CONEM 2022
CONGRESSO NACIONAL DE ENGENHARIA MECÂNICA
TERESINA - PI

ABCM
XI CONGRESSO NACIONAL DE ENGENHARIA MECÂNICA
DE 07 A 11 DE AGOSTO DE 2022, TERESINA-PI, BRASIL

INFLUENCE OF URBAN ARBORIZATION ON HUMAN THERMAL COMFORT: CASE STUDY FOR A UNIVERSITY CAMPUS

Gabriel Felipe Carvalho Silva, gfc.silva@discente.ufma.br[1]
Higor Medeiros Licá, higor.lica22@gmail.com[1]
João Vitor Rego Muniz, jvrmuniz@hotmail.com[1]
Glauber Cruz, cruz.glauber@ufma.br[1]

[1]Federal University of Maranhão – Department of Mechanical Engineering - Avenida dos Portuguses, 1966 – São Luís (MA)

Abstract. *Urbanization as a phenomenon of spatial change generates different local changes in the climate, which are characterized by an increase in surface and atmospheric temperatures (environmental radiation effect). Studies showed that this effect is minimized by cities arborization, since it increases the relative moisture and decreases the surface temperatures. In this context, this study aimed to compare the surface thermal dynamics of an arborized area and other non-arborized area in the Dom Delgado University City of the Federal University of Maranhão (UFMA) - São Luís (MA). The methodology employed was divided into two stages: the first refers to the measurement of temperatures, which were performed at previously determined fixed points, weekly for three months and at the same time (01:00 pm) and second stage consisted of the collected data treatment, where the average temperatures in each chosen point were analyzed, taking into account the different construction materials (wood, concrete, asphalt, red brick, ground, and acrylic paint) found at the specified location. In addition to the surface heat flow rate was calculated by radiation heat transfer. The results showed the concrete as one of the materials with the highest average surface temperature (≈ 53.54 ± 2.6 ºC), slightly higher than asphalt (≈ 52.37 ± 2.4 ºC) and more significant than the temperature in the arborized area, both at the reference height of the ground (≈ 36.53 ± 1.3 ºC) and at average heights, approximately 1.50 m (≈ 34.88 ± 1.1 ºC). For the thermal heat flow, the asphalt showed a higher value (650 W m^{-2}) in contrast to the arborized area (450 W m^{-2}). Such results showed the importance of the materials correct selection for the buildings construction in urban areas and relevance of the arborization for the human thermal comfort.*

Keywords: *environmental radiation, heat islands, heat transfer, urbanization, urban microclimate.*

1. INTRODUCTION

Urbanization is a phenomenon characterized by a change in a given geographical space, causing a profound socioenvironmental impact, since this overloads the ecological balance and modifies the climatic characteristics (MILLS, 2007). According to Arnfield (2003), the reduction of green areas in favor of the construction of buildings and roads, besides the existence of automobiles and factories, significantly change the soil conditions, airflow, rainfall index and, consequently, the temperature of the urban environment.

Considering unplanned cities, this phenomenon is intensified, since this disorderly growth leads to presence of few arborized areas, which soften the local temperature, causing a thermal discomfort, which is widely perceived in large cities (MARTINI, 2013). In this scenario, urban forestation is an important factor for the large cities, providing well-being and health to its citizens. Da Silva et al (2021) studied that the residues of this vegetation can also be used in the production of clean energy, partially replacing fossil fuels.

According to Jornal da USP (2017), a study conducted by Higher School of Agriculture “Luiz de Queiroz” (ESALQ) of the University of São Paulo (USP), found that in a determined urban area, the number of trees contributes significantly for the reduction of overheating. In this research performed to the city of Piracicaba (SP), the authors observed a reduction in the average temperature by about 1 °C. However, for such an effect to be reached it was necessary to increase the tree coverage to 14.31% for the dry season and 27.70% for the rainy season.

Thermal comfort conditions in urban areas are achieved mainly with the use of tree coverings (PINHEIRO and SOUZA, 2017). For Martelli and Santos Jr. (2015), the concept of thermal comfort necessarily implies in the definition of an index of temperature and relative humidity of the air, where humans feel comfortable due to favorable thermal conditions for the human body, for example, reduction of direct insolation, increase of evapotranspiration rates and reduction of wind speed.

In this context, this study aims to compare the surface thermal dynamics of an arborized area and another non-arborized area in the same location through periodic temperature measurements at points of materials with distinct compositional characteristics. The research was carried out at Dom Delgado University City, Bacanga Campus, Federal University of Maranhão (UFMA), São Luís (MA).

2. MICROCLIMATE OF THE URBAN COVER LAYER

For Monteiro (2003), the urban climate is a highly complex system that covers a determined land space and its urbanization. Such system is complex, dynamic and adaptive, presenting as essential characteristics for its maintenance, the anthropic and natural factors, for example, the presence or absence of natural vegetation cover and deforestation.

According to Oke (2002), an urban system is composed of two boundary layers delimited by height in relation to the surface: (1) urban canopy layer (UCL), which is located between the ground level and the average roof level, and (2) urban boundary layer (UBL), located above the roof level.

In the urban canoy layer (UCL), airflow and energy exchange processes are controlled by microscales that are site-specific and characteristic. However, in the urban boundary layer (UBL), the processes present larger spatial and temporal scales, taking into account the urban surface as a whole. The energy balance in the UCL for the walls is presented in Equation (1):

$$q" = q"_h + \Delta q"_s \tag{1}$$

where, q" is the radiation rate, $\Delta q"_s$ is the rate change in energy storage by the materials, $q"_h$ is the sensible heat exchange with the outside air. For the ground this radiation rate is calculated by Equation (2):

$$q" = q"_h + \Delta q"_s + q"_e \tag{2}$$

where $q"_e$ is the latent heat exchange with the outside air.

For Mathew, Khandelwal and Kaul (2018), the variation of temperature under different situations is directly linked to the amount of solar radiation, which each surface is subjected and also the amount of sunlight reflected and absorbed. The factor that quantifies the ratio between both energies by radiation is known as albedo or absorptivity (α_s), varying for each type of material used in the different constructions.

Dark surfaces and some materials commonly used in the construction present low albedo and therefore, a high absorption of solar radiation (INCROPERA and DEWITT (2014)). According to Incropera and Dewitt (2014), the heat flux by solar radiation is obtained by Equation (3).

$$q"_s = \alpha_s \cdot G_s - 0.22(T_s - T \infty)\, 4/3 - \varepsilon \cdot \sigma\, (T_s^4 - T_{sky}^4) \tag{3}$$

where, α_s is albedo or solar absorptivity of the surface material, G_s is the solar irradiation, T_s, T_∞ and T_{sky} are the temperatures in surface of the material, ambient and effective sky, respectively, ε is emissivity of the surface and σ is Stefan-Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4}).

3. EFFECTS OF URBAN AFFORESTATION

According to the last Census of the IBGE (2010) conducted in 2010, 87% of the Brazilian population lives in urban centers. In these regions, there is an increasing use of materials such as iron, steel, glass, tar, among others, which act as reflecting agents and contribute to the creation of heat islands or heat pockets in the large cities. Due to this condition, the climate is similar to the desert, being very hot and dry during the day, and cold and humid at night (JÚNIOR, 2011).

From this perspective, there is a need of large-scale afforestation, since trees represent an extremely important element for better environmental management in cities. These natural elements are able to improve the thermal comfort of people, reducing the temperature with high rates of transpiration and also the incidence of direct insulation, among other beneficial factors (PINHEIRO and SOUZA, 2017).

Several studies and field analyses presented the importance of using trees in large urban centers. For example, SVMA (2008) found that the most densely urbanized central regions of the city of São Paulo (SP) presented differences up to 10 °C more in the horizontal temperature gradient. The same phenomenon was observed by Martins (2012), which evidenced a temperature difference equivalent to 10 °C between the central region and peripheral areas in the city of Goiânia (GO).

For the Northeast region, Feitosa et al. (2011) studied the influence of urbanization on the surface temperature of the city of Teresina (PI), which applying georeferencing tools showed that between years 1989 and 2009 there was an increase of 60.4% of the area occupied by buildings, and consequently, a suppression of native vegetation. Comparing the maximum temperatures in the aforementioned years, it was observed a 15% increase in surface temperature, *i.e.*, in terms of average values, 34 °C in 1989 and 39 °C in 2009.

According to Martini, Biondi and Batista (2013), through analysis of the periodic patterns of meteorological elements, an urban forest fragment in the city of Curitiba (PR) provided a microclimatic improvement, with a decrease from 0.5 to 0.8 °C of temperature.

This relationship between afforestation, temperature and air relative humidity was also confirmed by Sant'Anna Neto (2000), which stated that in urbanized areas the temperature is higher and air relative humidity is lower than in surrounding rural areas. The presence of trees in urban environments brings improvement and microclimatic stability, because the plants release large volumes of water vapor into the atmosphere, providing shade, filtering radiation, among other benefits (MILANO AND DALCIN, 2000). By means the transpiration process and shading, vegetation enables the cooling of buildings, reducing surface temperatures and heating of these, and also prevents the sun rays from directly affecting people, providing a greater thermal comfort (PINHEIRO and SOUZA, 2017).

4. MAIN THERMAL PROPERTIES OF MATERIALS

The main thermal properties of the conventional building materials directly influence the behavior, regarding heat transfer phenomena (KREITH, 2003). According to Incropera (2014), for the different materials studied in this work, the emissivity (ε) and thermal absorptivity (α) are shown in Tab. 1.

Table 1 - **Thermal properties of the main materials used in civil construction.**

Materials	***ε***	***a***
Wood	0.82	0.59
Concrete	0.88	0.65
Asphalt	0.85	0.93
Brick	0.85	0.65
Ground	0.94	0.80
Ink	0.90	0.26

Source: Adapted from Incropera (2014) and Kreith (2003).

The following are presented some characteristics of the main materials used for the local studied in this research, namely: wood, concrete, asphalt, red brick, soil, and acrylic paint.

4.1 Wood

According to Moreschi (2014), wood is a material with relatively low thermal conductivity (0.12 W m^{-1} K^{-1}), due to its porous structure, which makes it a good thermal insulator. The heat flow through wood varies depending on the direction in which it acts and also on the irregularities of the physical structure (knots, cracks, etc).

Heat irradiation in wood is much lower than in other materials such as stones, bricks and metals due to low thermal conductivity, moderate densities and specific heat (MORESCHI, 2014).

4.2 Concrete

According to Cintra (2017), the properties and thermal performance of concrete depend directly on the materials that make up its structure, for example, cement or aggregate fragments and possible additives, because these components can modify the physical, chemical and dimensional characteristics of the concrete.

For example, Coelho et al. (2013), using a numerical analysis of concrete, found that due to the low thermal conductivity, this material presented a higher maximum temperature due to the difficulty of dissipating the heat flux generated internally. The authors, Cintra (2017) and Coelho et al. (2013) also noted that with the reduction of specific mass there was an increase in temperature due to greater porosity, difficulting the internal heat dissipation.

4.3 Asphalt

According to Callejas, Durante and Rosseti (2015), asphalt paving is one of the biggest causes of temperature rise and formation of heat islands in places where this is applied, due to its thermophysical properties, such as high thermal conductivity.

With increasing solar radiation, energy is stored in the asphalt sidewalk (high thermal conductivity, effectiveness and heat absorption), and is also released into the air through convection heat transfer and radiation. Between the morning and early afternoon periods, convection and irradiation are not sufficient to cool the asphalt, resulting in the energy accumulation on the sidewalk. As the solar energy decreases (early afternoon), the asphalt is gradually able to release the stored heat by means of convection and radiation, *i.e.*, being cooled (CALLEJAS, DURANTE and ROSSETI, 2015).

4.4 Ceramic brick

Red ceramic, widely used in bricks, is a low thermal conductivity material. Ceramic bricks limit the passage of heat through the wall, which results in a more pleasant thermal sensation (CERÂMICA LORENZETTI, 2018). The thermal conductivity of bricks is directly associated to the pores that these present, which are possible to be manipulated in the production process (SALEMA, 2014).

4.5 Soil

The thermal properties of soil, such as conductivity and thermal diffusivity, and propagation velocity vary between the depths and seasonalities in which it is found (CARVALHO, SOUZA and MAKINO, 2013). The soil presents a great ability to store heat, and the conductivity and thermal diffusivity are related to its moisture, because as the moisture of the dry soil increases, an increase in thermal diffusivity and release of air contained in the soil is produced (ALVALÁ et al., 2002).

4.6 Ink

According to Dornelles et al. (2011), white acrylic ink is a great thermal insulator and widely used for thermal comfort in buildings, reducing electricity consumption when using environmental air conditioning systems. This phenomenon is related to solar absorptance and surface roughness, whose greater roughness increases absorptance, providing the white paint with greater thermal resistance and heat reflection (DORNELLES et al., 2011; PEREIRA et al., 2019).

5. CLIMATE CHARACTERISTICS OF THE SÃO LUIS CITY (MA)

The São Luís city (2° 34′ 41″ S, 44° 16′ 50″ W) is the capital of the Maranhão State, founded on September 8, 1612 by French navigators. The city is located on the *Upaon-Açu* island (which means "Big Island", according to the *Tupinambás* Indians), in the South Atlantic between the bays of São Marcos and São José de Ribamar (PEREIRA, 2017). According to the 2010 census, São Luís city (MA) has approximately, 1,014,837 inhabitants (IBGE, 2010) and occupies a nominal area of 834.785 km^2 (PREFEITURA MUNICIPAL DE SÃO LUÍS, 2015).

The São Luís island (Fig. 1) is rich in manifestations and popular cultural expressions (*bumba-meu-boi*, *cacuriá* dance, traditional blocks, reggae festival, among many others cultures). In addition, it presents an abundant and peculiar cuisine, besides having the largest architectural set of Portuguese tiles in Latin America, being considered a cultural heritage of humanity by UNESCO in 1997 (PREFEITITURA DE SÃO LUÍS, 2015).

Figure 1. **Aerial view of the Historical Center of the São Luís city (MA), highlighting São Marcos Bay, Beira Mar Avenue and Leões Palace (seat of the Maranhão State government).**
Source: Viagens e Caminhos (2019).

According to a study conducted by Weather Spark (2019), the climate of São Luís (MA) is tropical, *i.e.*, it is hot and humid throughout the year. In general, the temperature ranges are between 25 and 32 °C, rarely are lower than 23 °C or higher than 34 °C. The city's climate is predominantly composed of two "seasons": one with a high precipitation index and average annual of around 2156 mm (cloudy sky) and another dry season (partly cloudy sky).

The hot season (August and December months), generally present a daily maximum temperature above 32 °C, with the hottest day registering average temperatures maximum and minimum around 32 °C and 26 °C, respectively. Whereas, the cooler season (January and April months) exhibits a daily average maximum temperature below 31 °C, with the coolest day recording temperatures around 25 °C and 30 °C, for average minimum and maximum values, respectively (WEATHER SPARK, 2019). Figure 2 shows an average temperature distribution throughout year 2019, with maximum and minimum temperatures characterized by the red and blue lines, respectively.

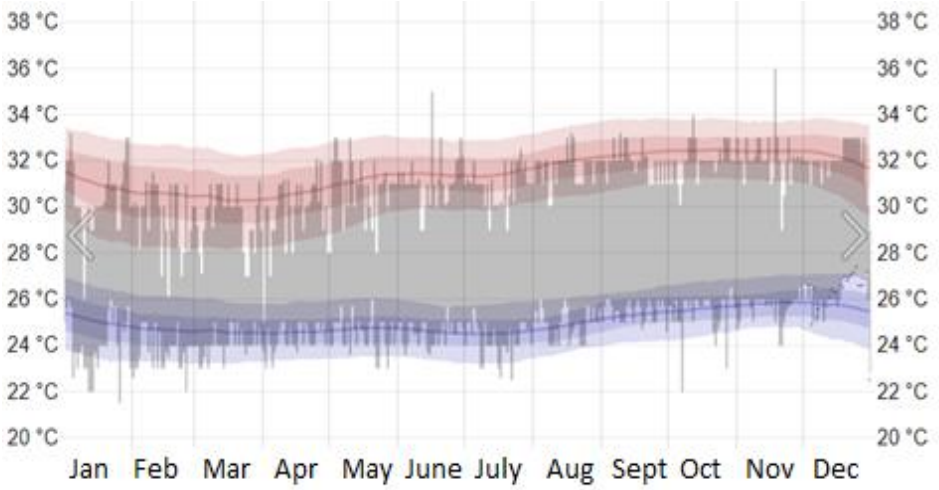

Figure 2. **Maximum and minimum temperatures measured over the year 2019 for the city of São Luís (MA).**
Source: Weather Spark (2019).

6. METHODOLOGY

In this research, a case study was carried out for the Dom Delgado Campus of the Federal University of Maranhão, São Luís (MA), Brazil between the months of August and November 2019. The experimental procedure consisted of weekly temperature measurements always at the same time, *i.e.*, at 01:30 pm in six distinct points, which are constituted from different materials. Figure 3 shows the exact measurement locations and points adopted.

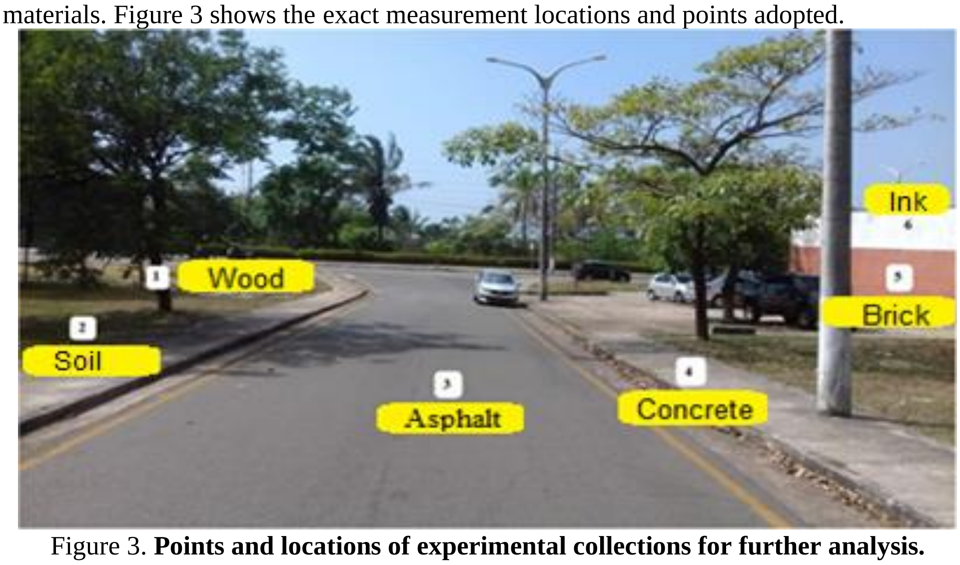

Figure 3. **Points and locations of experimental collections for further analysis.**
Source: Authors (2021).

The temperatures of the aforementioned points were measured with an Omegaette brand optical pyrometer and model OS542 - Infrared Thermometer, which is capable of measuring temperatures between -20 °C and 500 °C with ± 2 °C precision, where the distance from the measuring point to the device was adjusted at 900 mm. According to the manufacturer's manual for this device, there is a useful measuring area of circular geometry of about 59 mm² (OMEGA ENGINEERING, 2003).

7. RESULTS AND DISCUSSION

Throughout this research, ten measurements were taken at each previously defined point. The values found on the different measurement days are summarized in Fig. 4.

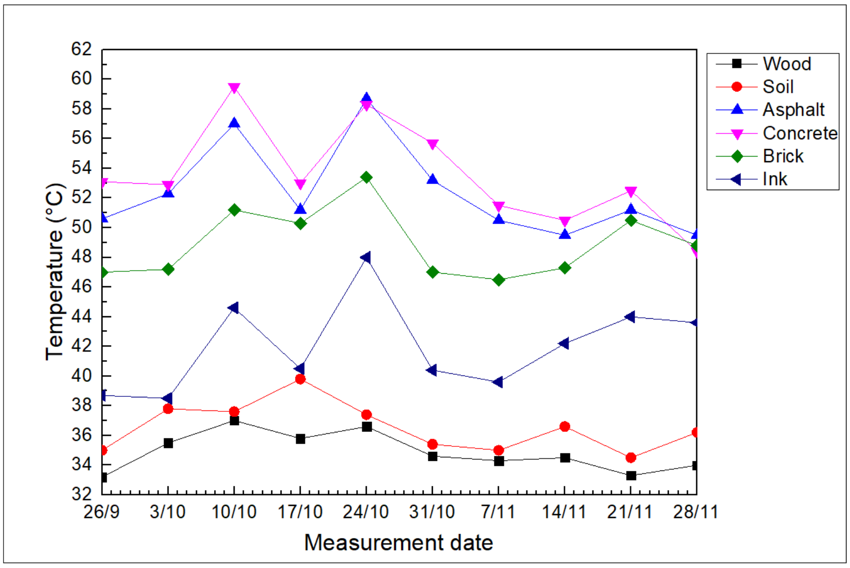

Figure 4. **Collected data on the different measurement days.**
Source: Authors (2021).

It was observed in Fig. 4, that the highest temperature recorded between the different points measured was 59.5 °C at point 4 (concrete) and lowest was 33.2 °C at point 1 (wood). It was also verified that on the same day, the highest temperature variation found was 21.7 °C, observed again between points 4 and 1, with a maximum of 58.3 °C and a minimum of 36.6 °C, respectively. These results may be directly related to the thermal properties of the materials, because although both have low thermal conductivity, concrete has higher absorptivity (α=0.65) than wood (α=0.59), which justifies its higher surface temperature observed. The wood structure, as a natural fiber composite, also influences heat flow through the function of the direction it this acts, as explained by Moreschi (2014), and corroborating with the values found for this study.

It was also noted in Fig. 4, a sharp variation between the temperature data of the points 3 (asphalt), 4 (concrete), 5 (ceramics), and 6 (acrylic paint), with this difference reaching 7 °C in some cases. In Figure 5, it can be observed the average temperatures of these measurements and visualize more objectively the results found in this research.

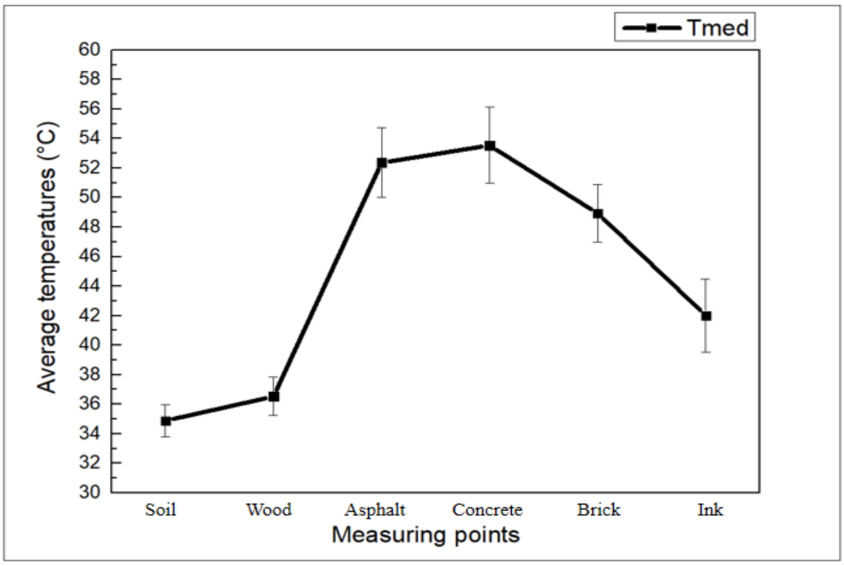

Figure 5. **Average Temperatures for each measured point.**
Source: Authors (2021).

From Figure 5, it was possible to observe that the highest temperatures were found at points 4 and 3, *i.e*., 53.54±2.58 °C and 52.37±2.36 °C, respectively, followed by point 5: 48.92±1.94 °C, point 6: 42.01±2.47 °C, point 2: 36.53±1.31 °C, and point 1: 34.88±1.08 °C. These behaviors can also be justified by the relationship between the absorptivity and thermal emissivity of the materials (Table 1), where those materials with higher surface temperatures present greater difficulties in dissipating the internal heat (Incropera and Dewitt, 2014).

The variations noted in points 1 (wood) and 2 (soil) are corresponding to the wooded area and presented the lowest values and variations. Labaki and Abreu (2010) highlighted the importance of afforestation in urban areas, listing some factors such as tree species and their influence areas, which corroborates with the results found in this study in relation to the points mentioned.

On the other hand, points 3 (asphalt) and 4 (concrete) presented considerably higher values, with a difference of 33.39% (18.66 °C) when compared to point 1 (ground) with the lowest temperature. For example, Raasch and Nardes (2017), and Martelli and Junior (2015) showed a similar behavior for the data obtained when these performed collections in wooded and non-wooded points. These studies also showed the influence of the main materials used in the civil construction on the local thermal comfort or microclimate of an urban system.

Point 5, referring to ceramics, showed a high temperature of 48.92±1.94 °C, close to those found for the asphalt and concrete. As already mentioned, red ceramic presents a characteristic of low thermal conductivity and is used to prioritize thermal comfort within buildings, since it retains large part of the absorbed heat. The consequence is the high surface temperature on the outside of the buildings, which can be observed by the data exhibited in this work.

The temperature measured in point 6 (42.01±2.47 °C), refers to the white acrylic paint, another material many used for thermal comfort of buildings, and that present a good solar absorption and reflection.

Figure 6 displays the calculated values for the heat flux by solar radiation at each position studied. For this calculation, the equation (3) was used, adopting G_s = 750 W m^{-2}, $\sigma = 5.67\times10^{-8}$ W (m^{-2} K^{-4}), T_∞ = 305 K, and T_{sky} = 263 K.

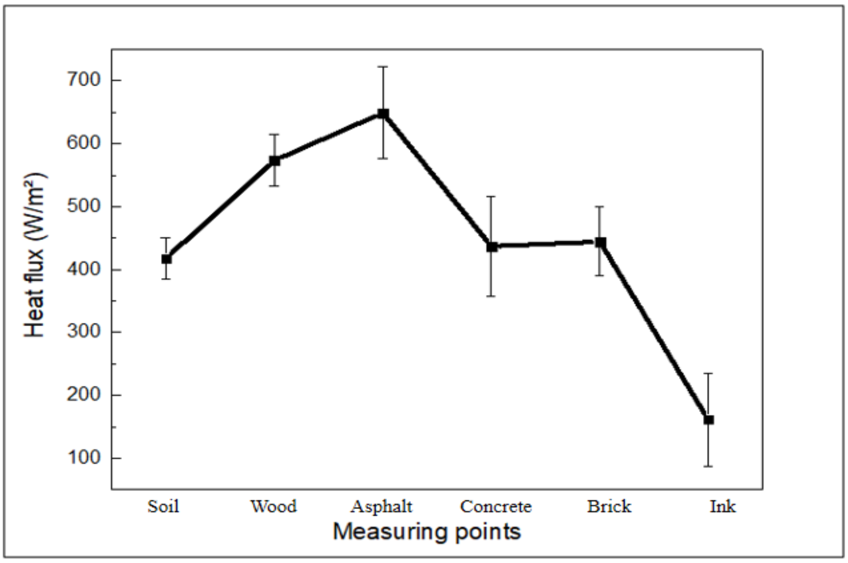

Figure 6. **Variations in heat flux by means of solar radiation.**
Source: Authors (2021).

In Figure 6, it was noted that there is a high heat flux mainly at points 2 (soil) and 3 (asphalt) equivalent to 553.44±40.98 W m^{-2} and 648.96±73.20 W m^{-2}, respectively. These values corroborate with the data of the temperatures found in these same points (36.53±1.31°C and 52.37±2.36 °C, respectively), and where it can be observed again the influence of the parameters of absorptivity and thermal emissivity on the heat flux. Similar results were found by Callejas et al. (2015).

Point 4 (concrete) presented a value for the heat flux of 437.11±79.43 W m^{-2}, which is lower compared to point 3 (asphalt), even though similar temperatures were observed in both (53.54±2.58 °C and 52.37±2.36 °C, respectively). These materials (concrete and asphalt) presented similar emissivities (0.88 and 0.85, respectively); however, exhibited a high discrepancy between their thermal absorptivity values (0.65 and 0.93, respectively). *i.e*., concrete will retain a greater amount of heat than asphalt, therefore, its heat flux is lower and surface temperature is higher. Other authors such as Cintra (2017) and Coelho (2013) showed similar conclusions about concrete and asphalt's thermal properties.

Point 5 (ceramics) showed a value similar to that found for the concrete (444.27±55.08 W m^{-2}), since these presented similar thermal properties, and corroborates with studies using both materials that prove their similar use as Salema (2019). For the point 6 (white acrylic paint), there was an abrupt decrease in the thermal flow value (161.59±73.97 W m^{-2}), which may be associated with the low absorptivity of this material, *i.e*., 0.26. Dornelles (2011) showed with more accuracy white acrylic paint's low thermal performance in retain heat, which corroborates with the results found in this study.

8. CONCLUSION

In general, the high surface temperatures in different materials allow an intense heat exchange, influencing the place thermal sensation. Hence, the importance of afforestation in large urban centers to combat the microclimate created by excess absorption of the solar radiation.

In São Luís (MA), due to its hot and humid climate, this effect is well characteristic and can be observed expressively in the same places, as shown in this study. The data pointed that the main sources of thermal discomfort were materials such as concrete, asphalt and ceramics, which present difficulties in dissipating internal heat, causing high surface temperature and consequent, increase in the thermal sensation.

The heat flow by solar radiation, which quantified the heat exchange between the materials and environment, showed that among the materials analyzed, for example, wood and asphalt obtained the highest values. However, due to its thermal characteristics of absorptivity and emissivity, wood proved to be the best material for human thermal comfort.

It was also evidenced the strong influence of the shade coming from the treetops on the surfaces that are exposed to the sun, whose same materials that presented an easy dissipating heat, and consequently, a greater environmental thermal comfort. It is also relevant to emphasize the need for a correct choice of different materials used in the civil construction, where this chooses can provide thermal well-being and environmental comfort for the local population.

9. REFERENCES

Arnfield, A. J. Two decades of urban climate research: a review of turbulence, exchanges of energy and water and the urban heatisland. International Journal Of Climatology - 23. Doi:10.1002/joc.859. Ano: 2003

Alvalá, R. C. S. et al. Medidas das Propriedades Térmicas do Solo no Pantanal Sul Matogrossense Durante Período Seco de 2002. [S.l.]: [s.n.]. 2002.

Callejas, I. J.; Durante, L. C.; Rosseti, K. A. C. Pavimentação Asfáltica: Contribuição no Aquecimento de Áreas Urbanas. E&S - Engineering and Science, v. 1, n. 3, 2015.

Carvalho, S. P.; Souza, J. R. S.; Makino, M. Observações e Estimativas de Propriedades Térmicas do Solo sob Floresta e Pastagem no Leste da Amazônia. Revista Brasileira de Meteorologia, v. 28, n. 3, p. 331 - 340, 2013.

Cerâmica Lorenzetti. Melhor isolamento térmico com tijolos de cerâmica, 2018. Disponível em: <https://blog.ceramicalorenzetti.com.br/melhor-isolamento-termico-com-tijolos-de-ceramica/>. Acesso em: Dezembro 2019.

Cintra, L. B. Avaliação Das Propriedades Térmicas de Concretos Com Ar Incorporado. Universidade Federal de Uberlândia. Uberlândia. 2017.

Coelho, N. D. A. et al. A Influência Das Propriedades Térmicas Do Concreto Na Construção De Barragens De Gravidade. XXIX Seminário Nacional De Grandes Barragens. Porto De Galinhas – PE: [s.n.]. 2013.

Da Silva, J. B. S. et al. Investigation of the urban pruning wastes as biofuels and possible utilization in thermal systems. Brazilian Journal of Development, v. 7, n. 3, p. 24730-24750, 2021.

Dornelles, K. A. et al. Desempenho Térmico de Tintas Brancas Com Microesferas Cerâmicas Para Uso em Cobertura de Edifícios. XI ENCAC Encontro Nacional de Conforto no Ambiente Construído. Búzios - RJ: [s.n.]. 2011.

Feitosa, S. M. R.; Gomes, J. M. A. Mota Neto, J. M.; Andrade, D. S. P. de A. Consequências da Urbanização na Vegetação e na Temperatura da Superfície de Teresina – Piauí. REVSBAU, Piracicaba, v. 6, n. 2, p. 58 - 75, 2011.

IBGE – Instituto Brasileiro De Geografia E Estatística. Características étnico-raciais da população: classificações e identidades. Rio de Janeiro: IBGE, 2012. Disponível em: https://censo2010.ibge.gov.br/. Acesso em: 20 jun. 2021.

Incropera, F. P.; Dewitt, D. P. Fundamentals of Heat and Mass Transfer. 7a. ed. [S.l.]: John Wiley & Sons, 2014.

JORNAL DA USP. Arborização proporciona mais conforto térmico em zonas urbanas, 2017. Disponivel em: <https://jornal.usp.br/ciencias/ciencias-ambientais/arborizacao-proporciona-mais-conforto-termico-em-zonas-urbanas/>. Acesso em: Junho 2021.

Júnior, L. S. A importância da arborização urbana. Revista ECO 21, Rio de Janeiro - RJ, n. 178, Setembro 2011.

Kreith, F. Principios da Transferência de Calor. São Paulo: Pioneira Thomson Learning, 2003.

Martelli, A., & Santos Jr., A. Árvore urbana de itapira - sp: perspectivas para a educação ambiental e sua influência no conforto térmico. Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental, n. 2, p. 1018-1031, mai-ago 2015.

Martini, A.; Biondi, D.; Batista, A. C. Variação Diária e Estacional do Microclima Urbano em Ruas Arborizadas de Curitiba-PR. Floresta e Ambiente, n. 20(4), p. 260-269, Outubro/Dezembro 2013.

Martins, B. O. Dinâmica populacional e temperatura do ar: Mudanças no padrão térmico na cidade de Goiânia- Go. Revista Geonorte, v. 2, n. 5, p. 319-330, 2012.
Mathew, A.; Khandelwal, S.; Kaul, N.. Analysis of diurnal surface temperature variations for the assessment of surface urban heat island effect over Indian cities. Energy and Buildings, v. 159, p. 271-295, 2018.
Milano, M. S.; Dalcin, E. Arborizacao de vias públicas. Rio de Janeiro: Fundação Parques e Jardins: Prefeitura do Rio: Light, 2000. xi, 206p, il
Mills, G. Cities as agents of global change. INTERNATIONAL JOURNAL OF CLIMA- TOLOGY - 27. Doi:10.1002/joc.1604. Ano: 2007.
Monteiro, C. A. F.; MENDONÇA, F. Clima Urbano. São Paulo: Contexto, 2003.
Moreschi, J. C. Propriedades Tecnológicas Da Madeira. Departamento de Engenharia e Tecnologia Florestal da UFPR. Curitiba, PR. 2014.
Omega Engineering, I. User's Guide: OS542 Infrared Thermometer. [S.l.]: [s.n.], 2003. 10 p.
Oke,T. R. Boundary Layer Climates. 2ed. London: Routledge,1987
Pereira, C. D. et al. Estudo Comparativo de Desempenho Térmico Entre Tintas de Cor Branca Aplicadas em Coberturas de Fibrocimento. Revista Anápolis Digital, v. 9, n. 2, 2019.
Pereira, M. R. D. S. A organização social do espaço urbano de São Luís-MA, 2017. Tese de Doutorado. Universidade de São Paulo. Disponível em: <https://www.teses.usp.br/teses/disponiveis/16/16139/tde-26062017-122610/en.php>. Acesso em: Junho de 2021
Pinheiro, C. R.; Souza, D. D. D. A importância da arborização nas cidades e sua influência no microclima. Revista Gestão & Sustentabilidade Ambiental, Florianópolis, v. 6, n. 1, p. 67-82, abr./set. 2017.
PREFEITURA DE SÃO LUÍS. A Cidade. Site da Prefeitura de São Luís, 2015. Disponível em: <https://www.saoluis.ma.gov.br/pagina/54/>. Acesso em: Dezembro 2019.
Salema. Estudo Comparativo Entre Cerâmica e Concreto: Tijolos e Telhas, 2014. Disponível em: <http://www.ceramicasalema.com.br/estudo-comparativo-entre-ceramica-e-concreto-tijolos-e-telhas/>. Acesso em: Dezembro 2019.
Sant’anna Neto, J. L. Mudanças Climáticas Globais: Implicações no Desenvolvimento Econômico e na Dinâmica Natural. Revista Pantaneira, v. 2, n. 2, p. 66-78, 2000.
SVMA, S. D. V. E. M. A. Atlas Ambiental do Município de São Paulo, 2008. Disponível em: <http://www.atlasambiental.prefeitura.sp.gov.br/>. Acesso em: 07 Dezembro 2019.
Viagens E Caminhos. São Luís do Maranhão – Quando ir, onde ficar, o que fazer, 2019. Disponível em: <https://www.viagensecaminhos.com/2016/11/sao-luis-do-maranhao-quando-ir-onde-ficar-o-que-fazer.html>. Acesso em: Dezembro 2019.
Weather Spark. Condições meteorológicas médias de São Luís, 2019. Disponível em:<https://pt.weatherspark.com/y/30549/Clima-caracter%C3%ADstico-em-S%C3%A3o-Lu%C3%ADs- Brasil-durante-o-ano>. Acesso em: Dezembro 2019.

10. COPYRIGHT RESPONSIBILITY

The authors are solely responsible for the content of this work.