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CLIMATE IMPACTS IN THE MARÉ FAVELA COMPLEX

IMPACTOS CLIMÁTICOS NO COMPLEXO DE FAVELAS DA MARÉ

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Abstract

Anthropogenic actions have caused increasing and alarming climate impacts in different regions of the planet. In a predominantly urban world, global warming does not distinguish between natural or hybrid environments nor formal or informal urban settlements. Rio de Janeiro is representative of the social inequalities in the country that affect the poorest strata of society more strongly. Paying attention to favelas and their populations is an important and original objective. It brings predictability to be local and regional actions related to vulnerable groups and raises awareness of environmental problems. Currently, there are about 1,000 favelas in the city, and approximately 45% of the population lives in favelas in the Planning Area (AP-3). This study focuses on one of the 16 communities that comprise the huge and emblematic Maré Favela Complex, which has about 140,000 residents. This community is called Nova Holanda and comprises approximately 14,000 residents. It is a settlement originally planned (1962) and emerged due to removal policies. The study highlights how careless human actions can result in environmental impacts in precarious settlements, particularly in favelas. The adopted methodology is based on computer simulations related to the microclimate, carried out mainly through the ENVI-met 3.1 program. This study, which has emerged from the fields of environmental sciences and urbanism, is important in developing diagnoses to provide subsidies for future proposals for upgrading slums based on concepts and guidelines normally adopted for the so-called formal areas of the city, even with possible adaptations.

Keywords: Precarious settlements, environmental quality, heat islands, computational simulation.

Resumo

As ações antropogênicas têm acarretado crescentes e alarmantes impactos climáticos em diferentes regiões do planeta. Em um mundo predominantemente urbano, o aquecimento global não distingue meios naturais ou híbridos, tampouco assentamentos urbanos formais ou informais. O Rio de Janeiro é representativo das iniquidades sociais do país que afetam mais fortemente as camadas mais pobres da sociedade. Dar atenção às favelas e suas populações representa um objetivo importante e original, pois traz previsibilidade às ações locais e regionais relacionadas aos grupamentos vulnerabilizados, além de conscientização frente aos problemas ambientais. Atualmente, há cerca de 1.000 favelas na cidade, com predomínio de cerca de 45% da população moradora de favelas na Área de Planejamento (AP-3). O presente trabalho se concentra em uma das 16 comunidades que conformam o enorme e emblemático Conjunto de Favelas da Maré, com cerca de 140.000 moradores: a Nova Holanda, com 14.000 moradores. Um assentamento, em essência planejado (1962), que surgiu em função das políticas remocionistas. O estudo destaca como ações antrópicas descuidadas podem resultar em impactos ambientais em assentamentos precários, com particularidade em favelas. A metodologia adotada é baseada em simulações computacionais relativas ao microclima, realizadas principalmente através do programa ENVI-met 3.1. Este estudo, que emerge dos campos das ciências ambientais e do urbanismo, tem como relevância desenvolver diagnósticos de forma a fornecer subsídios para futuras propostas de requalificação de favelas, partindo, portanto, de conceitos e diretrizes adotados normalmente para as ditas "áreas formais" da cidade, mesmo com possíveis adaptações.

Palavras-chave: Assentamentos precários, qualidade ambiental, ilhas de calor, simulação computacional.

Authors' contribution:
LDB: conceptualization, data curation, formal analysis, investigation, methodology, programs, validation, visualization, writing - original draft, review and editing. **PRCD**: conceptualization, formal analysis, research, methodology, programs, supervision, validation, visualization, writing - original draft, review and editing. **JM**: conceptualization, formal analysis, investigation, methodology, supervision, validation, writing - original draft, review and editing.

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Introduction

Human activities may have contributed to global warming by approximately 1.0°C, taking pre-industrial times as a reference (IPCC, 2018). Among various actions, the temperature increase may reach 1.5°C between 2030 and 2052 according to projections (IPCC, 2018), if concrete political, economic, operational, environmental measures are not adopted on a global, regional and local scale, mainly aiming to reduce greenhouse gas emissions. This fact should provide a general picture of an increase in average temperature on most land and ocean surfaces, extreme heat in inhabited regions, severe precipitation in several regions and the possibility of drought and precipitation deficit in many regions (IPCC, 2018). If, in nature, the consequences significantly affect plants, vertebrates, insects, etc., leading to impacts on biodiversity and the balance of many ecosystems among human groups, especially the most fragile, this situation requires specific attention (NYSTROM; SCHUG, 2020). Worsening disasters associated with nature by anthropogenic action poses not only a threat to the most vulnerable, in terms of resources and social protection, but also ends up "undermining efforts to end poverty in all its forms everywhere and to achieve sustainable development" (UNITED NATIONS, 2016).

Bruna and Pisani (2010, p.59) consider that regardless of the causes related to climate change, "the poorest populations are the most affected by all adverse weather events", mainly because, in general, they are settled in regions with greater vulnerability as in the case of favelas.

According to the "2010 Demographic Census – Subnormal Agglomerates" (IBGE, 2010), 6% of Brazil's population, 11,425,644 people, were living in subnormal agglomerations (AGSN) in 3,224,529 occupied private households. Approximately 88% of these households are located in 20 out of 36 metropolitan regions in the country. In the city of Rio de Janeiro, there are about 1.4 million residents who live in favelas, which corresponds to 22% of the total population.

The present study was carried out within the Maré Favela Complex. Located in Planning Area 3 (AP3), in the North Zone of the city of Rio de Janeiro, this complex has around 140 thousand inhabitants and approximately 48 thousand households, distributed into 16 communities. The research was carried out in one of the 16 existing communities: the *Nova Holanda* community, a settlement that emerged in 1962, from recurrent removal policies at the time. The main aim is to show the evolution of the territory occupation and associate the microclimatic characteristics common in favelas with their environmental conditions. The aim is to understand how the climatic variables were affected in the Maré Favela Complex (Complexo de Favelas da Maré), adopting a specific study for the *Nova Holanda* community due to the lack of planning and adaptation to climate issues. It can be observed that the consequences are not restricted to temperature values, but also to the action of extreme events that already cause damage to the region. In order to understand the current scenario, a computer simulation was carried out, allowing the reading of air temperature values and understanding of the blocks that the urban form offers to ventilation.

Global warming forecasts (IPCC, 2018), with increases of up to 1.5°C, may represent an important and much greater variation of air and surface temperature values, given the interaction with coating materials and wind blocks.

From a methodological point of view, the simulation carried out using the ENVI-met 3.1 program helps to assess the microclimatic conditions observed in the region, in different streets of the community, maintaining the heights of the buildings and existing building densities. Based on the measurements, it is expected to contribute to the proposition of mitigating and preventive measures, having systemic objectives, for the environmental balance of the place.

Rationale

The Non-governmental Organisation called *Observatório de Favelas*, based in the Maré Favela Complex (or simply Maré), Rio de Janeiro, RJ, proposed the following theme in 2009: "What is a Favela, anyway?". Based on that, some formulations were registered that are presented as the Declaration of Principles (SILVA *et al*., 2009). First, it is important to understand that the favela is a territory where the incompleteness of policies and State actions are recurrent: "(...) favelas are, in general, territories without guarantees of fulfilling social rights, which has implied the low expectation of these same rights on behalf of its residents" (SILVA *et al*., 2009, p. 96).

Favelas are places of historical recurrence, lacking basic sanitation, accessibility and housing infrastructure. Finally, recognizing them as part of the city means providing them with the "same" solutions, alternatives, care and strategies that can be found throughout the city: "Favela means an urban dwelling that summarizes the unequal conditions of Brazilian urbanization and, at the same time, the struggle of citizens for the legitimate right to inhabit the city" (SILVA *et al*., 2009, p. 97).

In general, they are fragmented and often unpleasant places, where spaces for recreation and sports are scarce. Another issue that makes the favela environment even more environmentally damaged is the lack of afforestation. "A common element in Rio's favelas is the lack of afforestation, especially in the more populous and densely populated ones. Buildings take up almost all available spaces and the few existing trees resist concrete" (REDES DA MARÉ, 2019, p. 61).

"Although it bears the hallmark of the city of Rio de Janeiro, at the beginning of the 20th century, (...), favelas could be found in most large Brazilian cities and, since 2000, also in medium-sized cities" (PASTERNAK; D'OTTAVIANO, 2016). In Rio de Janeiro, at the beginning of the 20th century, the urban reform of the city, led by Pereira Passos, removed part of the *tenement* (favelas) without offering the impoverished population an alternative to housing. In general terms, this is the context of the emergence and consolidation of favelas in the locality, which made them the main alternative of housing for the poor throughout the 20th century (ABREU, 2013).

Abreu (2013) points out that from 1930 to 1950, Rio de Janeiro had a great population growth, caused mainly by the increase in the migratory flow towards the Capital of the Republic. Several factors contributed to the demographic growth in this period, the most important of which was the industrial growth of the city, which initially began to attract a large workforce from nearby states and later from the northeastern states, when the Rio-Bahia highway was constructed.

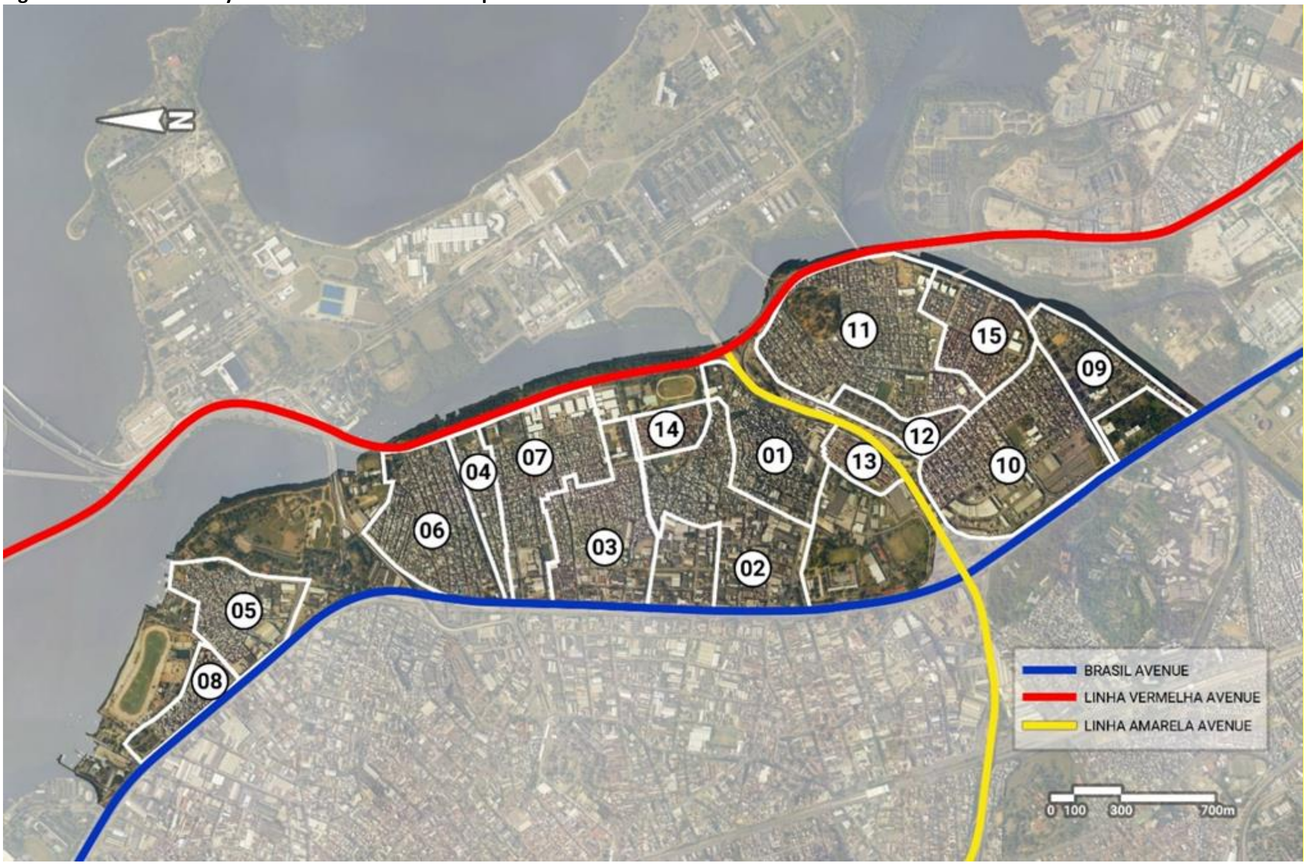
In the 1930s, during the transformations that were taking place in Rio de Janeiro, the city began to be restructured and the State began to intervene in sectorizing industries, defining an industrial zone that would be located in a large part of the North Zone, in addition to the railway track that reaches *Central do Brasil, railway station at Rio de Janeiro city center.*

One of the most important projects implemented was the construction of *Brasil* Avenue (opened in 1946). A new structuring axis was created that intended not only to resolve issues related to traffic at the time, but also to incorporate new land into the urban fabric, aiming at industrial occupation. However, another type of land occupation was implanted there, competing with the industry: the favelas. In the 1940s, 1950s and

1960s, the process of the favelas emerging continued to be quite intense, and they were located mainly close to important roads such as *Avenida Brasil* and railways. The vast majority of favelas that emerged in the city from 1948 to 1960 are located near *Avenida Brasil* (ABREU, 2013): "*Avenida Brasil* contributed to the occupation and consolidation of Maré, because, in addition to promoting landfills and access roads, which were starting points for many occupations, it attracted many people who worked on the construction in the surroundings" (DINIZ; BELFORT; RIBEIRO, 2012, p. 82).

The Maré Favela Complex (Figure 1) was consolidated between the 1940s and the beginning of the 2000s, from the initiative of residents or housing programs promoted by governments. Currently, its territory has three important roads, two of which limit the territory and another that crosses the complex: *Avenida Brasil*, *Linha Vermelha* (President João Goulart highway) and *Linha Amarela*, respectively.

Figure 1 - Location and layout of the Maré Favela Complex



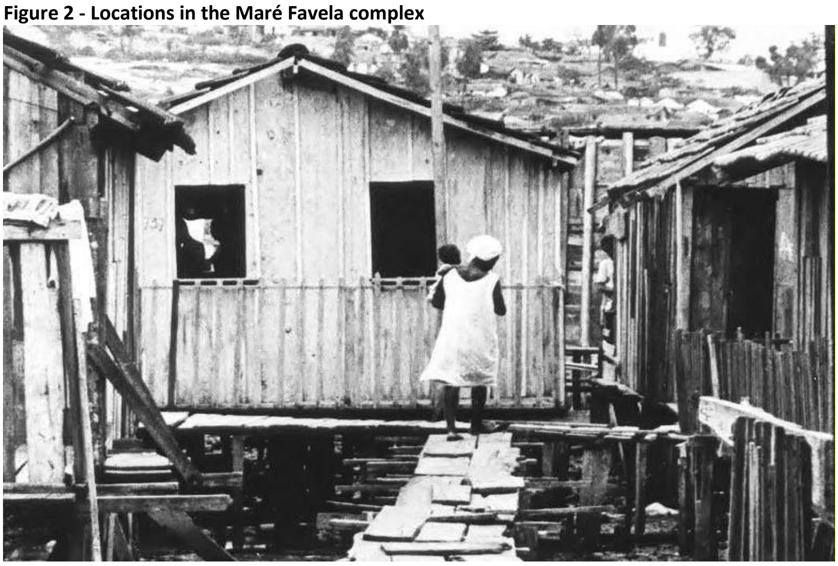
Source: adapted from Google Earth (image taken in 2021).

Figure 1 shows the 15 communities that are now recognized by the government as those that comprise the Maré neighbourhood, since in 1994 the Maré Favela Complex was transformed into a neighborhood (Municipal Law nº 2,119, of January 19, 1994), and was called "*Bairro Maré*" Maré (neighbourhood). However, for the residents, there is still a community (Marcílio Dias) that is recognized as part of this complex. Due to territorial discontinuity, however, it was left out of what today comprises the Maré neighbourhood (number 08 on the map in Figure 1). In this study, only the communities that comprise the Maré Neighbourhood, popularly known as *Complexo de Favelas da Maré*, will be considered.

The communities that comprise the Maré neighbourhood (Figure 1) and the base year of their emergence are, in chronological order: 01 - Morro do Timbau (1940), 02 - Baixa do Sapateiro (1947), 03 - Parque Maré (1953) , 04 - Parque Rubens Vaz (1954), 05 - Parque Roquete Pinto (1955), 06 - Parque União (1961), 07 - Nova Holanda (1962), 08 - Praia de Ramos (1962), 09 - Vila do João (1982), 10 - Conjunto Esperança (1982), 11 - Vila dos Pinheiros (1983), 12 - Conjunto Pinheiros (1989), 13 - Conjunto Bento Ribeiro Dantas (1992), 14 - Nova Maré (1996) and 15 - Novo Pinheiros (2000). From the map in Figure 1, it can be observed how the emergence and expansion of the Maré Favela Complex developed.

Currently, the Maré Favela Complex has a population of 139,073 inhabitants, living in 38,273 households (REDES DA MARÉ, 2019). It is the largest group of favelas in Rio de Janeiro and has a population equivalent to that of an average Brazilian city. The communities that comprise it have very different characteristics and spatial processes, ranging from planned to spontaneous ones, from regular to irregular, and from formal to informal. The differences between the forms are due to factors ranging from the origins of the population, the organisation of the community and the political and social contexts. Its territory was built from a region originally characterized by mangroves and swamps that were gradually taken over by the residents, and later by government actions. A process of transforming a predominantly natural environment into a completely artificial region, where mangroves were no longer present until they were heavily degraded as an ecosystem (AMADOR, 2013). Figure 2 shows how the houses were implemented in the initial process of occupation of almost all the communities that emerged there.

Figure 2 - Locations in the Maré Favela complex



Source: Museu da Maré, Rio de Janeiro, RJ.

Stilt houses appeared, in general, in the Guanabara Bay and were constantly flooded or muddy when the tide rose. Housing precariousness was enormous, forcing people to live in a totally unhealthy environment, where difficulties include - and still are - a lack of drinking water supply, sanitary sewage, garbage collection, etc. (CARVALHO, 2016).

The community chosen for this specific study was *Nova Holanda* (1962) (Figure 1 and Figure 3), which currently has a population of 13,799 people distributed in 4,601 properties (REDES DA MARÉ, 2019, p. 23). This favela is located in the landfill area of Guanabara Bay, bordered by *Avenida Brasil (Brasil Avenue)* and *Linha Vermelha (Linha Vermelha Avenue)*, two lanes that have intense vehicle traffic in the metropolitan region.

Figure 3 – *Nova Holanda* Community

Source: adapted from Google Earth (image taken in 2021).

The origin of Nova Holanda "dates back (...) as a Provisional Housing Center (*Centro de Habitação Provisória* - CHP), created by the State of Guanabara Government in the 1960s, in the context of politics of sanitizing spaces" (REDES DA MARÉ, 2019, p. 36) in Governor Carlos Lacerda's administration. Residents of other favelas were brought to this landfill region to acquire "'new habits' – cleanliness, hygiene, coexistence – considered more appropriate by the government – residents were victims of prejudice and stigmatized as 'uncivilised'" (REDES DA MARÉ; OBSERVATÓRIO DE FAVELAS, 2014, p.57). Idealised as CHP, "[the] dwellings (Figure 4) were uniform and distributed in lots of five metres wide and ten metres long. The structures were built out of wood and followed two models: one part was low-rise dwellings and the other two floors, known as duplexes" (REDES DA MARÉ; OBSERVATÓRIO DE FAVELAS, 2014, p. 86).

Figure 4 – *Nova Holanda* and original dwellings

Source: Museu da Maré, Rio de Janeiro, RJ.

Because this community was originally implemented by government action, it was created with the same characteristics as the so-called formal city of the time: grid layout, standardized streets and blocks; however, with structures and features of a temporary nature, since the residents, supposedly, would stay there for a limited time and then would be transferred to other regions where they would receive permanent housing. The years passed and *Nova Holanda*, as well as the whole of Maré, underwent transformations. The wooden houses were replaced by masonry structures. New houses were built, and expansion took place both horizontally and vertically. As a result, impervious soil areas grew, since in all available spaces people were building more and more houses, respecting only the limit of the pavements and in many cases not even that (REDES DA MARÉ, 2019).

In addition to the political and social issues that led to the emergence of the *Nova Holanda* community, the approach to another issue is relevant: the process of transforming the place where it was implanted, to better understand its current state. The process of transforming an environment can increase the impacts arising from climate change, either by flooding caused by torrential rain, by excessive heat due to the materiality introduced in an environment or by the degradation of the natural environment, mainly, in this case, the green areas and mangroves, among others. It is important to understand the transformation process of an environment and how the history of interventions impacted, positively or negatively, to propose regenerative or mitigating actions.

Thus, a study was carried out presenting phases of the formation and consolidation process of the *Nova Holanda* community. Figures 5a-d illustrate this process.

Figure 5 – Nova Holanda consolidation process: (a) pre-implementation area, (b) -implementation, (c) evolution and (d) consolidation

Source: the authors.

Figure 5a depicts the pre-implementation area of *Nova Holanda*, in 1961, one year before it was implemented. The diagram shows a a strip of landfill advancing over the mangrove, which, in this case, was done by the populations that were occupying the region. The mangrove area was almost entirely intact, as was the channel (*Canal do Fundão*). At this time, the original features of the environment were well preserved, where the tidal cycle covered and uncovered the mangrove strip.

The image in Figure 5b represents 1962, the year *Nova Holanda* was implemented. It can be observed that the strip of landfill continued to grow, at the initiative of those who arrived to live there. For the implementation of the Nova Holanda CHP, carried out in two phases, the government made a large landfill over the mangrove, abruptly altering the environment. At this time, the mangrove strip was greatly reduced. The channel boundary remained with the same layout.

After implementing *Nova Holanda*, the other communities that were around it continued to grow in the same process of filling in and building on the mangrove. It can be seen in Figure 5c that its entire surroundings are already occupied, and all the surrounding mangroves are no longer there. The landfill shown in this figure is the result of government action that, in the late 1970s, intervened in an extensive mangrove strip along the existing communities (Project-Rio), thus creating the current territory layout, in which the environmental elements were abruptly affected. The dashed line on the landfill strip represents what would later become the current *Linha Vermelha Avenue*, implemented in 1992. It is also observed that in new scenarios of areas that are continuously filled with landfills, there are practically unused territories, but there are areas reserved for new occupations (whether formal or informal).

Figure 5d shows *Nova Holanda* today, with the total occupancy of its boundary, whether by housing or other equipment for collective use. Nowadays, the Red Line is already in place. Comparing Figure 5a with Figure 5d, the intense transformation that the region underwent during this period can be observed. The process of extinguishing the mangrove has been occurring continuously, the channel strip was greatly reduced, the permeability of the soil was modified both by the buildings and by paving the roads, which were almost non-existent. The consolidation of this community, in a definitive way, was a contingency to the housing aspirations for those who only had that option.

ENVI-met was used for the simulations, which is a three-dimensional non-hydrostatic microclimate model developed to calculate and simulate climatic variables in urban areas with a typical grid resolution of 0.5 and 10 m. It considers the complete radiation set (i.e., direct, reflected and diffuse solar radiation and long-wave radiation) and models the evolution of climatic variables during diurnal cycles using laws of fluid dynamics and thermodynamics. Its calculation involves the state of the atmosphere combining the influence of buildings, vegetation, surface characteristics, soils and climatic conditions. The main input parameters include meteorological data, initial projections of soil moisture and air temperature, building dimensions, street width, number of floors and urban coverings, and vegetation. In this case, the tree species size is informed and, in case there is not exactly the same individual, the choice is made by similarity.

ENVI-met has been widely used and evaluated for different purposes, especially the effects of different urban design options to assess the outdoor thermal environment (SILVA; BARBOSA; DRACH, 2020; BARBOSA; DRACH; CORBELLA, 2019; NG *et al*., 2012; CHOW *et al*., 2011; KRÜGER; MINELLI; RASIA, 2011). Their studies range from analysing the effect of the height of buildings on the thermal comfort of cities (CARFAN; GALVANI; NERY, 2012) to microclimate studies in parks considering the built elements, ground coverings, vegetation and shading in order to assess the thermal comfort and sensation of its users in different seasons (ÉGERHÁZI; KOVÁCS; UNGER, 2013); it also makes it possible to assess the impact of heat mitigation strategies in current scenarios and in climate change scenarios (MIDDEL; CHHETRI; QUAY, 2015); and, finally, it can also assess urban forms and how they can provide a more comfortable microclimate on hot days throughout the year (TALEGHANI *et al*., 2015), and variations can be observed even at specific times of the day.

Assis (2006) indicates that both in tropical and temperate areas, local climate change is associated with effects of energy transformation in the area, depending on its morphology, the thermal properties of the surface materials and anthropogenic heat flux. A reduction in the rates of evaporative and convection cooling is observed due to soil impermeabilization, a decrease in the surface covered by vegetation and the reduction in wind speed due to the increase in surface roughness.

The amount of heat absorbed by a region is related to the density of built-up areas and the existence and disposition of water bodies, green areas and open spaces. Among the strategies for tropical areas, Emmanuel (2005) lists the need to work in small spaces, looking for improvements in comfort conditions in each city block. The author proposes using natural materials (vegetation and water) as cooling agents and presents the efficiency of microscale actions, showing that many small parks can influence the microclimate of an area more than their surroundings would do.

Oliveira, Andrade and Vaz (2011) state that even small green areas can contribute to mitigating the effects of urban heat islands, which represents a possibility of working in slum regions that usually have few unoccupied areas that can be used for planting. However, the authors point out that the thermal performance of green infrastructures and their influence on the surrounding environment depend on the climatic and urban characteristics of the city.

From the microclimate point of view, however, it can be said that strategies that can mitigate the effects of the changes imposed on the region are not being developed, such as a systematic introduction of green areas. Interventions in the soil cover, with the removal of natural elements and replacement by materials with greater capacity to absorb solar radiation, contribute to local heating. During the summer rains, mainly the recurring floods add to these issues due to the lack of soil permeability associated with the precarious rainwater drainage system.

Methodological procedure

The stages for developing this research can be defined in: a) bibliographic review, data collection *in loco* for the most faithful reproduction possible of the analyzed scenario; b) delimitation of the study area; c) computer simulation using the ENVI-met 3.1 tool which includes: a survey of physical and climatic data to generate the computational model used with input data, development of the simulation, reading of the data output files to generate images and d) an analysis of the results and reflection on possible actions to adapt the thermal issue to local characteristics.

The computational tool: ENVI-met

To contextualize the study, a three-dimensional model was developed that aims to faithfully illustrate the implementation of buildings and general lines of urban morphology. Thus, (1) the study area can be defined; (2) the scenario with the current urban configuration can be simulated; (3) the current air temperature values can be determined and the consequences arising from successive increases in temperature can be evaluated; (4) mitigating measures can also be proposed based on increasing green infrastructure in the community.

The computer simulations were performed using the ENVI-met 3.1 software, developed for climate simulations in urban areas. The Leonardo 3.75 software was used to visualize the results.

The model generated for ENVI-met is formed by three-dimensional cells (grid cells) in the shape of a cube and, therefore, 3 dimensional: dx, dy and dz. Depending on the dimensions of the area of interest, the model may not be able to simulate the entire area, making it necessary to fractionate it. The model was generated with 3.0m x 3.0m x 3.0m cells, so that the region of interest can be simulated with refinement capable of providing detailed information on local variations. The computational model also has the geolocation information of the region, among them: latitude, longitude, time zone and geographic north.

Study area: Nova Holanda

The choice of this community was due to its long process of transformation over its 59 years of existence, making it one of the most representative communities in the Maré Favela Complex. The permanence and entire transformation process are the result of the residents' struggle, however, the way in which this happened contributed to a place that has low environmental quality.

The section chosen (Figure 6) for this study represents a small part of the community. However, due to the fact that it is quite homogeneous in terms of the street layout (orthogonal), built mass (buildings that occupy the entire block), height of the buildings (2 and 3 floors) and high soil impermeability, it summarizes the characteristics found in the community.

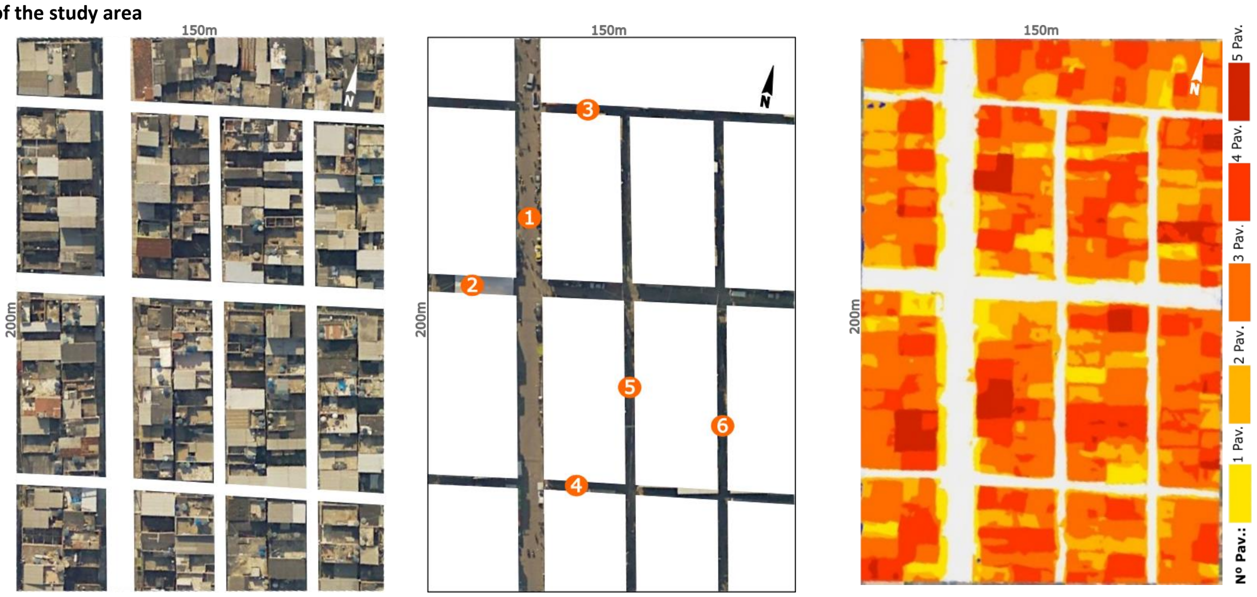
Figure 6 – *Nova Holanda* Community and chosen section for the study.

Source: adapted from Google Earth (image taken in 2021).

Characterization of the simulated areas

The dimension of the studied area was based on the size of blocks existing in several districts of the city of Rio de Janeiro (150 x 200m), totalling an area of 30,000m² (Figure 7).

Figure 7 - Dimensions and characteristics of the studied area - (a) detail of the analysed clipping, (b) identification of the streets and (c) templates of the study area



(a) (b) (c)

Sources: (a), (b) adapted from Google Earth (image taken in 2021) and (c) the authors.

In the analysis of the studied section, one of the questions raised concerns the block, or rather, the constructive density within them. Figure 7a shows a high constructive density as the interior of all the blocks is occupied by buildings joined together, creating large blocks of impermeable material. Another drawback can be observed concerning this lack of spacing between the buildings, - the low ventilation of the dwellings - mainly in those that are on the lower floors due to the lack of openings (fenestration) in the buildings. Another issue concerns the lack of vegetation in the blocks and between the houses and the strong impermeability of the soil. The high constructive density and little ventilation inside the block can also be noted.

Another important point raised in the section under study refers to the roads. Figure shows that six roads comprise the area under analysis. Two of them with widths around 6 metres (lanes 1 and 2), laid out as the main streets and another 4 (lanes 3, 4, 5 and 6) with dimensions referring to the local streets of the neighbourhoods of the city, up to 3 metres wide. Sometimes the occupation of the pavements and part of the streets is observed as an extension of the dwellings.

In the environments comprising the roads, the lack of greenery is also noticeable, whether any sized tree, shrubs or small flower beds on the pavements. The circulation routes are extremely arid regions, considering that they are completely covered by asphalt and concrete (streets and pavements), without the presence of vegetative elements and permeable areas, that is, there is high soil impermeability.

Another issue considered in the study was vertical density, or rather, verticalization. In a study developed concerning the templates (Figure 7c), it was observed that the *Nova Holanda* community has buildings ranging from 2 to 5 floors, predominantly with 3 floors in general. In the analysed section, the number of buildings with 1 and 2 floors is very low, there are many buildings with 3 floors, followed by those with 4 and in some points up to 5 floors. Buildings are generally erected with a ceiling height of approximately 3 metres. Thus, in a simplified way, there are walls that are almost 9 metres high on all sides of the roads.

Considering the existence of this built-up mass with a height of 9 metres throughout almost the entire section studied and adding to this the lack of space between the buildings, a very homogeneous roughness in the section can be pointed out, which impairs the wind passage between buildings.

ENVI-met reading output files

As it is possible to read the results for different variables, times and height levels, some possibilities were tested in this work, aiming to provide the reader with a more detailed overview of the region. Thus, the results of temperature, relative air humidity and wind speed were selected.

For the air temperature results, 2 hours, 2 pm and 9 pm were initially analysed, which were representative in the thermal comfort analyses. The first hour represents the moment of most intense heat during the day, while the second shows the amount of heat being dissipated in the atmosphere, that is, how much heat a region produced during the day and that is dissipated at night: the so-called Heat Island. For the relative humidity analysis, a fixed time (2 pm) was also taken into account, but with different levels (heights).

To understand the effects of height variation on the thermal sensation experienced, the Universal Thermal Climate Index – UTCI (BRÖDE *et al*., 2012a) and the RayMan Pro software (MATZARAKIS; RUTZ; MAYER, 2007) were used. The data used to calculate the UTCI were air temperature, air humidity and wind speed obtained at 2 pm at the three levels studied.

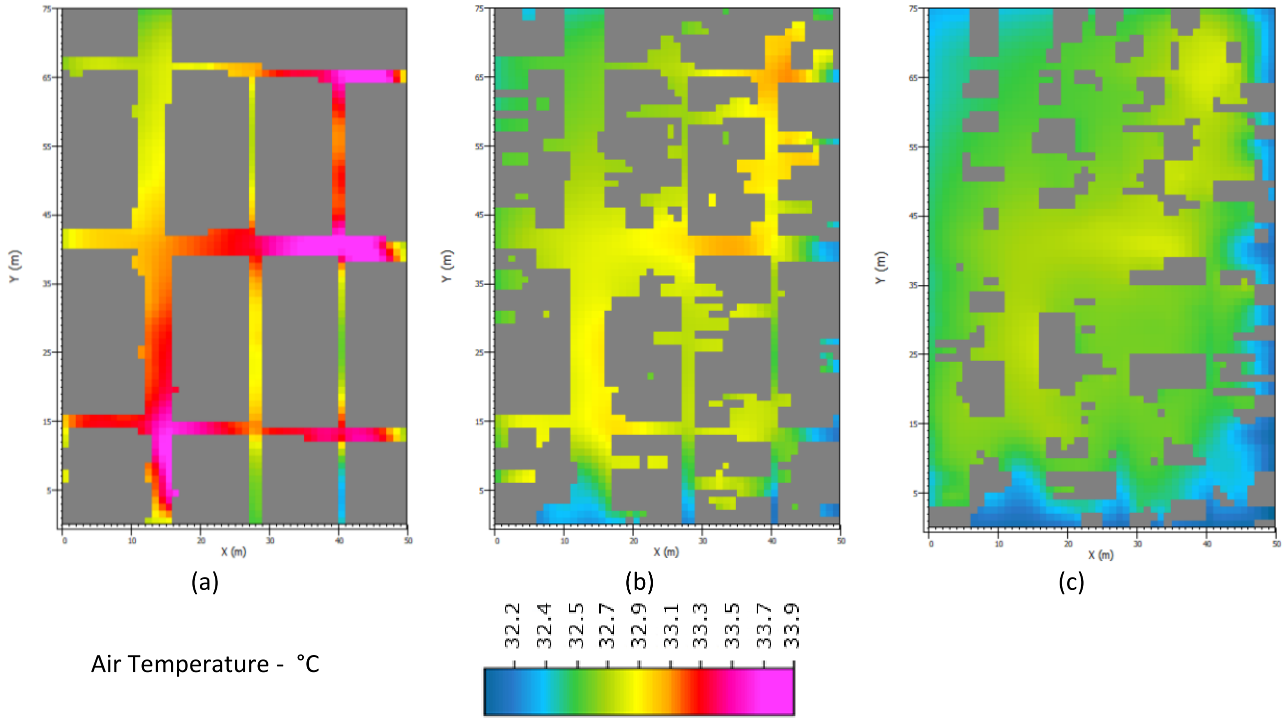
Results and discussion

The results for temperature and relative humidity, in addition to wind speed, are presented in this topic. For the two times, 2 pm and 9 pm, three height levels were selected for reading and analysing the results: the first, at the pedestrian level; the second corresponding to the terrace, or roof slab, of the buildings of approximately two floors; and the third for the rooftops of three-story buildings, common in the region, mostly still located on what corresponds to a third floor. This procedure made it possible to identify the variations in air temperature on the roofs as the region presents a verticalization process. Thus, *Nova Holanda* is compact and homogeneous and, consequently, has a high population, considering the housing characteristics of the place.

The data presented in Figure 8a-c identify the air temperature results at 2 pm. In Figures 9a-c, the results for 9 pm can be observed, which are representative in the thermal comfort analysis, aiming, as previously mentioned, to find evidence of a moment of intense solar radiation and another after sunset, with heat dissipation in the atmosphere.

Figure 8a shows a height of 1.2 metres, at pedestrian level and all roads present points with air temperature values higher than those observed in their surroundings. In some sections of lane 6, specifically at the crossing points with lanes 2, 3 and 4, higher temperature values are also noted, compared to the rest of the lane. The sections with the lowest temperature values are found in parts of roads 1, 5 and 6. It can be observed that the concentration points of heat zones occur at the road intersections.

Figure 8 – Results for air temperature at 2 pm - (a) 1.2 m, (b), 6.0 m, (c) 9.0 m.



Source: the authors.

Considering the circulation of an individual through this section, he/she may possibly feel an air temperature variation of almost 2°C when walking through the streets and passing through intersections.

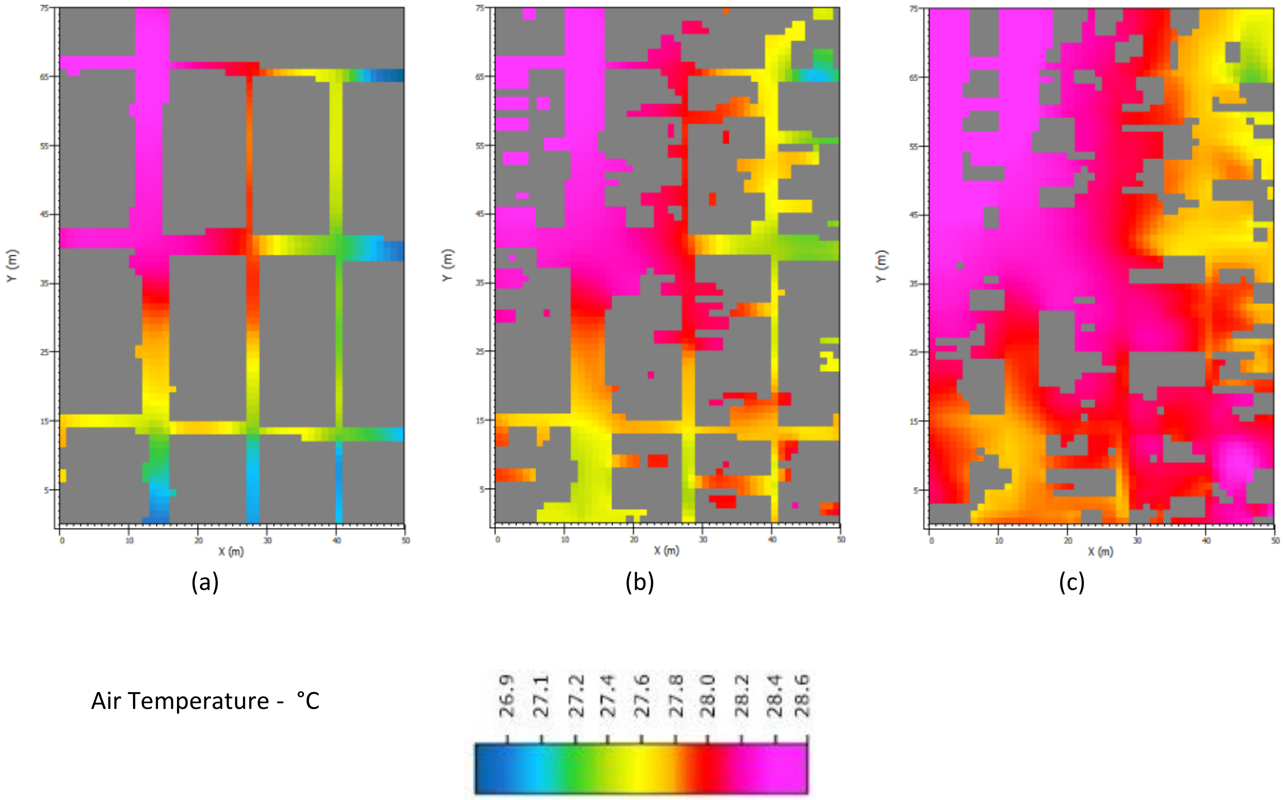
For the result obtained at 6.0 metres (Figure 8b), it can be- observed that the spot with the highest values of simulated air temperature is restricted to the vicinity of the intersections of lanes 2 and 3 with lane 6. Figure 7c illustrates that most of the clipping comprises 3-storey buildings. This means that residents may be less affected by the hot air mass, dissipated by the higher wind speed, given the greater permeability of the urban fabric at this height level. As not all buildings exceed 6 metres, the slabs can represent a space with greater air circulation, contributing to their more intense use.

The results at 9.0 metres (Figure 8c) show that the large mass of hot air presented a reduction of more than 1.5°C in the whole studied area. Observing the result at 6.0 metres (Figure 8b), two observations can be made. The first one is that with the increase in porosity of the urban fabric, since not all buildings have 3 floors, the greater air circulation helps the dissipation of the hot air mass observed at the pedestrian level by up to approximately 2°C. – which can represent an important variation if the size of the study area is observed. A first glance at this scenario may indicate that, as the region presents the whole complex with more than 3 floors, this behaviour will tend to be altered to promote greater heating at the levels studied. This other factor could have worsened with the introduction of covers over the slabs, promoting partial or total closures, which are normally made of fibre cement tiles, but these were not considered in this simulation process.

Observing the built materiality of this section, it is as if at the 9-metre level there was even greater air circulation sufficient to promote thermal exchanges capable of dealing with the concrete in the roof slabs as many of these are below the level of 9 metres.

The air temperature results of the night period, more specifically at 9 pm, are shown in Figure 9 a-c.

Figure 9 – Results for air temperature at 9 pm: (a) 1.2 m, (b), 6.0 m, (c) 9.0 m.



Source: the authors.

For this time, it can be observed that the dissipation of the hot air mass is related to the wind direction associated with the permeability of the mesh. It should be noted that the temperature calculated by the simulation at 9 pm is lower than the minimum observed at 2 pm. The section that covers road 1 of the area concentrates an air mass with the highest temperature values. Considering the height of 1.2 metres (Figure 9a), it can be stated that those who need to circulate or live on the ground floor can observe a variation of 1.7°C in this immediate neighbourhood region, even at this time.

Two questions can be raised in relation to this intra-urban temperature variation in this section The first one is the direction of the sunset, which allows the incident solar radiation in some sections for a longer time, even with less intensity. Another factor may be related to the materiality existing in that environment. It is important to remember the characterization of the studied section (Figure 7 a-c), which presents a high amount of artificial elements comprising its environment.

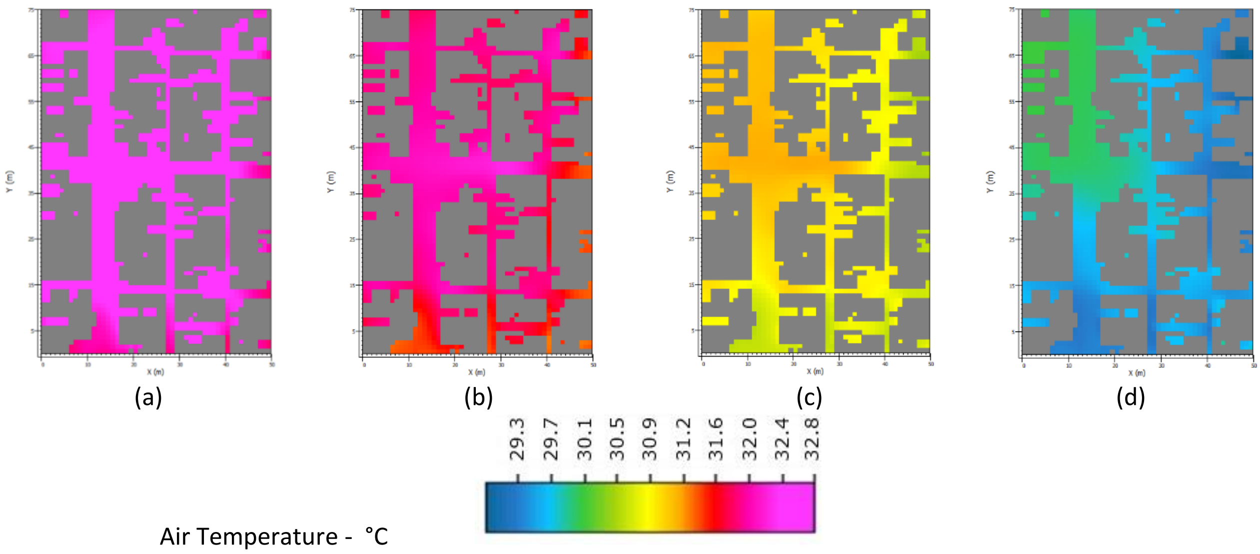
For levels of 6.0 and 9.0 metres (Figures 9b and 9c), where the building mass becomes smaller, it can be observed that the layer of warm air spreads. Its greater presence at 6.0 metres and 9.0 metres may be related to the solar energy absorbed by the slabs and covering materials, such as concrete and fibre cement, which is returned to the atmosphere in the form of heat.

It is important to note that even though this air mass is in its dissipation process, it covers almost the whole section under analysis (Figure 9 c). Analysing the scale values, practically the entire area is covered by the highest values of the table of colours (red and pink), despite the simulated temperature range presenting a variation of 1.7°C. This is also related to the production and heat dissipation process of the roofs, which in this case are the concrete slabs (material with low thermal efficiency in terms of heat production).

After these two analyses, another was carried out in the afternoon (Figures 10 a-d), considering the issue of the summer in Rio de Janeiro, characterised by high temperatures to identify the dynamics of this variable during the afternoon.

Considering the issue of verticalization and compaction of the site, it was considered important to observe the air temperature dynamics throughout the afternoon to understand how the intra-urban temperature varies in this period. It is a period pointed out by the residents as one of the hottest, many referring to it as the moment when "the torch is lit". Therefore, the results presented in Figure 10 a-d were generated for 3 pm, 4 pm, 5 pm and 6 pm, at the level of 6 metres high, that is, at the height of the roof slab of most of the buildings. The results in Figure 8 indicated a reduction in air temperature values vertically by almost 2°C. The results were equalized in a single colour scale so that the results could also be compared visually.

Figure 10 – Results for air temperature in the afternoon: (a) 3 pm, (b), 4 pm, (c) 5 pm and (d) 6 pm.

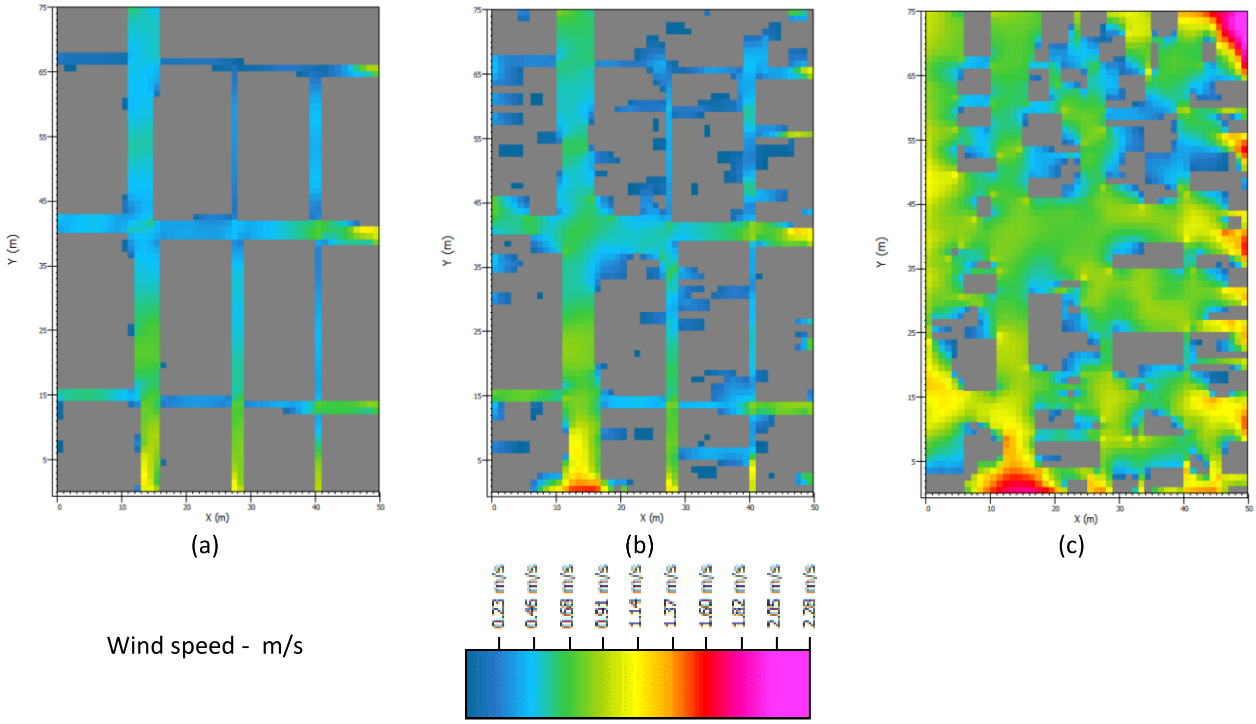


Source: the authors.

The observation of the results indicates that at 3 pm (Figure 10a), the colour pink occupies almost the whole simulated area, corresponding to values above 32°C. At 4 pm (Figure 10b), the air temperature values show a small reduction in red that indicates values between 31.2 and 32°C. At 4 pm (Figure 10b), the air temperature values show a small reduction in red that indicates values between 31.2 and 32°C. The image of Figure 10c, related to 5 pm, shows the scenario beginning to change as the air temperature values above 31.2°C disappear in the simulated area, and even occasionally the minimum temperature is already 30.5°C. At 6 pm (Figures 10d), the maximum value observed is 30.1°C. From the results presented, it was observed that in the afternoon, the dynamics of intra-urban temperature results in a reduction of up to 3.5°C from 3 pm to 6 pm. In Figure 8, a reduction of approximately 1.0°C at 6.0 metres can also be noted, if compared to the pedestrian level. Thus, the occupation of "slabs" by the local population as leisure or workspaces seems to be an intuitive choice in the search for lower air temperature values and greater ventilation.

The images in Figure 11 present the results for the wind values in m/s and show the greater permeability of the mesh as the reading is taken at higher levels, that is, 6 metres and 9 metres.

Figure 11 - Wind speed results for 2 pm: (a) 1.2 m, (b), 6.0 m, (c) 9.0 m



Source: the authors.

The wind dynamics in the section analysed at 1.2 metres (Figure 11a) is characterized by the presence of very low values, almost always below 0.7 m/s, which, according to the Beaufort Scale, is not equivalent to a light breeze. Poor ventilation contributes to air stagnation in the region, even making it difficult to dissipate pollutants.

At 6.0 metres (Figure 11b), there are some drafts (very weak breeze), and lane 1 is the largest ventilation channel in the complex. The presence of a breeze, level 2 of the Beaufort Scale, can be noticed at 9.0 metres (Figure 11c), however, the complex still has a breeze.

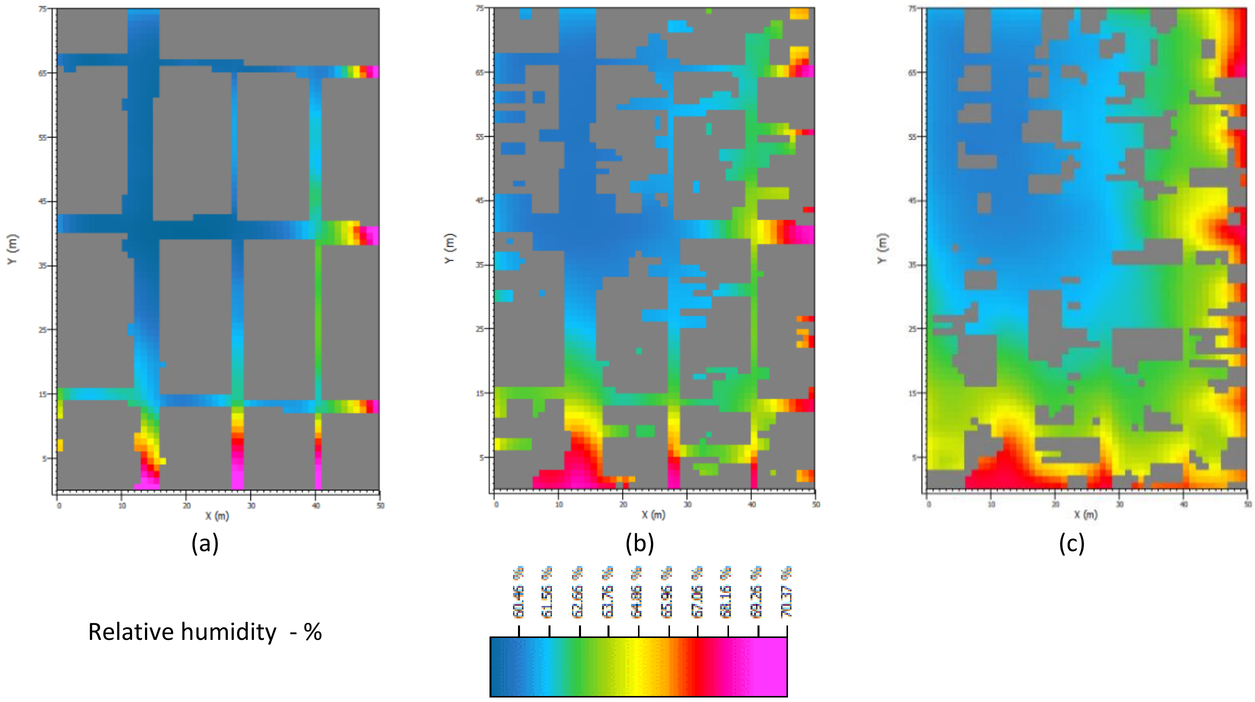
Considering the results of the wind at different height levels, an increase in speed can be observed as the urban fabric becomes more permeable. It should be noted that the values observed here are related to the initial condition established for January, that is, an average of 3m/s.

The results related to relative air humidity correspond to a fixed time (2 pm), however, with different height levels (Figure 12a-c).

The results at 2 pm (Figure 12a) indicate that the highest levels of humidity are located on the edges, following the same wind speed dynamics (Figure 11a). Based on the *Nova Holanda* community's position and the dynamics of this variable, as well as the wind variable, it can be indicated that it has been caused by the nearby maritime area (*Canal do Fundão*) and the wind is dragging it into the community. Regarding its displacement and scope, it can be observed that the walls created by the buildings cause damage. As the wind speed, humidity increases as its values are read for the 6 and 9 metre levels.

In general, it can be observed that the analysed section is benefitted by the relative humidity of the neighbourhood (*Canal do Fundão*), because its interior does not have any vegetation or other elements that add moisture.

Figure 12 - Results for relative air humidity for 2 pm: (a) 1.2 m, (b), 6.0 m, (c) 9.0 m



Source: the authors.

The UTCI (BRÖDE *et al*., 2012b) was adopted to measure the thermal sensation of users. It is an index used for outdoor temperature situations applying the concept of an equivalent temperature. To calculate it, an estimate of the values obtained for each of the levels at 2 pm was used.

The results are presented following the "thermal stress" categories (MATZARAKIS; MAYER, 1996), later calibrated by Krüger, Minella and Rasia, (2011). The calibrated categories are shown in Table 1 (KRÜGER; ROSSI; DRACH, 2017).

Table 1 - Calibrated "thermal stress" categories

UTCI	Thermal stress categories
9 °C	absent
26 °C	moderate
32 °C	strong
38 °C	very strong
46 °C	extreme

Source: Krüger, Rossi and Drach (2017).

The results calculated from the values observed by temperature and air humidity ranges in each of the levels in January 2021, at 2 pm, are listed in Table 2. The calculations were considered for a human being of standard height.

Table 2 - Estimated "thermal stress" values for 2 pm in January, 2021

Levels (m)	Assumed air temperature (°C)	UTCI (°C)	Thermal stress categories
1.2	29.3	3.6	strong
6.0	29.7	33.9	strong
9.0	30.1	34.2	strong

Source: the authors.

From the estimated results, it can be stated that, in terms of thermal sensitivity, all the points observed in the studied area as a whole and at the time and date evaluated result in UTCI values that fall into the category of strong "thermal stress" consistent with the summer months of the city of Rio de Janeiro.

Conclusion

Compiling the results on the analyzed section, considering the different times and the different levels of height, it can be pointed out that the thermal discomfort appears as a problem for the region. This problem occurs throughout the analysed section, at least at some time of day, or at some height range. Considering that this section of 200 x 150 metres is very representative of the whole *Nova Holanda* community and, given the homogeneity of the urban fabric, the probability of these same results being repeated throughout the community can be considered, except for some variations.

This estimated scenario of strong "thermal stress", felt both by those who are on the streets and those who are inside their homes, can be pointed out as a result of local climatic conditions associated with the transformations imposed by the occupation of the place. The formation, development and consolidation processes of the community imposed the systematic reduction of green areas and water bodies through grounding processes. The mangrove and tidal microclimate have nothing to do with what exists today in the same place.

The excessive impermeability of the soil, the built mass and the lack of vegetation resulted in an environment where the temperature indexes are high, the wind circulation is sometimes blocked and the humidity levels are altered.

In addition to the low environmental quality arising from the issue of comfort, another problem that is associated with the conformation of a place is the issue of rainfall and the impacts it can cause. In Rio de Janeiro, for example, summer is characterized by high temperatures during the day and heavy rains at the end of the day. Thus, the stretch serves as a beacon for what happens in many favelas and in places where soil impermeability is very high: flooding caused by the summer rains. In vulnerable places such as slums, urban cleaning services are precarious and rainwater sewage systems are poor, compared to the so-called “formal” areas of the city. Several communities in the Maré Favela Complex suffer from flooding during heavy rains.

This flooding scenario could be aggravated in the near future if the projections on climate change are confirmed and if nothing is done to mitigate these impacts, especially in vulnerable communities.

The evolution of the urban form in the Maré Favela Complex, particularly in the region of the *Nova Holanda* community, involved grounding actions throughout a process of population growth that started approximately six decades ago. It is a struggle of communities not only unassisted but also oppressed by the history of removals and denial of the right to housing. However, this continuous action promoted an urban densification that resulted in a reduction in the environmental quality of the region, which can be observed from the analysed results. As a result of urban occupation without systemic planning, with a large change in land cover, replacing natural elements by artificial ones, with a greater capacity to absorb solar energy, an environment with low environmental quality and vulnerable to environmental impacts was produced.

As alternative actions to mitigate this problem, one can think of a feasibility study for planting greenery, taking into account the particularities of the place, creating small flower beds where pavements are wider, using tiles with more thermal efficiency, painting existing roofs in colours that reduce heat absorption and even growing vegetation in small beds on top of the slabs.

Currently, this study is still in the development process and it is expected, after completing it, to obtain a better understanding of the favela environment, especially regarding environmental comfort and, mainly, to gain more knowledge of proposals for positive changes, so that housing and urban environments with higher environmental quality are achieved for their residents.

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