that these recommendations will contribute to urban management, so that it may act in the critical areas and, based on the revision of urbanistic parameters, promote guidelines for more appropriate projects on urban and architectural scales.

References

ASSIS, E.; FERREIRA, D.; KATZSCHNER, L. Construção de um mapa climático analítico para a cidade de Belo Horizonte, Brasil. *Revista Brasileira de Gestão Urbana*, Paraná, v. 9, p. 255-270, 2017.

ASSIS, W.; MACHADO, L. Proposta metodológica de mapeamento de unidades topoclimáticas. *Revista Brasileira de Climatologia*, Curitiba, v. 21, p. 186-204, 2017.

AZERÊDO, J. F. F. A. *Verde que te quero confortável*: a contribuição da arborização urbana para o conforto termoambiental ao nível do usuário pedestre. 2017. Tese (Doutorado) – Universidade Federal de Pernambuco, Recife, 2017.

BARROS, H.; LOMBARDO, M. Zoneamento climático urbano da cidade do Recife: uma contribuição ao planejamento urbano. *Revista GEOUSP – Espaço e Tempo*, São Paulo, n. 33, p. 187-197, 2013.

BAUMÜLLER, J. *et al. Klimaatlas Region Stuttgart*. Stuttgart: Verband Region Stuttgart, 2008. 167 p.

BENÉVOLO, L. *A cidade e o arquiteto*. São Paulo: Perspectiva, 1991.

BRASIL. Lei n° 12.651, de 25 de maio de 2012. Dispõe sobre a proteção da vegetação nativa; altera as Leis n°s 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis n°s 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória n° 2.166-67, de 24 de agosto de 2001; e dá outras providências. *Diário Oficial da União, Brasília*, DF, 28 maio 2012. Disponível em: https://www2.camara.leg.br/legin/fed/lei/2012/lei-12651-25-maio-2012-613076normaatualizada-pl.pdf. Acesso em: 10 ago. 2017.

BRASIL. Lei n° 10.257, de 10 de julho de 2001. Regulamenta os arts. 182 e 183 da Constituição Federal, estabelece diretrizes gerais da política urbana e dá outras providências. *Diário Oficial da União*, Brasília, DF, 11 jul. 2001. Disponível em: https://www2.senado.leg.br/bdsf/bitstream/handle/id/70317/000070317.pdf. Acesso em: 7 agosto 2020.

_________. Lei n° 6.766, de 19 de dezembro de 1979. Dispõe sobre o Parcelamento do Solo Urbano e dá outras Providências. *Diário Oficial da União*, Brasília, DF, 20 dez. 1979. Disponível em: http://www.planalto.gov.br/ccivil_03/leis/l6766.htm. Acesso em: 2 jul. 2020.

COSTA, A. *Análise bioclimática e investigação do conforto térmico em ambientes externos:* uma experiência no bairro de Petrópolis em Natal/RN. 2003. Dissertação (Mestrado em Arquitetura e Urbanismo) – Universidade Federal do Rio Grande do Norte, Natal, 2003.

FREITAS, R. *Entre mitos e limites:* as possibilidades do adensamento construtivo face à qualidade de vida no ambiente urbano. Recife: Ed. da UFPE, 2008.

FROTA, A. B.; SCHIFFER, S. R. *Manual de conforto térmico:* arquitetura, urbanismo. 5. ed. São Paulo: Studio Nobel, 2001.

IBGE. INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. *Cidades e Estados*. Disponível em: https://www.ibge.gov.br/cidades-e-estados/pe/recife.html. Acesso em: 22 abr. 2020.

_________. *Mapa de clima do Brasil*. Rio de Janeiro: Diretoria de Geociências: Ministério do Planejamento, Orçamento e Gestão, 2002. Disponível em: https://geoftp.ibge.gov.br/informacoes_ambientais/climatologia/mapas/brasil/Map_BR_clima_2002.pdf. Acesso em: 8 jun. 2013.

INMET. INSTITUTO NACIONAL DE METEOROLOGIA. *Normais climatológicas do Brasil 1981-2010*. Disponível em: http://www.inmet.gov.br/portal/index.php?r=clima/normaisClimatologicas. Acesso em: 22 abr. 2020.

IPCC. PAINEL INTERGOVERNAMENTAL SOBRE MUDANÇAS CLIMÁTICAS. Aquecimento global de 1,5°C. *Relatório especial do Painel Intergovernamental sobre Mudanças Climáticas (IPCC)*, 2018. Disponível em: https://www.ipcc.ch/site/assets/uploads/2019/07/SPM-Portuguese-version.pdf. Acesso em: 6 ago. 2020.

LACAM. LABORATÓRIO DE CONFORTO AMBIENTAL. *Estudo de mapas de vegetação da cidade de Recife*. Recife: Departamento de Arquitetura e Urbanismo, Universidade Federal de Pernambuco, 2016.

MASCARÓ, L. *Ambiência urbana*. Porto Alegre: Sagra-DC Luzzatto, 1996. 199 p.

MENDONÇA, V. *Conforto térmico na concepção da forma urbana:* o caso do Porto Olímpico no Rio de Janeiro. 2012. 101 p. Dissertação (Mestrado em Engenharia Urbana e Ambiental) – Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, 2012.

MONTEIRO, C. *Clima urbano*. São Paulo: Contexto, 2003.

NG, E. *et al. Final report of Hong Kong urban climatic map and wind environment – Feasibility study.* Hong Kong: CUHK, Department of Architecture, 2012. Disponível em: https://www.researchgate.net/publication/283806656. Acesso em: 11 mar. 2020.

PBMC. PAINEL BRASILEIRO DE MUDANÇAS CLIMÁTICAS. Mudanças climáticas e cidades. *Relatório especial do Painel Brasileiro de Mudanças Climáticas* [RIBEIRO, S. K.; SANTOS, A. S. (ed.)]. Rio de Janeiro: PBMC, Coppe-UFRJ, 2016. Disponível em: http://www.pbmc.coppe.ufrj.br/documentos/Relatorio_UM_v10-2017-1.pdf. Acesso em: 6 ago. 2020.

RECIFE. *Curva de nível e recursos hídricos.* Recife: Prefeitura da Cidade do Recife, 2018. [Arquivo em formato shapefile (.shp)].

__________. Lei nº 17.511/2008. Promove a revisão do Plano Diretor do Município do Recife. *Diário Oficial da Prefeitura do Recife,* Recife, 29 dez. 2008. Disponível em: https://leismunicipais.com.br/a1/plano-diretor-recife-pe. Acesso em: 7 ago. 2020.

RECIFE. *Unidades ambientais do Recife*. Recife: Seplam/PCR, 1993.

REIS, N. *Notas sobre urbanização dispersa e novas formas de tecido urbano*. São Paulo: Via das Artes, 2006.

RIBEIRO, C. *Atualização e aprofundamento do mapa de análises climáticas do município de João Pessoa-Paraíba*. 2013. 159 p. Dissertação (Mestrado em Arquitetura e Urbanismo) – Centro de Tecnologia da Universidade Federal da Paraíba, João Pessoa, 2013.

RIBEIRO, C; BRAZ, A.; SILVA, F. Mapa de análises climáticas de João Pessoa – Paraíba. In: ENCONTRO NACIONAL DE CONFORTO NO AMBIENTE CONSTRUÍDO, 12., 2013, Brasília. Anais [...]. Brasília: UnB-FAU, 2013. p. 1-10.

ROMERO, M. *Princípios bioclimáticos para o desenho urbano*. São Paulo: Projeto, 1988.

ROVATI, J. F. Urbanismo versus planejamento urbano? *Revista brasileira de estudos urbanos e regionais*, v. 15, n. 1, p. 33-58, maio 2013.

SOUSA, J. *Influência da forma urbana na ventilação natural:* um estudo de caso no Cais José Estelita. 2014. 179 p. Dissertação (Mestrado em Desenvolvimento Urbano) – Universidade Federal de Pernambuco, Recife, 2014.

SOUZA, V. *Mapa climático urbano da cidade de João Pessoa-PB*. 2010. 114 p. Dissertação (Mestrado em Arquitetura e Urbanismo) – Centro de Tecnologia da Universidade Federal da Paraíba, João Pessoa, 2010.

SPOSITO, E. *Geografia e filosofia:* contribuição para o ensino do pensamento geográfico. São Paulo: Ed. da Unesp, 2004.

UNITED NATIONS. *World Urbanization Prospects:* The 2018 Revision (ST/ESA/SER.A/420). New York: Department of Economic and Social Affairs, Population Division, United Nations, 2019a.

__________. *World Population Prospects 2019:* Highlights (ST/ESA/SER.A/423). New York: Department of Economic and Social Affairs, Population Division, United Nations, 2019b.

Ruskin Fernandes Marinho de Freitas

Graduated in Architecture and Urbanism from the Universidade Federal de Pernambuco, with a master's degree in Geography from the same institution. He obtained a doctorate degree at the Marseille-Luminy University, in France. He worked, between 2007 and 2013, at the Pernambuco State Agency for Planning and Research as technical manager of the Metropolitan Developing Region and manager for Urban and Regional Studies. Since 1996, he has been a professor at UFPB, on the Graduate Course in Architecture and Urbanism and on the Post-Graduate Program in Urban Development, and is a supervisor for master's and doctorate degrees. He develops research activities at the Laboratório de Conforto Ambiental (LACAM). He was the head of the Architecture and Urbanism Department between 2013 and 2015. He has been the coordinator of the graduate course in Architecture and Urbanism since 2019. He has experience in and publications on urban and regional planning, as well as environmental comfort and bioclimatic architecture and urbanism.

Email: ruskin37@uol.com.br

ORCID: 0000-0001-7347-8302

Authorship contribution: Supervision; Writing – first draft; Writing – review and editing.

Jaucele de Fátima Ferreira Alves de Azerêdo

Graduated in Architecture and Urbanism at the Universidade Federal de Paraíba, with a diploma in Advanced Studies from Villes et Sociétés at the Institut National des Sciences Appliquées of Lyon (2004), a master's degree in Urban Development from the Universidade Federal de Pernambuco (UFPE) and a doctorate in Urban Development from the same institution. She has been an adjunct professor at UFPE, the internship coordinator for the Architecture and Urbanism course, since 2018, and is coordinator of the Laboratório de Conforto Ambiental (Lacam), where she develops research activities. She has experience in and publications on Architecture and Urbanism, with emphasis on environmental comfort.

Email: jaucele_azeredo@hotmail.com

ORCID: 0000-0002-5853-8052

Authorship contribution: Supervision; Writing – first draft; Writing – review and editing.

Laís Teixeira de Carvalho

Graduated in Architecture and Urbanism from the Universidade Federal de Pernambuco. Currently, she is obtaining a specialization degree in Master BIM: Management Tool and Projects at the Instituto de Pós-graduação (Ipog)/Recife.

Email: carvalhotlais@gmail.com

ORCID: 0000-0002-0769-5461

Authorship contribution: Writing – first draft.

Renato Freitas da Costa

Graduated in Architecture and Urbanism from the Universidade Federal de Pernambuco and a researcher at the Laboratório de Conforto Ambiental (Lacam). He received an Honorable Mention for the UBS Architectural Project, at the XI José Miguel Aroztegui Biennial, in the Ibero-American Student Contest of Bioclimatic Architecture, in 2019 (Theme: Healthcare facilities). He is interested in and has publications on environmental comfort, urban projects and design.

Email: rena.fc22@gmail.com

ORCID: 0000-0002-3516-123X

Authorship contribution: Writing – first draft.

Submitted: May 6, 2020.

Approved: November 16, 2020.

How to cite: FREITAS, R. F. M.; AZERÊDO, J. F. F. A.; CARVALHO, L. T.; COSTA, R. F. Climate map as an instrument for urban planning. *Revista brasileira de estudos urbanos e regionais*. v. 23, E202108en, 2021. DOI 10.22296/2317-1529.rbeur.202108en