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Analysis of the formation of heat islands from the perspective of different paving materials

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Abstract
One of the main causes of the heat island phenomenon is the high thermal absorption of the surface materials and their heat retention capacity. Aiming to contribute to the study of materials that can help minimize the heat generated, the objective was to carry out a temperature analysis and its relation to the formation of heat islands among four paving materials used in the city of Maringá/PR: asphalt roll, interlock cement pavement, draining floor and rubberized floor. Density and urban morphology have influences on the study of the physical behavior of materials, which is why four locations in sun and shade, in different areas with different usages, were chosen. The evaluation was carried out using data from the Meteorological Station of Maringá, temperature data collected in the field, in the winter period, using mobile transect equipment. The data collected indicate that the asphalt roll adds a greater amount of heat, on the other hand, permeable materials dissipate less heat into the atmosphere, especially after the rains. In the following days after the precipitation the impermeable materials increase the surface temperature and relative temperature of the air exponentially, as soon as all the water has drained away, whereas permeable materials, due to the presence of water, increase the surface temperature and relative temperature gradually as the days without rain are prolonged, showing that soil permeability and the amount of vegetation cover are crucial factors for mitigating concentrated heat in urban centers.
KEYWORDS: Thermal analysis, Thermal comfort, Relative temperature and Surface temperature.

1 INTRODUCTION

The continuous urbanization process, due to population growth and socioeconomic development, plays a key role in global climate change (WANG, 2021). Factors such as the growth of cities, excess of materials with high capacity for absorbing solar radiation, concentration of infrared radiation in large urban centers and the release of sensible heat through combustion in industrial processes and motor vehicles, increase the temperature, contributing to the global climate change (WREGE et al., 2017).

Climate change is one of the Sustainable Development Goals (SDGs) of the 2030 Agenda, as the increase in temperature can lead to the so-called heat islands, contributing to environmental damage and human health (DEILAMI et al., 2018).

The changes influence and impact the life of cities, since the decrease of the natural vegetation cover, due to the high concentration of buildings, infrastructure urban materials, with high energy potential for absorbing heat from solar radiation, together with human activities , generate an air dome causing a significant increase of the temperature (AMORIM, 2019).

The reduction of local temperature, in a large center, without the use of vegetation cover, directly affects the soil surface, since the excess of buildings combined with the materials used, give rise to impermeabilization, a fact that can be revised with afforestation (ZHU , 2019).

The materials used in urban structures, such as facades and roofs, play an important role for thermal balance through the absorption of solar radiation and the dissipation of part of the accumulated heat through convection with the atmosphere, increasing the temperature (SANTAMOURIS et al., 2019).

Therefore, the excess coverage used leads to a phenomenon called Heat Islands (HI), where there is a temperature difference between the urban center and its surroundings and the rural area of the city (AMORIM, 2020). HI can be classified into Urban Heat Islands (UHI) and

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Rural Heat Islands (RHI), and vegetation thermally influences the decrease in the local temperature, transforming it into an Island of Coolness (IC) (MELO-THÉRY et al., 2021).

Thus, the technical characteristics of the materials used determine, to a high degree, the energy and the conditions of consumption and comfort, being then the study of atmospheric conditions and geographic conditions the key points to identify the effect of heat islands in cities and, in the future, how to mitigate them (QUEIROZ et al., 2022).

As a way of mitigating this phenomenon, afforestation continues to be the form most addressed by public agencies, due to the fact that other mitigating forms such as thermochromatic painting and the reduction of the albedo of materials become costly for public managers (LI et al., 2016).

The use of parks, squares, forests, urban afforestation and even poket parks aims to form a mass of cold air, balancing the microclimate of the city (ALVES, 2017). However, there are cases where that can't be done, due to infrastructure, urban growth and the high concentration of materials with a high degree of albedo (ROSENZWEIG et al., 2006).

The challenges of mitigating the adverse effects of urban climate on human thermal comfort, minimizing energy consumption, among other aspects, it is necessary to better understand how the urban microclimate can be influenced by natural and human built agents. This understanding allows us to go further in the intervention of public open spaces in order to provide their social function in the dynamics of the city (SYNEEFA; SANTAMOURIS, 2016).

Such observations emphasize important issues to be incorporated into urban planning, for which can't only rely on consultations of urban indexes and climate variables during the design of the city, but also the specification and planning of public roads and sidewalks, restricting the materials to be used as mitigating form of the urban heat islands (MOHAJERANI et al., 2017). This generates specific microclimatic situations in different urban zonings and changes the condition of the upper atmosphere (DEILAMI et al., 2018).

2 OBJECTIVE

Carry out a comparative thermal evaluation between the asphalt roll, interlock cement pavement, draining floor and rubberized floor, used as paving materials in an urban center in southern Brazil, in order to contribute to the minimization of heat islands.

3 METODOLOGIA

The study area is located in the state of Paraná, municipality of Maringá, located on the Tropic of Capricorn Line (MONTANHER; MINAKI, 2020) between the geographic coordinates 23º 15' e 23º34' S e 51º 50' a 52º 06' W (Figure 1), with altitude variation from 360 to 599 meters, in the Mesoregion of North Central Paranaense. The estimated population is 436,472 inhabitants, with a total area of 487 km², and a demographic density of 733 inhabitants/km². The municipality is included in the geological area of the Santo Anastácio Formation of the Bauru Group, where there are long, flattened spikes, with slight undulations on their tops, and with watersheds between the hydrographic basins of the Pirapó and Ivaí rivers (IBGE, 2021). In the Guarapuava Plateau where Maringá is located, there is a predominance of Oxisols and Nitosols (NOLLA, et al., 2020). The region's climate is characterized by two well-defined seasons, the rainy summer and the dry winter.

Figure 1- Map of the location of Maringá-PR

Source: The authors (2023)

The research addresses as an analysis method, the one proposed by Monteiro and Mendonça (1976), with emphasis on thermal comfort from the study of temperature behavior in its diurnal and seasonal variations under the local space.

Two types of data capture were used: fixed station of the meteorology station of the Geography Department of the State University of Maringá (UEM); and mobile transceivers, using on-site atmospheric thermometers, laser thermometers and a thermometer coupled to an infrared camera.

In order to understand the local space, the geological and urban conditions were considered, that is, relief, structure, function and location of the materials already introduced in the paving of the municipality. The analysis of these attributes was associated with the elements of construction and afforestation in order to compose the necessary foundation for the selection of observation points and data collection.

The work included the study of four paving materials classified into two categories: permeable (draining interlocking cementitious floor and rubber flooring for waste) and impermeable (asphalt and interlocking cementitious flooring) (Figure 2).

Figure 2 -A) Interlock Cement Paving B) Asphalt roll C) Rubberized Rloor D) Draining Floor.

Source: The authors (2020).

The data collection points used in this study (Figure 3) were selected because that they are located in different zones of land use and occupation, with most points presenting the four types of materials (Chart 1).

Figure 3- Map of the location of the points selected

Source: Google Earth-Pro (2020).

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Chart 1 – Characteristics of the collection points

luminosity	Local	Land Use and Occupation	Material	Coordenada Geográfica
Sun	Point 1	Highly populated commercial and residential	Interlock Cement Paving Asphalt roll Rubberized Rloor Draining Floor	-23.417829, -51.938438
Sun	Point 2	Moderately dense commercial and residential	Interlock Cement Paving Asphalt roll Rubberized Rloor Draining Floor	-23.426211, -51.938198
Shade	Point 3	Low-density commercial and residential	Interlock Cement Paving Asphalt roll Rubberized Rloor Draining Floor	-23.437002 -51.933367
Shade	Point 4	industrial and commercial	Interlock Cement Paving Asphalt roll Rubberized Rloor	-23.423732 -51.920435

Fonte: O autor (2022).

To obtain data from each point, three equipments were used simultaneously. The emissivity index was measured using an AMPROBE 20:1 Infrared Camera - IRC-110 (Chart 2). The air temperature and humidity indices were obtained using the Datalogger UX100-023ª. The surface and relative temperature of the materials were obtained using an industrial infrared digital laser thermometer with a resolution of 0.1 c/f. emissivity of 0.95 (∑), IR Thermometer AMERO2.

Chart 2- Thermal Emissivity Index of materials

Tipology	Material	Emissividade (∑)
Impermeable	Asphalt roll	90
Impermeable	Interlock Cement Paving	95
Permeable	Draining Floor	95
Permeable	Rubberized Rloor	90

Fonte: O autor (2022).

The air temperature data in the period contemplated in this study were provided by the meteorological station of the municipality located at the State University of Maringá. For the data collected, an analysis of normality was performed using the Shapiro-Wilk test. To determine possible correlations between Relative Air Humidity (RH) and radiation, Pearson's "r" correlation coefficient was used at different sampling times.

To verify the existence of a correlation between the air temperature, the surface temperature and the relative temperature, between the sampling points and the materials, Pearson's "r" correlation was used, with previous angular transformation of the values through the RStudeo Software.

The Krustal-Wallis non-parametric test was used to observe possible differences between surface temperatures and different paving materials and surface temperature at

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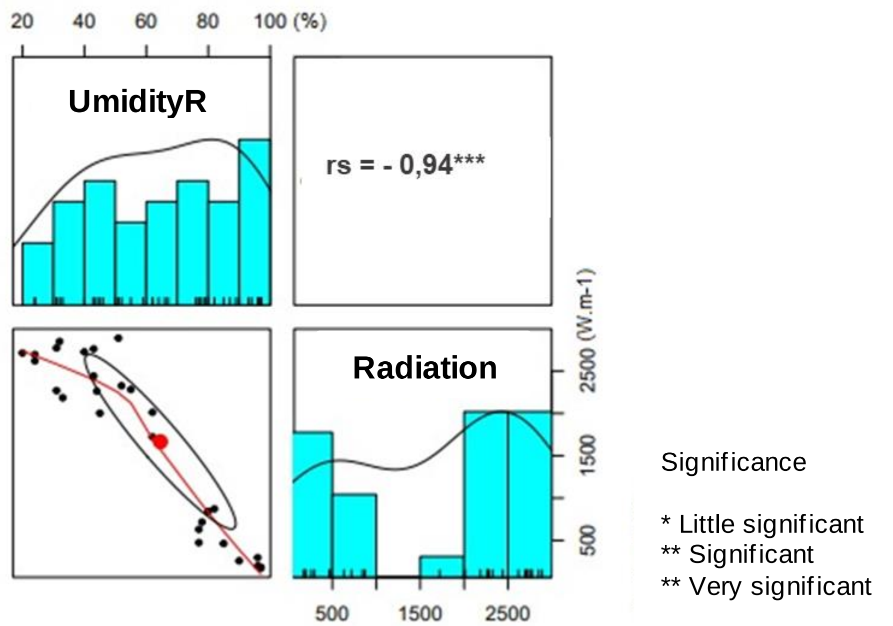
different sampling sites. Differences between medians were performed using Dunn's test, with p-value adjustment. The statistical significance level adopted was $p < 0.05$.

4 RESULTS AND DISCUSSION

Through the data provided by INMET, a correlation was observed between global radiation and relative humidity. It is possible to observe a significant negative correlation ($p < 0.001$) between relative humidity and global radiation. At the beginning of the day the global radiation is almost zero, as the hours of the day pass the global radiation increases, causing the RH contained in the atmosphere to tend to decrease causing evaporation (Figure 4). However, this correlation can be influenced by other factors such as the amount of clouds and overcast skies. This direct relationship between global radiation and relative humidity was also observed by Almorox et al. (2020).

Figure 4 – Spearman correlation (Sc) between Global Radiation and Relative Humidity of the air, at different sampling times.



Source: The authors (2022).

Throughout the day, a negative and significant correlation with relative humidity can be observed (Figure 5). RH is related to temperature, radiation. The greater the radiation, the greater the incident temperature, and, consequently, the lower the RH. At the beginning of the day, the radiation found is only that reflected by the moon, as the hours go by, there is a gradual increase in radiation and, consequently, an increase in temperature. These patterns refer to data sampled during the day in the time slots collected. It is possible that in places of great soil sealing, the phenomenon of Nocturnal Heat Islands can occur, promoting the concentration of heat even

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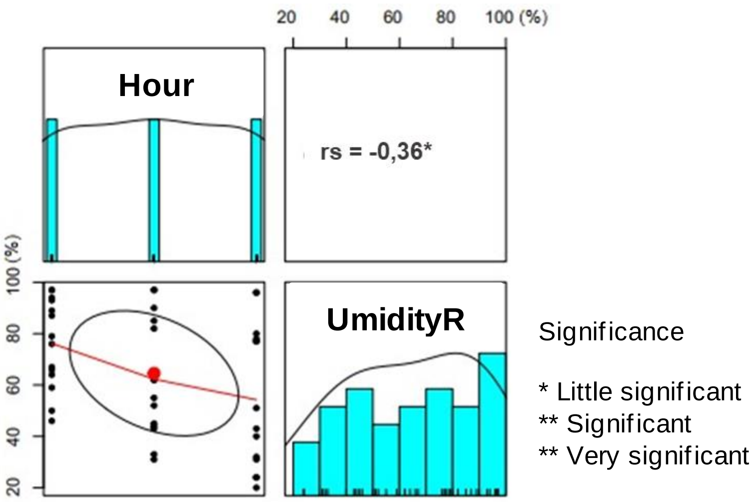
at night, and therefore, there is a great exchange of heat between materials and atmosphere.

Regarding relative humidity, no significant correlation was observed at different sampling times (rs = 0.13; p> 0.05). As the sampling period was short, it probably does not interfere in a preponderant way in the loss or gain of radiation.

Figure 5 – Spearman correlation (SC) between relative humidity (RH) at different sampling times.



Source: The authors (2022).

Regarding temperature (Figure 6), it was possible to observe that the correlation between surface and atmospheric temperatures is positive and significant (p<0.01), demonstrating that the magnitudes are directly proportional, and the surface temperatures of the paving materials influence the local microclimate (LIAO et al., 2022). In this way, the greater and slower the heat exchange between the materials and the atmosphere, the greater the possibility of forming urban heat islands. , et al., 2020).

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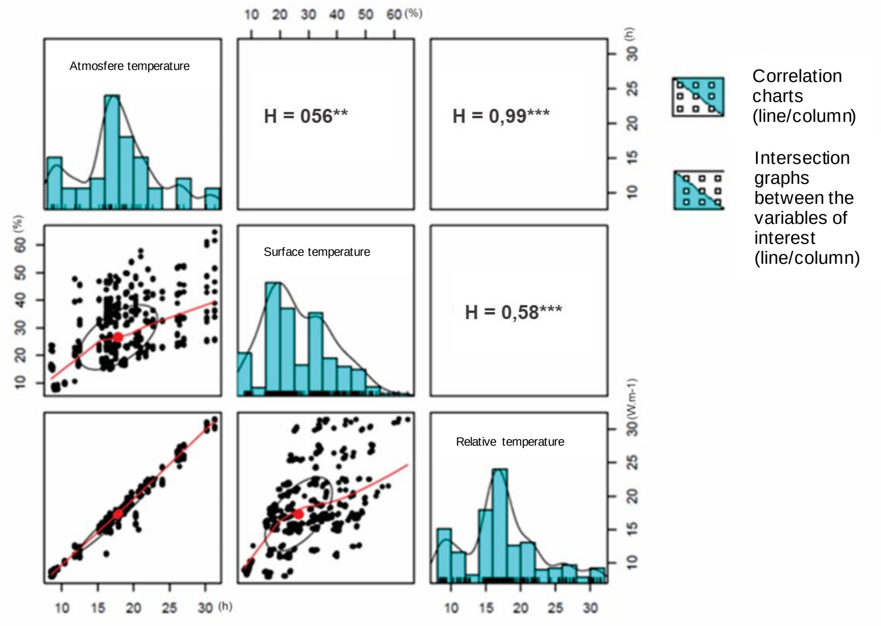
Figure 6 – Kruskal-Wallis (H) test values comparing atmospheric, relative and surface temperatures. Values in asterisks show significance between variables.

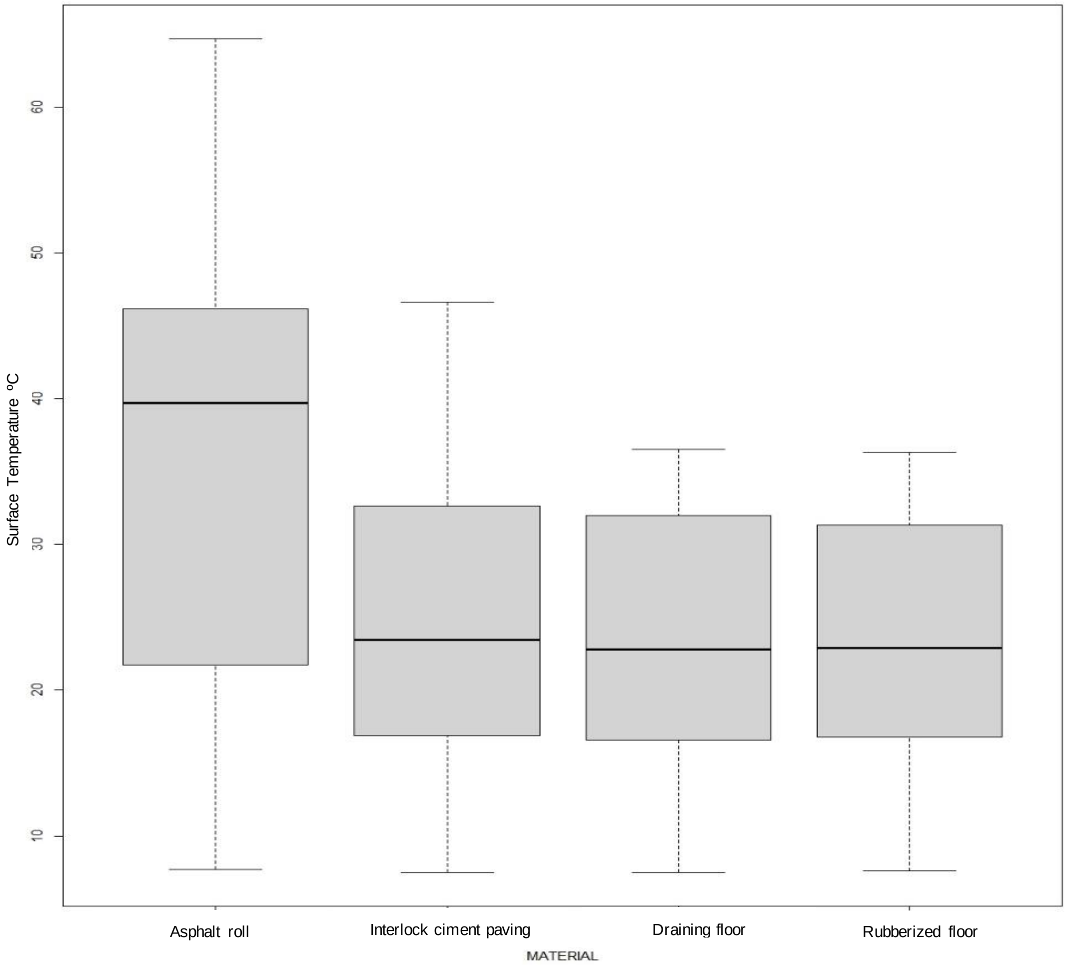


Source: The authors (2022).

The identification of temperatures of urban surfaces is essential to characterize the urban thermal field, since UHI occur close to the surface, indicating a strong influence of urban geometry and the reflectance of surface materials on the climate (MEGDA; MAIERO, 2022). This identification is the starting point for researching the variables (materials and urban morphology) and mitigation practices, in addition to being part of the development of the analyzes as a whole (SILVA et al., 2018).

Regarding surface temperature, there was a significant difference between the asphalt roll and the other three materials tested (Figure 7). Impermeable paving materials with darker colors, contributing to the formation of albedo (ROSENZWEIG et al., 2006) and heat islands (SANTAMOURIS et al., 2019; RICHARD et al., 2021; LIAO et al. , 2022). The asphalt roll in environments where there is a lack of urban afforestation or in regions where the urban infrastructure with a high degree of human density, becomes the main material that encourages the appearance of ICU (AMORIM, 2020). For the other materials, no significant differences were observed between them.

Figure 7 – Relationship between the 4 paving materials (asphalt roll, interlock cement flooring, draining floor and rubberized floor) and surface temperature.



Source: The authors (2022).

Vegetation influences the control of air temperature inside urban areas, as well as in their surroundings, creating unique microclimates insofar as it interferes with the flow of solar radiation, sometimes by preventing surface heating and, consequently, daytime heating of the surface layer of the air in that region of the city, due to its shading (CRUZ, 2021).

According to Amorim (2019), the types of materials, as well as soil impermeabilty, construction density and vegetation are responsible for the spatial variability of surface temperatures within the environment. In the surroundings of the urban fabric, permeable soils that have vegetation cover can reduce UHI and generate Freshness Islands (AMORIM, 2020).

At the points where the asphalt roll absorbed less heat (points 3 and 4), there was local vegetation cover, demonstrating the ability of the vegetation to reduce the local temperature (HE et al., 2019). Even if, in a small scale, the second material that presented a higher surface temperature was the interlock cement floor, noting that the permeability of the material decreases the heat absorption capacity, as was also observed by Wang et al. (2022).

On the other hand, in the points without vegetation cover (points 1 and 2), surface

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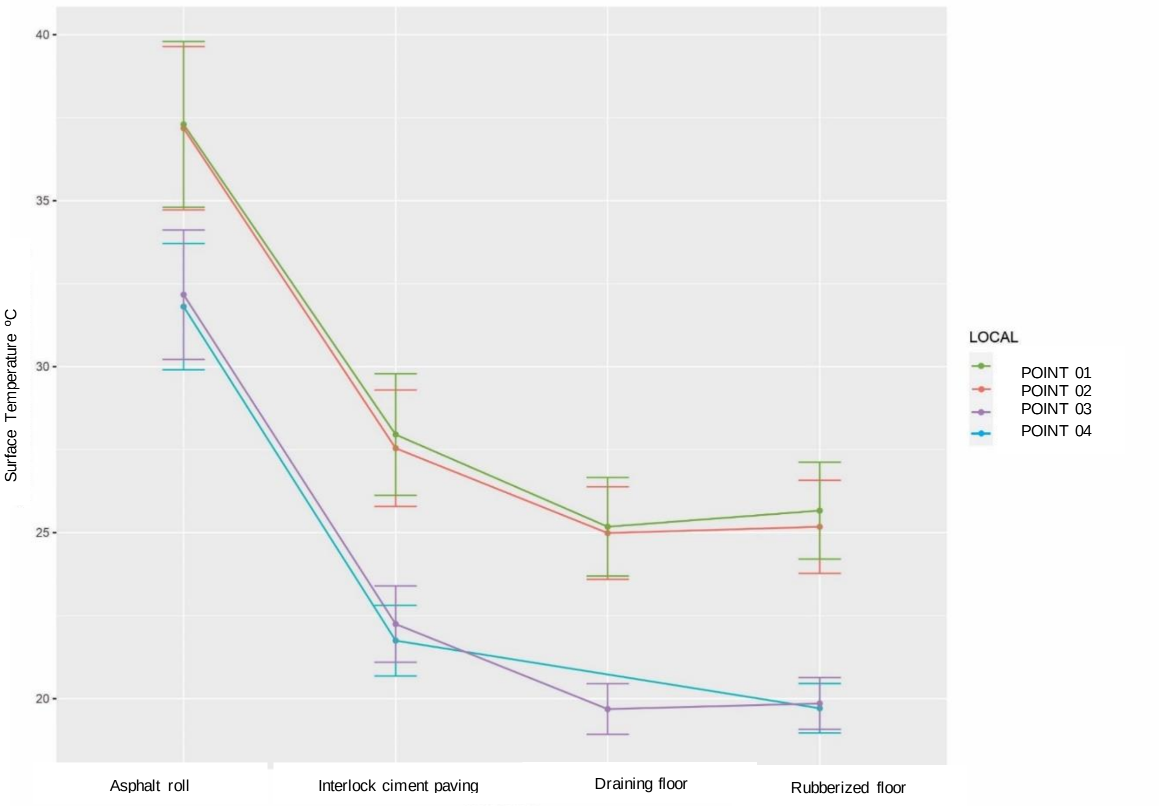
temperatures were higher than in the points with cover (points 3 and 4) (Figure 8). The presence and type of vegetation cover, the density of afforestation, the presence of tree species with larger crowns, canopy size and tree development are factors that can help reduce local temperature (SHINZATO; DUARTE, 2018).

Figure 8 - Graph showing the relationship between surface temperature and analyzed materials, using collection points as a variable.



Source: The authors (2022).

It is important to emphasize that at the collection points that have materials with vegetation cover, the temperatures between each one of them remained similar, demonstrating the mitigating capacity that the vegetation has in making the materials retain heat for themselves and therefore help in mitigating the formation of the ICU (FARHADI; FAIZI; SANAIEIAN, 2019). In their study, REIS et al. (2022) observed a reduction in surface temperature due to the type of vegetation and the size of the canopy, reinforcing the importance of green areas for the thermal comfort of the population in the urban environment.

Pavements strongly affect the urban climate and the thermal balance is determined by factors such as the amount of solar energy absorbed, the infrared radiation emitted, the heat transferred by convection to the atmospheric air, the heat stored in the mass of the material and the heat conducted for the soil (SANTAMOURIS, et al., 2019). In this study, it was observed that in the asphalt roll there is an increase in surface temperature, showing a significant difference between the increase in surface temperature in all locations. It is possible to identify significant

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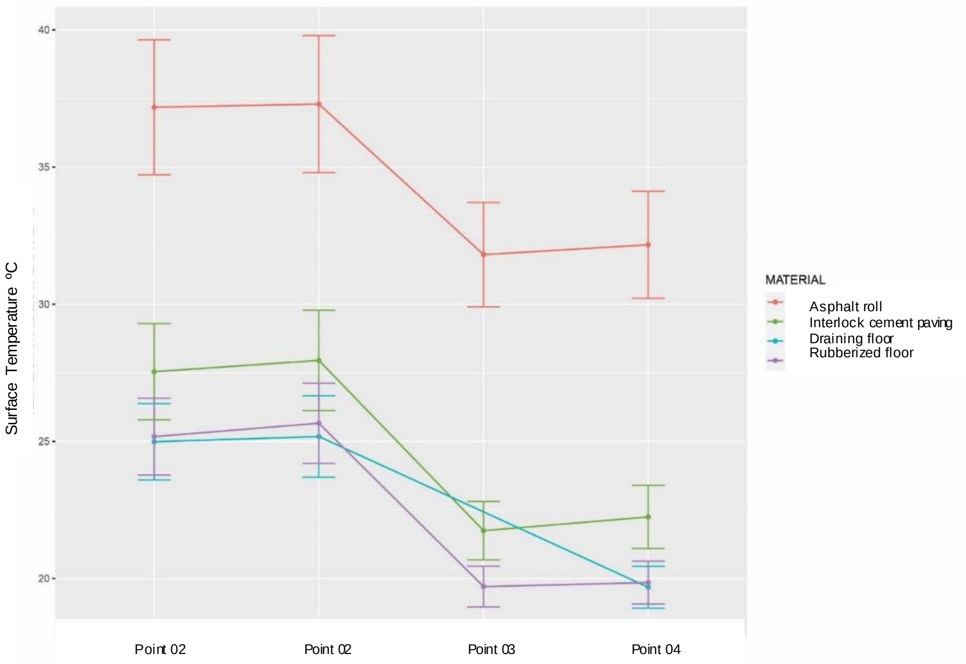
differences between points 1 and 3 ($p<0.001$), as well as between points 2 and 3 ($p<0.01$).

Important factor to be highlighted is that. during the period in which precipitation occurred, all measured temperatures were constant. Water, by thermal conduction of heat transfer, by form of contact adds more heat to itself (DONGLIANG et al., 2022). Later after this period, it is noticed that, mainly in the asphalt blanket, there is a big difference, since it is an impermeable material. After the water drains, this material begins to easily retain heat (SEN; ROESLER, 2019). The behavior of variation between the full sun and shade collection points can be observed, emphasizing the fragility of the asphalt roll in relation to thermal disturbance (Figure 9). Studies with permeable pavements are directed towards increasing capillarity, finding that its thermal response depends on the availability of water for evaporation (SANTAMOURIS, 2013). It deserves attention the fact that there is limited scientific information about its thermal performance.

Figure 9- Graph showing the relationship between surface temperature and collection points, using the analyzed material as a variable.



Source: The authors (2022).

The differences observed in this study (Figures 8 and 9) are related to the ability to exchange heat between materials and the atmosphere, since the materials that most absorb heat for themselves and tend to perform a slow exchange with the atmosphere, one of the main causes of urban heat islands. This capacity of materials can be influenced by factors such as: albedo, color, dirtiness, wear, color loss, materials used in their manufacture and impermeability, and each material behaves differently depending on the local microclimate (MOHAMMAD HARMAY; CHOI, 2023) .

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5 CONCLUSION

The study carried out allowed comparing the various paving materials used in the urban ecosystem with regard to the formation of urban heat islands (UHIs). it was possible to show differences between these materials such as: their properties, absorbance, coloring and permeability. In addition to these factors, the presence of vegetation on the materials is also a factor that can influence the formation of urban heat islands.

One of the aspects to be highlighted is that among the impermeable materials, the asphalt roll is the main material that absorbs heat and causes the thermal balance between the atmosphere and the pavement to become unbalanced, enabling the formation of UHIs. Permeable materials behave similarly among themselves, especially after several days of precipitation, demonstrating thermal equilibrium. It often provides a rapid exchange of heat between the atmosphere and the paving. It is noteworthy that the permeability of the material facilitates the natural flow of water to the soil, and avoids other urban problems such as floods and the reduction of water bodies in urban environments, an important factor related to water infrastructure and the sustainable management of cities.

In addition to the permeability of the material to be used in paving, the color also influences, due to its ability to retain heat. Thus, new studies must be carried out to evaluate the colors available for these materials, avoiding the increase in their temperature.

This study demonstrated that the presence of vegetation in the urban environment minimizes the temperature, since lower values were recorded in places where there was vegetation, although with the asphalt roll, temperatures are higher than in other materials. Vegetation cover is a way of mitigating the effects of ICU, enhancing the fundamental aspect of Municipal Urban Tree Planting Plans.

New studies regarding paving materials should be conducted in order to find out which is the ideal paving to mitigate the effects of heat islands. Furthermore, new studies on the effects of population density, precipitation and the presence and type of vegetation cover will not only contribute to improving the landscape, but as an effective way to reduce urban heat islands.

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