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Comportamiento térmico de diferentes superficies urbanas durante un día cálido de verano

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RESUMEN

Cambio climático, clima urbano, isla de calor urbano (ICU), confort térmico y cambios en el uso y la ocupación del suelo, son términos comunes especialmente en los grandes centros urbanos, que tienen altas concentraciones de asfalto y concreto, pero pocas áreas verdes. En tal contexto, esta investigación tuvo como objetivo analizar el comportamiento térmico de diferentes superficies urbanas durante un caluroso día de verano en una ciudad tropical, con datos horarios recopilados de 6.00h a 20.00h, para ayudar a los planificadores y agentes a tomar decisiones, teniendo en cuenta la importancia de la vegetación para la regulación de los microclimas urbanos. El follaje (dosel), césped, asfalto a pleno sol y asfalto sombreado fueron las superficies estudiadas con el termómetro infrarrojo digital Raytek MiniTemp, mientras se usaba una cámara térmica FLIR SC660 para registrar recortes de paisajes con y sin vegetación. Los resultados mostraron que el asfalto a pleno sol tuvo la amplitud térmica más alta, alcanzando los 65°C, mientras que la misma superficie, pero sombreada por los árboles de la calle, no superó los 34°C, ambos a las 12:00h. La temperatura superficial más alta ocurrió en el techo de un automóvil de color oscuro (95°C). En las horas cálidas del día, la vegetación (hojas de árboles y césped) mantuvo temperaturas estables en el rango de 30 a 46°C, debido al agua contenida en sus tejidos, demostrando ser un elemento clave en la regulación de microclimas durante el verano tropical.

Palabras clave: Temperatura de Superficie; Clima Urbano; Uso de la Tierra y Ocupación; Imágenes Térmicas; Zonas Verdes Urbanas.

Thermal behavior of different urban surfaces during a hot summer day

ABSTRACT

Climate change, urban climate, urban heat island (UHI), thermal comfort and changes in land use and occupation are common terms especially in large urban centers, which have high concentrations of asphalt and concrete, but few green areas. It is in this context that this research aimed to analyze the thermal behavior of different urban surfaces during a hot summer day in a tropical city, with hourly data collected from 6:00 a.m. to 8:00 p.m., in order to assist urban planners and managers in their decision making, given the importance of vegetation for microclimatic regulation. Tree leaf (canopy), grass, asphalt in full Sun and asphalt shaded by trees were the surfaces studied with the Raytek MiniTemp infrared digital thermometer, while with a FLIR SC660 thermal camera, landscape clippings with and without vegetation were analyzed. The results showed the asphalt in full Sun with the highest thermal amplitude, reaching 65°C, while the same surface shaded by trees did not exceed 34°C, both at 12:00 p.m. The highest surface temperature occurred in the roof of a dark car (95°C). In the warmer hours of the day, the vegetation (tree leaf and grass) kept stable temperatures in the range of 30 to 46°C, because they contain water in their compositions, showing to be a fundamental element in the microclimate regulation during the tropical summer.

Keywords: Surface Temperature; Urban Climate; Land Use and Occupation; Thermal Images; Urban Green Areas.

INTRODUCCTION

In large urban centers, verticalized gray masses predominate in the landscape with little or no vegetation, which can be a problem because trees are primarily responsible for microclimate regulation (Zhou, Huang & Cadenasso, 2011); while herbaceous vegetation and lawns also help, but with less impact, as they do not promote cooling at pedestrian height (Ng, Chen, Wang & Yuan, 2012).

Understanding surface temperature is essential in urban climatology (Oke, 1978). It modifies lower air (canopy) layers of the urban atmosphere, contributing to the occurrence of an urban heat island (UHI) phenomenon, characterized by the temperature differences between urban and peripheral rural areas (Voogt & Oke, 2003). The first survey relating urban surface heat islands to surface temperature was made 41 years ago, in the USA, mapping 50 different locations, verifying differences of up to 6.5°C between urban-rural zones, in Louisville/KY, with the aid of NOOA 5 satellite and Very High Resolution Radiometer (VHRR) thermal sensor, with 1 km spatial resolution (Matson, McClain, McGinnis Jr. & Pritchard, 1978).

Remote sensing appears as an important tool for the knowledge of natural and anthropogenic phenomena, i.e., remote surface analysis using Geographic Information Systems (GIS), satellite imagery, geostatistics, GPS, topography etc. For example, with high resolution aerial thermal images (overflight) it is possible to map the thermal field of the urban surface, identifying comfort and discomfort zones, being asphalt in full Sun the main component of the highest surface temperature values (Mendes, Polizel, Hamamura, Baptista & Silva Filho, 2015).

The objective of this research was to analyze the thermal behavior of different urban surfaces during a hot summer day in a tropical city.

METHOD

About 40% of the world's population (equivalent to three billion people) is estimated to reside in tropical zones (Tropical Countries Population, 2020). The study area of this research is located in Piracicaba/SP/Brazil (22° 42' S and 47° 38' W), under climate type Cwa (according to Köppen-Geiger classification) – with a subtropical dry winter and hot and rainy summer (annual average precipitation of 1300 mm, at 546 m altitude) (Biosystems Engineering, 2019).

The fieldwork was done in two days, following the weather forecast of clear skies, to avoid high cloudiness and consequent precipitation, since these later weather conditions are frequent during the local summer. In the first day, on January 23, 2019, two records were made with the FLIR SC660 thermal camera (Figure 1), considering landscapes with and without vegetation. This is a portable camera, equipped with the standard 24° lens, large high resolution 5.6” flip-out LCD, weight of 1.8 kg, 640 x 480 pixels infrared resolution, 3.2 Mpixel, auto focus, ± 1°C accuracy and standard temperature range -40°C to 1500°C (FLIR, 2009). On the second day, the temperature of different urban surfaces was monitored, such as tree leaf/crown (Licania tomentosa [Benth.] Fritsch.), grass (Paspalum notatum Flüggé), asphalt in full Sun and asphalt shaded by trees. The air temperature, which was recorded by a local Meteorological Station (Biosystems Engineering, 2019), 4 km away from the measurements was also recorded. Both tree and grass are native to Brazil. Measurements were taken from 6:00 a.m. to 8:00 p.m., hourly, with a tolerance of ± 15 min, using the Raytek MiniTemp digital infrared thermometer (Figure 1). This thermometer measures the surface temperature of a given point. Although it is not possible to obtain a thermal image like the FLIR SC660, it is more portable and is available at a more affordable price (approximately USD 70). It works in the range of -18°C to 400°C (0 to 750°F), also with 1°C accuracy (Raytek, 2019).

Figure 1: FLIR SC660 thermal camera and Raytek MiniTemp infrared thermometer, respectively. Source: FLIR (2009) and Raytek (2019).

RESULTS AND DISCUSSION

Infrared thermographies have been studied in recent surveys with the FLIR SC660 Infrared Camera to map thermal comfort zones (Mendes et al., 2015), analyze concrete deterioration (Huh, Tran, Lee, Han, Ahn & Yim, 2016), track environmental contamination (Lega, Kosmatka, Ferrara, Russo, Napoli & Persechino, 2012), agricultural monitoring (García-Tejero, Ortega-Arévalo, Iglesias-Contreras, Moreno, Souza, Cuadros-Tavira & Durán-Zuazo, 2018), animal health (Soerensen, Clausen, Mercer & Pedersen, 2014) and muscle pain intensities in humans (Al-Nakhli, Petrofsky, Laymon & Berk, 2012), which demonstrate the possibilities of use not only in geography, but also in engineering, agronomy and medicine.

Warmer surfaces tend to be impermeable, dark, low reflectance and may exceed 65°C under the summer Sun (Gartland, 2010). In our case study, the highest surface temperature occurred on the upside of a dark colored car (95°C, measured with Raytek MiniTemp) at 12:00 p.m., during equipment testing a few days before the field measurements, followed by asphalt in full Sun (65°C), while the vegetation was in the range of 30 to 40°C (Figure 2). The maximum air temperature was 31.2°C, at 2:00 p.m. A great effort on the part of the density of vegetation is necessary to reduce the air temperature by 1°C. Although it seems small, it is possible to reach more than 10°C in the thermal sensation depending on the exposure to full sun and shade, percentage of the relative air ratio, wind direction/speed, surface temperatures in and around use, among other conditions (Monteiro, 2018), however, one of the high difficulties in afforesting public roads is the presence of aerial wiring (Velasco, Lima & Couto, 2006).

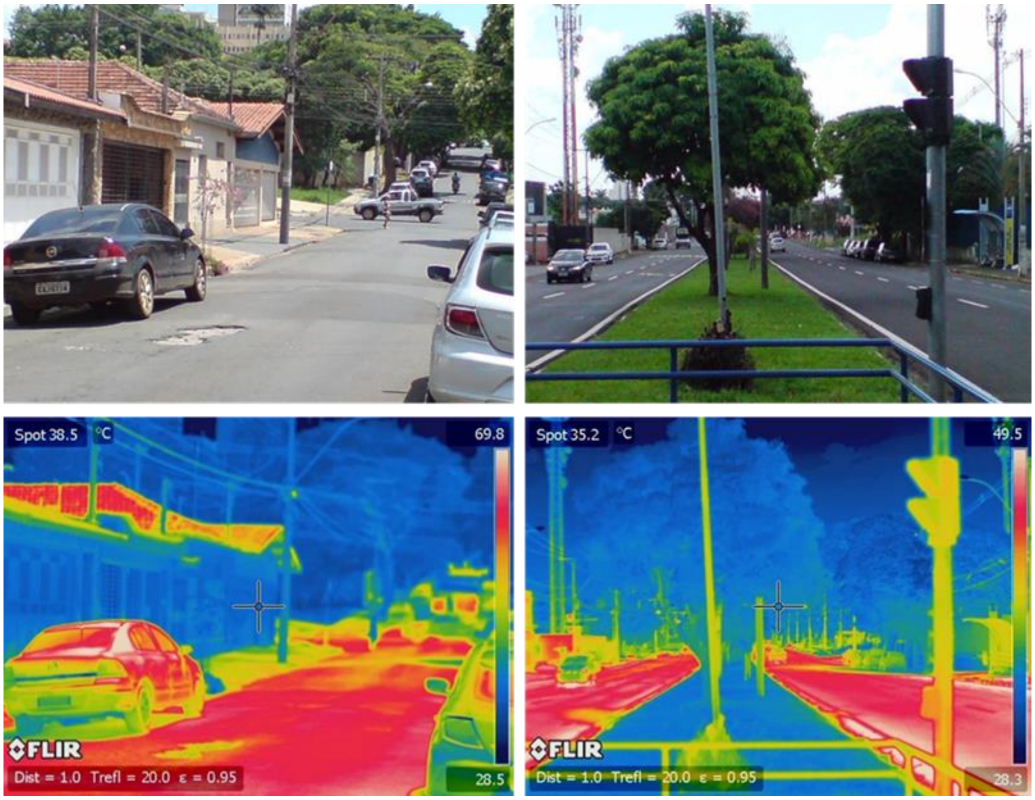

Figure 2: Thermal image of two different landscapes taken at 1:45 p.m. (Rua Visconde do Rio Branco, 1537) and at 2:30 p.m. (Rua Cássio Pascoal Padovani, 1315), respectively.

Hourly measurements indicated that the asphalt in full Sun had the highest thermal amplitude (40°C), ranging from 25°C at 6:00 a.m. to 65°C at 12:00 p.m., while the same surface, but shaded by nearby trees on sidewalks, did not exceed 34°C, at the same time. In the warmer hours of the day (afternoon), the vegetation (tree leaf and grass) maintained stable temperatures in the range of 30 to 46°C (Figure 3).

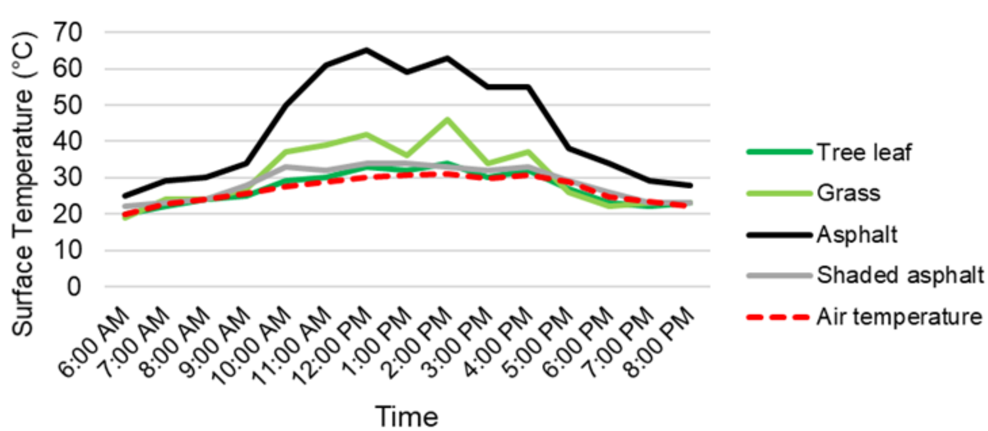

Figure 3: Hourly thermal behavior of different surfaces in the urban environment, recorded during a tropical summer day.

It can be seen from Figure 3 that there is no smooth curve for asphalt and grass. This can be explained by passing clouds for a few minutes, cooling these surfaces. As mentioned earlier, the local summer is characterized by high temperatures associated with high cloud cover, with the consequent occurrence of rainfall. Thus, the values recorded here may be even more extreme. On this day there were two moments of rain: at 4:30 p.m. and 6:30 p.m., uniformizing surface temperatures. The peak in air temperature occurred at 2:00 p.m., with 31.2°C (Biosystem Engineering, 2019).

Comparing grass and tree leaf temperature performance, it is noticed more stable values in the later, because it contains more water than the former. Since the specific heat of the water is high (1 cal/g.°C), it takes a longer time to change its temperature, increasing or decreasing, which guaranteed such stability. The grass is a type of C4 plant and the tree (Licania tomentosa), C3, which differ in the carbon fixation process during the photosynthetic process. At high temperatures, stomata close mainly in grass (C4), reducing transpiration without affecting carbon fixation during the day. C3 plants occurring mainly in humid tropical regions and do not have adaptations to reduce photorespiration and fix carbon only by the Calvin Cycle, producing as a final product 3-phosphoglyceric acid; while C4 plants, adapted to the conditions of arid environments, also fix carbon by the C4 pathway, producing oxaloacetate. This pathway is an adaptive mechanism that such plants have that allows greater self-control under environmental conditions, enabling them to be more economical than C3, since they lose less water during photosynthesis, because warming their surfaces more (Sage & Monson, 1999), i.e., in short, the grass transpires at night, opening its stomata and consequently becoming cooler than trees; during the day, the opposite happens: the tree gets fresher because transpiration.

In Basel, Switzerland, Leuzinger, Vogt & Körner (2010) analyzed the temperature of tree tops of 10 distinct species, often planted on the streets of central European cities, and found values between 24 and 29°C, being air temperature at 25°C. The coldest ones were in parks (as opposed to the ones in the streets), except conifers (Pinus spp.), which were close to the air temperature, verifying that the smaller leaves have smaller thermal amplitudes; on the other hand, the larger trees are generally more efficient in producing good shades, and they concluded that urban tree temperatures are species-specific and depend on many factors such as location, leaf size, stomatal conductance and canopy architecture.

CONCLISIONS

The vegetation, composed of trees and grass, proved to be a fundamental element in the microclimate regulation during the tropical summer, since it presented lower thermal amplitude in surface temperature (14°C), contrary to the asphalt in full Sun, which varied from 25°C to 65°C, with a range of 40°C. In addition, the asphalt shaded by the street trees was 12°C amplitude (22°C to 34°C), proving, thus, to be an alternative of cooling to urban planners.

Both used tools (Camera Thermal FLIR SC660 and Raytek MiniTemp Infrared Thermometer) presented satisfactory results in this investigation. Obviously, it will depend on the financial availability of stakeholders, but was shown here that it is possible to use them to propose improvements in the urban climate. We also have free satellite imagery (such as Landsat-8, thermal band 10) available to complement research like this, but, while the objective here was to analyze at the microclimatic level, the images allow us to analyze larger areas, but in less detail (like whole cities).

This study provides information for decision makers, to plan and manage urban landscapes, enabling them to reduce climate and environmental inequalities among residents, especially regarding thermal comfort. Given the large amount of direct insolation received in tropical areas. Further research is needed to assess the potential and viability of using solar energy as an energy matrix.

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