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Evaluation of urban-architectural performance in urban morphology for selection of urban ventilation corridors

Evaluación del desempeño urbano-arquitectónico en la morfología urbana para selección de corredores de ventilación urbana

Avaliação do desempenho urbano-arquitetônico na morfologia urbana para seleção de corredores de ventilação urbana

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Abstract

Climate change and related phenomena are exacerbated over time, occurring with greater frequency and intensity. Among them, urban heat islands are out, resulting from land use changes in cities and the impermeability of urban territory. Therefore, heat islands tend to be more intense in certain areas. Most urban environmental problems are related to infrastructure, so it is proposed to select avenues that meet cooling characteristics through the evaluation of urban morphology and determination of LST, leading to the design of urban ventilation corridors, making use of city elements to improve environmental conditions.

Keywords: Climate change, architectural design, urban areas.

Resumen

El cambio climático y los fenómenos relacionados con esté, se exacerban con el paso del tiempo, presentándose con mayor frecuencia e intensidad, entre ellos resaltan las islas de calor urbano, consecuencia del cambio de uso de suelo en las ciudades y a la impermeabilidad del territorio urbano, por lo tanto, las islas de calor suelen tener mayor intensidad en determinadas áreas. La mayoría de los problemas ambientales urbanos se relacionan con la infraestructura, por lo que se propone la selección de avenidas que cumplan con características de enfriamiento mediante la evaluación de la morfología urbana y determinación de LST, dando lugar al diseño de corredores de ventilación urbana, haciendo uso de elementos de la ciudad para mejorar las condiciones medioambientales.

Palabras clave: cambio climático, diseño arquitectónico, zona urbana.

Resumo

As mudanças climáticas e fenômenos relacionados são exacerbados ao longo do tempo, ocorrendo com maior frequência e intensidade, entre eles as ilhas de calor urbanas, em decorrência da mudança no uso do solo nas cidades e da impermeabilidade do território urbano, portanto, as ilhas de calor tendem a ter maior intensidade em determinadas áreas. A maioria dos problemas ambientais urbanos está relacionada à infraestrutura, por isso a seleção de inundações que atendam às características de resfriamento é proposta por meio da avaliação da morfologia urbana e determinação do LST, dando origem ao desenho de corredores de ventilação urbana, fazendo uso de elementos da cidade para melhorar as condições ambientais.

Palavras-chave: mudanças climáticas, projeto arquitetônico, área urbana.

Introduction

Climate change-related phenomena pose a series of challenges for society, as there is a certain stratification regarding the resources and infrastructure necessary to face these changes. One of the most frequent phenomena is the formation of urban heat islands (UHI), which is defined as the variation in near-surface temperatures in urban areas (Kim et al., 2024), which are usually higher at certain points compared to surrounding or rural areas.

This phenomenon has received greater attention in recent years, as it is being exacerbated by land use changes in the territory. Additionally, the absence of green areas accelerates the presence of environmental problems in the area, ranging from thermal comfort issues for users to the excessive and unsustainable consumption of water and energy as a short-term alternative to mitigate the adverse effects brought about by high temperatures.

Given the exacerbation of the heat island phenomenon, its intensity is attributed to the characteristics of the urban region, such as the population, construction materials, building density, impermeable surfaces, among others (Hurduc et al., 2024). On the other hand, the evaluation of the elements that make up the city allows for diagnosing the causes that generate the heat island phenomenon, as well as developing a series of proposals that adapt to the particularities of the territory, thus ensuring their effectiveness at the time of implementation.

According to previous research, various thermal discomfort indices can be used to assess urban thermal stress (Kim et al., 2024), especially in situations that pose greater challenges to achieving thermal comfort, as conditions related to climate change demand it, particularly during heatwaves, which have grater intensity and frequency. According to Hurduc et al. (2024), one of the alternatives used to diagnose the intensity of the phenomena relies on the use of geostationary satellites, whose main advantage is the high temporal sampling.

The need to provide an accurate diagnosis according to local microclimatic characteristics suggests using the determination of Land Surface Temperature (LST), which is a variable characterized by its strong diurnal and seasonal variability (Hurduc et al., 2024), and can show significant spatial variations according to its particulares surface characteristics (albedo, heat capacity, thermal emissivity, among others).

Due to the variability of LST in territories with diverse characteristics, it is necessary to propose strategies that allow addressing and mitigating phenomena such as heat islands using existing resources in the city. Previous research has confirmed that urban morphology is a factor that influences urban microclimatic variations, among which compact urban form improves land and energy use efficiency, as well as providing accessibility to services and facilities (Liao et al., 2023). However, it is necessary to evaluate the conditions to determine if other urban morphologies allow for improved thermal comfort and the use of services that enable achieving thermal comfort.

To achieve this, the design of urban ventilation corridors incorporates linear elements of the landscape with lower resistance to air flow between sources of cold and heat generated by the buildings present in the city, as well as other elements such as rivers, green spaces, roads and other aspects related to urban equipment (Guo et al., 2023). These corridors incorporate the elements that make up the city, which can be considered factors that exacerbate changes in the urban microclimate, but within them lies the implicit solution to improve air quality and mitigate the adverse effects of urban heat islands.

The local climatic effects of urban ventilation corridors represent varied ventilation capacity depending on the characteristics of the study area, as well as the possibility of mitigating adverse effects, in addition to reducing heat islands. Despite being a strategy that adapts to territorial particularities, it is still a developing strategy where it is necessary to evaluate the ventilation capacity of urban ventilation corridors Liu et al., 2020), as previous research has focused on assessing the potential for ventilation.

The present research aims to analyze the ventilation potential of urban ventilation corridors, whose selection is based on the evaluation of the urban-architectural performance of the urban components of the municipality of Metepec, a municipality belonging to the State of Mexico, Mexico, where the urban components will be examined and their impact on both the change of the urban microclimate and their capacity to improve environmental quality, using existing components on site.

Method

The determination of UHI is usually obtained through various methodologies; in this case, it was carried out by determining LST, taking as a reference the research by Hurduc et al. (2024), using vector files and Raster-type files obtained through geostationary satellites to perform a diagnosis via remote sensing, and subsequently contrasting the information obtained with empirical evidence through field visits.

To begin the diagnosis regarding the presence of heat islands in Metepec, Geographic Information Systems were used to determine the territorial delimitation by Basic Geostatistical Area (AGEB), using .shp files available in the Geostatistical Framework (INEGI, 2021) as inputs. Subsequently, urban morphology was determined based on the territorial distribution of roadways, whose characteristic analysis is based on the assumptions established by Schjetnan, Peniche, and Calvillo (1984).

For the selection of satellite images, the thermal variability between the cold and warm parts of the year was used as a reference. This selection was sampled by monitoring the average maximum temperature recorded in meteorological databases during the month of January (winter season) and the month of May (spring season). It is worth noting that the month of May was selected because the country of Mexico experienced a significant drought where high temperatures were recorded, leading to the collapse of energy, water, and ice supply systems, a situation that justifies the relevance of addressing this issue during a historical phenomenon.

The satellite images were obtained from the Landsat 8 OLI_TIRS satellite. According to the temperature monitoring conducted in the meteorological databases, the highest temperatures were recorded on 01/12/2024 with 24°C; however, the satellite image is not available in the Earth Explorer databases, a situation that represents a bias in the development of the research. On the other hand, the information regarding the month of May indicates that the high temperatures recorded correspond to the 21st and 24th, however, the availability of satellite images closest to these dates corresponds to 05/18/2024.

Both satellite images were taken during the day, at approximately 4:59 PM. When the sample images were taken, there was a terrestrial cloud cover of 33.57% in January and 2.27% in May. Note the difference in cloud cover during the winter season compared to the significant drought that the Mexican Republic experienced, particularly in the municipality of Metepec, State of Mexico.

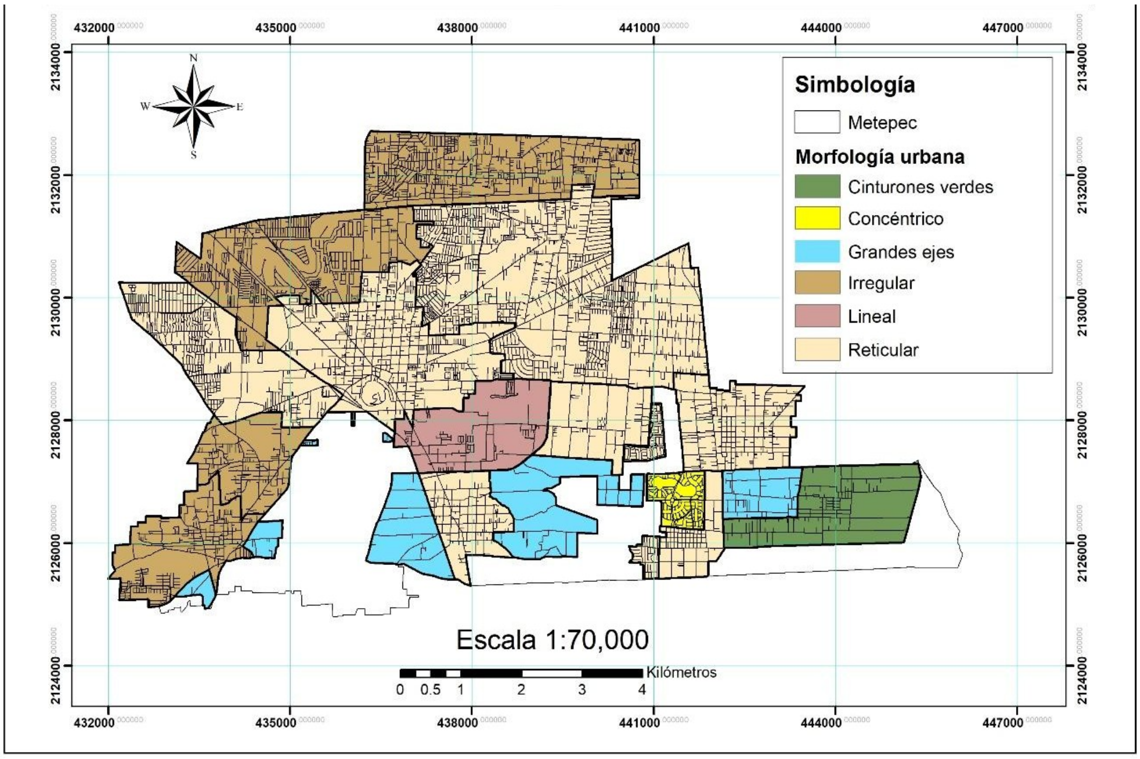
Subsequently, for the determination of LST in Metepec, a series of algorithms were applied that allowed for the diagnosis of the presence of heat islands on the surface, relating this phenomenon to the surface's reflectivity capacity. The applied procedures refer to the determination of the Normalized Difference Vegetation Index (NDVI); Proportional Vegetation Index (PVI); Land Surface Emissivity (LSE); Spectral Radiance at the Top of the Atmosphere (TOA); Brightness Temperature (BT) and finally the determination of Land Surface Emissivity (LST).

Finally, once the data regarding the reflectivity of the LST in the territory of Metepec was obtained, in addition to obtaining the description of urban morphology, the necessary characteristics were gathered to select the routes with the greatest potential for urban ventilation, highlighting the characteristics of each place.

Results

According to the territorial analysis conducted on the municipality of Metepec through remote sensing, the presence of various urban morphologies was determined, whose characteristic is one of the variables that influence the change in the microclimate experienced in the area (see Map 1). The description is broken down as follows: Green polygons, corresponding to green belts, according to Schjetnan, et al., (1984), are cities structured through green areas, whose advantages offer city and roadway organization, in addition to being a hub for establishing urban equipment. However, land use and architecture require control, their adaptability to topography is complicated, and the initial implementation is costly.

Map 1-Urban Morphology- Metepec México



Source: Own elaboration, 2024

The polygon marked in yellow belongs to a system of concentric or radial urban morphology. In the municipality, it is described as a residential area with elaborate architectural design. Its structure develops through increasing rings that are equidistant from the center, in addition to adapting to the flat topography of the territory. However, it is important to highlight that the development of this type of morphology is costly both in infrastructure and roadways.

The localities characterized by the system of large axis morphology consist of large avenues that traverse the city, creating an almost automatic system of city organization that enhances the perception of the landscape by providing interesting perspectives. On the other hand, it hierarchizes the roadways and facilitates urban transport transit; however, it faces the challenge of having problems at avenue crossings. Additionally, buildings located near the avenues must adhere to construction regulations, as they must follow the architectural and land use control established by the municipal council. Finally, due to its spatial distribution, primary activities are concentrated, concentrating vehicular traffic at certain points.

According to the irregular system of urban morphology, also known as "broken plate," it occurs due to disorganized growth; however, the distribution of urban equipment tends to be interesting within the urban system. Additionally, the system considered disorganized easily adapts to various topographies and promotes pedestrian systems. On the contrary, it also has a series of disadvantages, the main one being the difficulty in planning the urban structure, which hinders traffic, causing traffic congestion.

On the other hand, the linear system can sometimes be confused with the major axes system; however, it can be distinguished due to its morphological characteristics analogous to a fishbone, as the main road structure branches into secondary roads. The advantages it offers are described as the ease of growth without modifying the basic structure, the installation of infrastructure is favored, public transportation adapts easily, it facilitates the concentration of elements, avoiding excessive dispersion in infrastructure, and it also adapts to topographies where it is difficult to establish human settlements. Despite the numerous advantages, the challenges focus on situations where there are traffic inconveniences, the possibility of taking alternate routes is reduced, and it also promotes an inadequate distribution of activities carried out in the city.

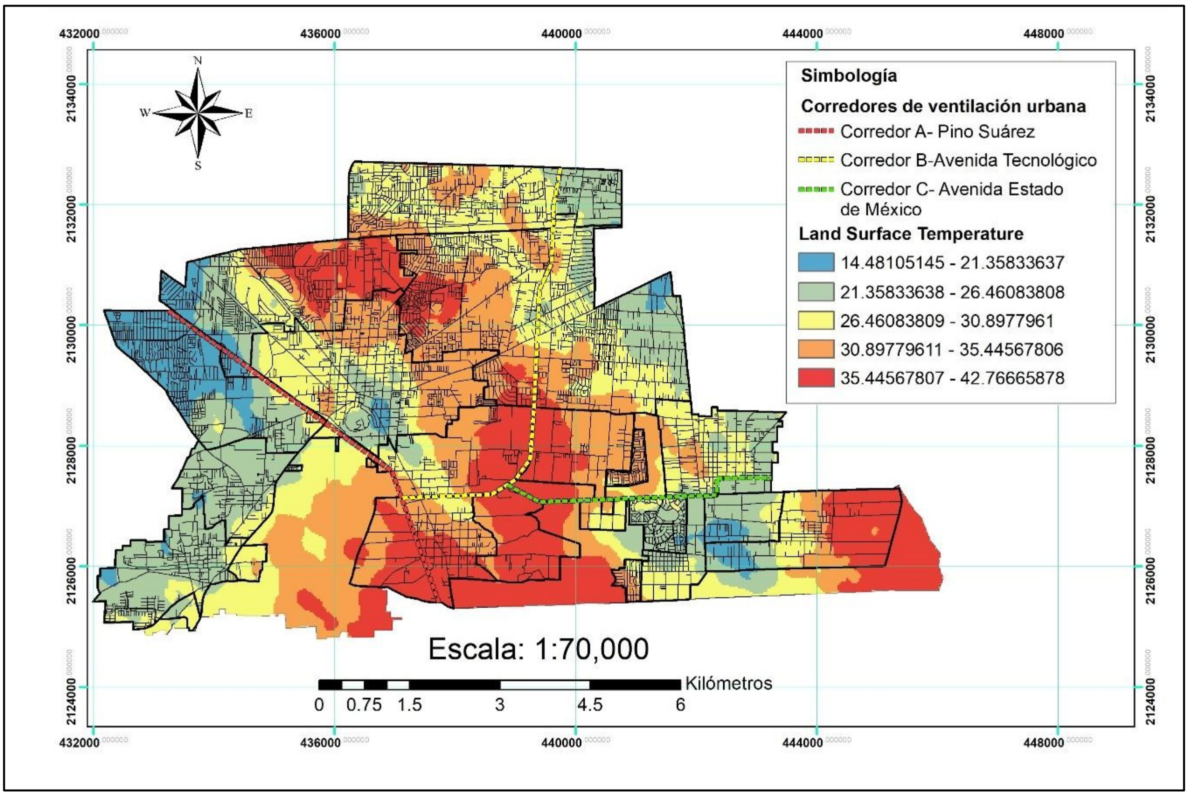
Finally, the reticular morphology system is characterized by its orthogonal shape, which generates square or rectangular blocks, that is, straight lines predominate. Such morphology represents the ease of subdividing the territory, with respect to urban growth, it provides continuity in the blocks or streets, has a certain degree of adaptation to topographies, and in case of difficulties in certain roadways, it offers a variety of alternatives for circulation. However, it is very characteristic that makes the landscape monotonous, and in the absence of proper hierarchy, intersections can be dangerous. Additionally, this urban morphology favors private transportation more than public transportation.

The behavior of heat islands

The analysis of heat islands can be varied, which will be varied depending on the weather conditions, which are extremely variable, and their characteristics are not usually constant or similar, but rather there are a series of factors that influence their behavior. It is worth noting that the results of this research show the evaluation of the behavior of heat islands in the month of January, which corresponds to the cold part of the year, as well as in the month of May, whose characteristic is that it is one of the hottest months recorded, due to the occurrence of a significant heatwave.

On the other hand, the urban morphology system of each locality that constitutes the municipality of Metepec was used as a reference, which served to delineate and select roadways that could function as possible urban ventilation corridors. In other words, the characteristics of the city are considered as possible triggers of environmental problems, but within them lies the solution to mitigate some environmental issues such as heat islands.

Map 2- Temperatures Metepec, January 2024.



Source: Own elaboration, 2024

The classification of urban ventilation corridors was based on the urban-architectural characteristics of important roadways that traverse most of the municipal territory (see Map 2), selecting three corridors: Corridor A- Pino Suárez, Corridor B- Avenida Tecnológico, and Corridor C- Avenida Estado de México. According to the proposed analysis, color codes analogous to traffic light colors were assigned, where the color red (Corridor A) represents the area with the highest complexity in the city due to the large number of anthropogenic elements it comprises; the color yellow (Corridor B) is assigned to areas where urban infrastructure is present, but it is balanced by the distribution of natural areas. Finally, green (Corridor C) was assigned where there is lower building density and a greater presence of green areas, that is, where there is less surface roughness and wind circulation is favored.

Regarding the description of each of the proposed urban ventilation corridors and their relationship with heat islands, the description is broken down as follows: The A-Pino Suárez Corridor has a greater establishment of infrastructure, which consists of residential areas, residential subdivisions, important commercial zones, green infrastructure, and parks. According to Map 2, which establishes the thermal variation due to the variability of Land Surface Temperature (LST), the blue polygons represent the areas where the lowest temperatures are concentrated, while the red polygons represent the areas with the highest thermal stress.

The cooler areas are recorded in zones with a reticular urban morphology and residential use; however, they begin to increase with the establishment of commercial zones, where the color of the roadways, the predominance of parking lots, and the use of cooling systems (air conditioning) come into play. Additionally, since the analysis was conducted during the colder part of the year, that is, in winter, the vegetation present in the areas may reduce its presence, which depends on the type of species distributed in the polygons that represent greater thermal stress. On the other hand, areas with a medium degree of temperature concentration (that is, a yellow tone that degrades to green or blue) graphically represent the important role that green areas play as temperature buffers, in this case, the Cerro de Metepec.

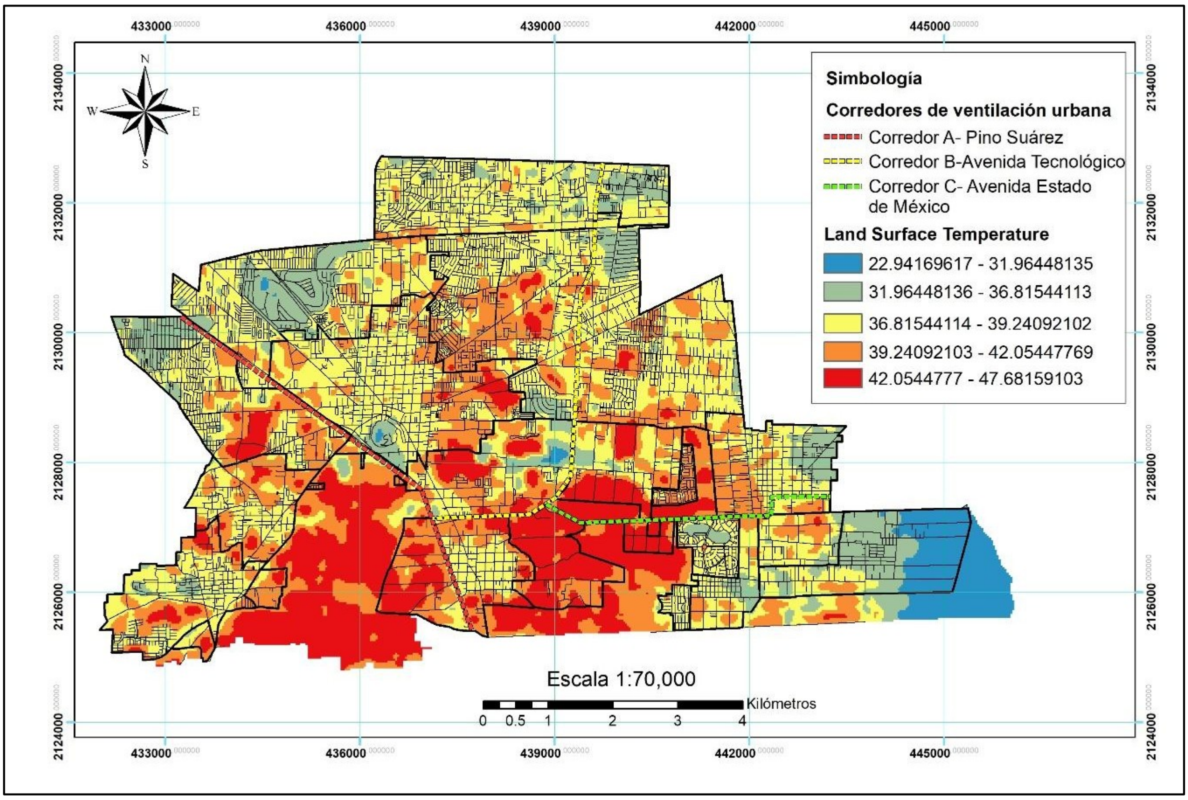
The B Corridor - Avenida Tecnológico is composed of residential areas, the presence of schools, commercial zones, and features an important environmental park. The areas that represent the highest thermal stress are also due to places where vegetation is reduced because of the season in which the analysis was conducted. It is worth noting that this polygon includes the Bicentennial Environmental Park. On the other hand, temperatures do not usually concentrate in the highest range of thermal stress but rather position themselves at a medium level (mainly yellow or orange tones) since the corridor is established in residential areas with a reticular urban morphology.

Finally, the C-Mexico State Avenue Corridor is made up of areas with low building density or neighborhoods dedicated to agriculture. In this corridor, the urban settlement Residencial Foresta is located, whose architectural characteristics favor the concentration of temperature, but the presence of an artificial lake serves as a temperature buffer. It represents the same situation of thermal stress related to vegetation; despite having the presence of a green belt, the condition of the vegetation can favor the retention of LST on the land surface.

Regarding the analysis of the thermal behavior of urban ventilation corridors conducted during the warm part of the year (May), belonging to spring, combined with the experience of an important phenomenon, which was a severe heatwave that represented a reality concerning the exacerbation related to the increase in temperature, however, it was not only manifested as a heat island in certain points of the cities but also significantly affected surrounding areas. The behavior of the heat islands during this phenomenon is depicted in Map 3, likewise, the thermal behavior of the three selected urban ventilation corridors is evaluated.

As observed in map 3, the polygons marked in red represent areas with the highest thermal stress. Since it is a month belonging to spring, the presence of green areas has increased, and the surface's reflectivity capacity is greater. Therefore, the areas that retain the highest LST refer to barren lands or places where agriculture is practiced, while the smaller polygons representing areas with lower thermal stress refer to parks or green areas. It is worth noting that the delineation of polygons with low LST strictly follows the shape of the green areas.

Map 3- Temperatures Metepec, may 2024.



Source: Own elaboration, 2024

In this section of the analysis, the A-Pino Suárez Corridor is found in a medium-high LST retention range, where despite the urban morphology of the localities that make up each section of the corridor, they retained similar amounts of surface temperature, where the color of the roadways and the concentration of the vehicle fleet may have influenced. It should be noted that the humidity levels during this period were extremely low. On the other hand, Corridor B- Avenida Tecnológico went through the same situation, with areas of greater thermal stress corresponding to zones with bare soil or designated for agriculture. Lastly, the C-Mexico State Avenue Corridor has the same conditions regarding the degree of thermal stress, despite being close to an important green belt, which generally shows a lower degree of thermal stress due to the environmental conditions represented by its context.

Discussion

Empirical evidence related to seasonal thermal variability shows certain characteristics that tend to remain consistent regarding the concentration of temperatures on the Earth's surface, which either maintain elevated thermal stress or perform the function of temperature buffers.

According to the proposal that relates urban morphology to temperature concentration, it has a certain degree of incidence, as there are various variabilities both in the shape of the city, which represents the wind circulation capacity between the buildings, and in the material with which the roads are paved, or they may not be paved at all. Another element related to variations in thermal stress is the characteristics of the facades, that is, the urban-architectural elements present in the area, as well as the activities carried out in each of the locations.

Returning to the topic of the urban form of Metepec and its relationship with the concentration of land surface temperatures, it is determined that urban morphologies along with the particular characteristics of the localities coincide with the variability of thermal stress recorded by the LST determination process, as the generated maps were contrasted with satellite images, as well as field visits, especially in the areas where the highest temperature points were recorded.

Regarding urban morphology, the localities with the green belt system present low temperatures due to their proximity to green areas; however, high temperatures are recorded due to the time of year, when foliage may be reduced or nonexistent, as well as a low presence of green areas. The concentric or radial system also has reduced temperatures, due to the colors of the buildings, and the presence of a body of water mitigates the temperatures recorded in the area.

The major axis system consistently shows areas with high thermal stress, which is due to agricultural activities carried out in the territory, or, despite being an area with low construction density, the presence of bare soil exacerbates the situation. On the other hand, the irregular system does not show a presence of high thermal stress despite having disorganized and unplanned urban growth, where the possibility of establishing green areas within the urban sprawl is low. It is worth noting that it does not exempt the city from experiencing high thermal stress situations, but it classifies the localities at a medium level of thermal stress.

Regarding the linear system, there is a great variability in temperatures within the polygonal perimeter, as it includes areas of high thermal stress, as well as areas with low temperatures, which depends on the infrastructure, characteristics, colors, design, materials, etc. Lastly, the reticular system has variability in temperature concentration depending on the locality being addressed; those near significant green areas retain lower surface temperatures compared to those surrounded by human settlements, paved roads, vehicular congestion, and high pedestrian density.

Heat islands will be generated in areas where important economic activities are carried out, whether it be the establishment of educational institutions or commercial zones. The areas that are close to significant green spaces enjoy the benefits of environmental services; these areas may be less prone to using thermal comfort systems, mainly cooling systems. However, it depends on natural conditions to determine this assertion.

Final considerations

The use of geostationary satellites represents an important tool for analyzing urban heat islands, as the application of geo-algorithms allows for an immediate diagnosis of the phenomenon experienced depending on the desired timeframe, since, thanks to satellite images, the input is quickly accessible. On the other hand, a series of methodologies, as well as available databases, can be followed that effectively adapt to the researcher's needs.

The behavior of heat islands will be varied, with characteristics that will differ even within the same municipality; the characteristics of each locality that makes it up will directly influence the concentration of the land surface. It is important to note that in this type of characteristics, it was possible to select the roadways that could form the three proposed urban ventilation corridors, as their characteristics allow for the evaluation of the potential for maximum ventilation with the least possible investment, making the implementation of urban ventilation corridors an economically viable strategy. This is because, indeed, we work with the elements present in the city, which can represent a series of difficulties and trigger various phenomena, but within these elements, the solution to these situations can be found. Therefore, it is not necessary to restructure the city, but rather to adapt the components of a complex urban system towards the direction of improving environmental quality and habitability.

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Autor 1: Preparation, textual production, discussion of results.
Autor 2: Preparation, textual production, discussion of results.