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ANALYSIS OF SURFACE THERMAL BEHAVIOR FOR THE STUDY OF URBAN HEAT ISLANDS: AN EXPERIMENT USING UNMANNED AERIAL VEHICLE (UAV)

Análise do comportamento térmico superficial para o estudo de ilhas de calor urbanas: um experimento utilizando Veículo Aéreo Não-Tripulado (VANT)

Análisis del comportamiento térmico superficial para el estudio de islas de calor urbano: un experimento con Vehículos Aéreos No Tripulados (VANT)

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Abstract: The objective of this study was to analyze the variation of horizontal superficial temperature of different typologies of surfaces through thermographies using a thermal camera embedded in an unmanned aerial vehicle (UAV). The temperature data of some typologies of ground cover (asphalt, cement sidewalk, lawn and trees) and buildings cover (ceramic roof and cement tile) were analyzed. The results showed that there was a greater retention of heat by the asphalt covering, followed by the cement sidewalk. The temperature of the lawn was high during the day, but at night it was the surface with the lowest temperature among all analyzed. The top of the tree

accumulated less heat during the day and it took longer to lose it during the night, getting the lowest thermal amplitude. At the building covering surfaces, while the temperature of the ceramic roof suffered little variation during the day, the cement tile suffered a high variation, showing that it is not a good thermal insulator. The use of UAV allowed a quick acquisition of the thermographies of the selected targets. The weather analysis was a determining factor to carry out the UAV missions.
Keywords: Urban climate. Urban heat islands. Thermography. UAV.

Resumo: O objetivo deste estudo foi analisar a variação da temperatura superficial horizontal de diferentes tipologias de superfícies por meio de termografias utilizando uma câmera térmica embutida em um veículo aéreo não tripulado (VANT). Foram analisados os dados de temperatura de algumas tipologias de cobertura do solo (asfalto, calçada de cimento, gramado e árvores) e cobertura de edifícios (telhado de cerâmica e telha de cimento). Os resultados mostraram que houve uma maior retenção de calor pelo revestimento asfáltico, seguido pela calçada de cimento. A temperatura do gramado era elevada durante o dia, mas à noite foi a superfície com a menor temperatura entre todas as analisadas. A copa da árvore acumulava menos calor durante o dia e demorava mais para perdê-lo durante a noite, obtendo a menor amplitude térmica. Nas superfícies de revestimento do edifício, enquanto a temperatura da cobertura cerâmica sofreu pouca variação durante o dia, a telha de cimento sofreu uma grande variação, mostrando que não é um bom isolante térmico. A análise episódica do tempo foi determinante para realizar as missões com VANT.
Palavras-chave: Clima urbano. Ilhas de calor urbana. Termografia. VANT.

Resumen: El objetivo de este estudio fue analizar la variación de la temperatura superficial horizontal de diferentes tipos de superficies mediante termografía utilizando una cámara térmica empotrada en un vehículo aéreo no tripulado (VANT). Se analizaron los datos de temperatura de algunos tipos de cubierta de suelo (asfalto, acera de cemento, césped y árboles) y cubierta de edificación (techo de cerámica y teja de cemento). Los resultados mostraron que hubo una mayor retención de calor por el revestimiento asfáltico, seguido por la acera de cemento. La temperatura del césped fue alta durante el día, pero por la noche fue la superficie con la temperatura más baja entre todas las analizadas. La copa del árbol acumuló menos calor durante el día y tardó más en perderlo durante la noche, obteniendo la menor amplitud térmica. En las superficies de revestimiento del edificio, mientras que la temperatura de la cubierta cerámica tiene poca variación durante el día, la teja de cemento tiene una gran variación, lo que demuestra que no es un buen aislante térmico. El análisis meteorológico episódico fue crucial para realizar misiones con VANT
Palabras clave: Clima urbano. Islas de calor urbano. Termografía. VANT.

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1. INTRODUCTION

The growing attention given to environmental issues and the consequent search for sustainable development by current societies has accentuated concerns related to the impacts associated with the changing of natural environment into a built environment. Several authors have reported the microclimate differences promoted in cities by the urbanization process (LOWRY, 1967; LOMBARDO, 1985; OKE, 1987; PITTON, 1997). It is known that changes in the landscape determine conditions that directly affect the quality of life of its inhabitants. The definition of "urban ecosystem", according to Gómez, Tamarit and Jabaloyes (2001), refers to the replacement of the natural habitat with another one more suited to the needs of people today. However, the artificial environment has exceeded the biological capacity of its inhabitants, who feel an increasing need for balance involving natural elements, such as free spaces for buildings, the presence of vegetation and water. The change in the climate of cities can be caused by the following factors: the materials used in construction and paving; the format of cities; human activities that generate heat; the removal of surface water and the presence of pollutants in the air (LOWRY, 1967).

The climate presents three scales of approach: the macroclimate or mesoscale, which covers the regional scale and is directly related to meteorological properties; the local climate or local scale, which is related to climate change on a smaller scale. Therefore, it makes possible to ascertain modifications resulting from the variation of the relief; and the microclimate or micro scale, which includes variations resulting from the influence of buildings, landscape elements, urban geometry and the properties of surface elements (OKE, 1987).

The introduction of complex geometries that includes cities in the natural landscape are known to affect dramatically the energy balance at the interface between surface and atmosphere, which is, the planetary boundary layer. The most pronounced detectable effect is the one of positive thermal anomalies, associated with the temperature of the urban night air, that are the urban heat islands (UHI). The causes and implications of this warming depend on the investigation scale, from individual buildings along hours to entire urban areas over the years. However, the most commonly studied UHI is the air temperature close to the surface found below the level of the buildings inside the urban cover layer, which is where human lives. Therefore, the magnitude of the UHI is extremely relevant for health

studies, human comfort and energy construction management (OKE, 1976; ALEXANDER; MILLS, 2014).

According to Amorim (2019) the literature points out three main types of urban heat islands as a function of the layer where they are found: 1 – the surface heat island diagnosed by remote sensing, which allows the temperature calculation of the targets (OKE et al., 2017); 2 – the lower atmospheric heat island, which Oke (1978) called urban canopy layer (UCL), whose temperature is recorded between ground level and the average level of roofs. In this case, temperatures are measured below the level of the top of buildings, through different procedures, such as mobile transects (itinerant measures with vehicles) and fixed points through a network of temperature sensors inserted in the urban mesh and rural environment; and 3 - the heat island of the upper urban atmosphere, the urban boundary layer, called by Oke (1978).

The surface structure affects the local climate by modifying the airflow, transporting atmospheric heat and short and long wave radiation balances, while the surface coverage modifies the albedo, the availability of moisture and the potential for heating and cooling ground (STEWART; OKE, 2012). The data use from surface meteorological stations and from thermographies obtained by special cameras allows quantifying the thermal variation based on these types of urban soil use, together with techniques like remote sensing, that consists in a quick and practical tool in the identification of heat concentration places (COSTA; FRANCO, 2013).

The mainly difference between the images obtained by UAVs and satellite is related to the different levels of spatial and temporal resolution that each platform provides. While the figure of the Landsat-7 satellite has a spatial resolution of 30 x 30m pixel, the unmanned aircraft has a spatial resolution that can be adjusted by the aircraft's altitude, varying between centimeters and up to a few meters. Regarding the temporal resolution, unmanned aircraft allow the choice of the period of repetition of the lifting, unlike the satellite, which facilitates the dynamic monitoring of targets over a region. On the other hand, since the unmanned aircraft is characterized by recent advances in technologies, there is a lack of images from previous years to make temporal comparisons. Another advantage presented by these aircrafts is that they don't remain dependent on the interference of clouds to obtain images in regions of tropical and subtropical weather. Besides the very low cost of

their images, compared to images from high-resolution satellites, such as IKONOS and QUICKBIRD, the unmanned aircraft can operate in impractical conditions for orbital platforms and don't require significant human ways of support (NEWCOME, 2004).

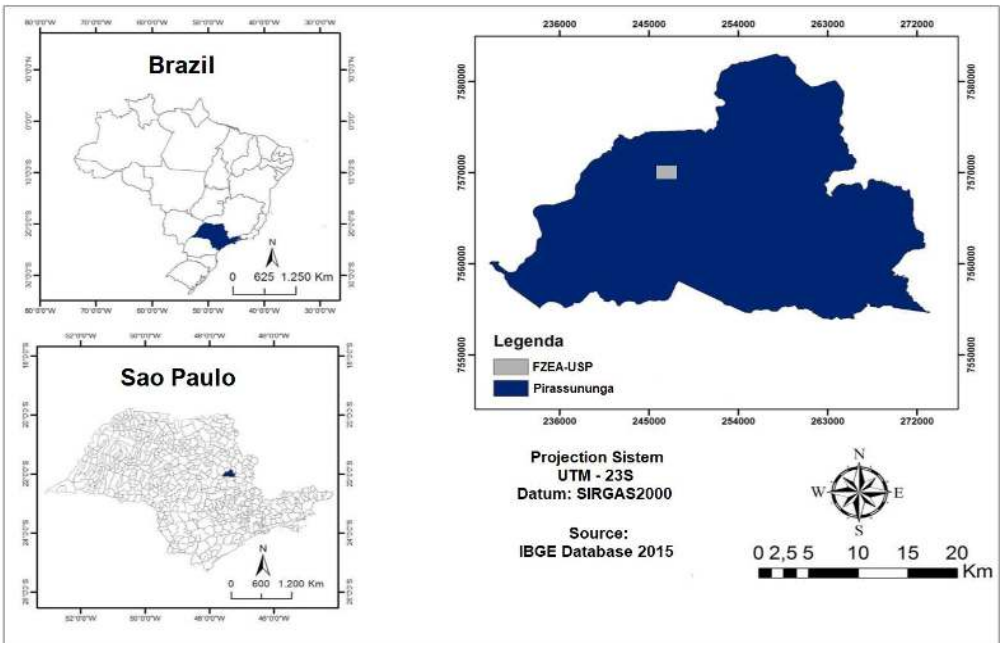
The proposition of new methodologies for the study of the urban climate is relevant, whereas it makes possible to get data on a micro scale in a more dynamic way, optimizing the investigation work by the researchers. The objective of this study is to analyze the variation of the horizontal surface temperature with different coverage typologies and, furthermore, the variation of the air temperature and humidity by using an UAV to obtain the surfaces thermographies and atmospheric data.

2. METODOLOGY

2.1. Study area

The experiment was conducted on the campus of the Faculty of Zootechnics and Food Engineering, University of Sao Paulo, FZEA-USP, in the city of Pirassununga, at the central-eastern region of the state of Sao Paulo (Figure 1). Pirassununga is situated at 21º59'46" S latitude and 47º25'33" W longitude, at an average altitude of 627 meters.

Figure 1 – Location of Pirassununga and FZEA-USP.



Source: Adapted from Ribeiro (2020).

According to the classical Köppen-Geiger classification, the region's climate is Cwa, hot with a dry winter (PEEL; FINLAYSON; MCMAHON, 2007). From the perspective of dynamic climate approach, the region is identified by the passage of cold fronts throughout all year. According to Monteiro (1973), the Pirassununga region has a climate controlled by equatorial and tropical air masses, characterized by alternately dry and humid tropical climates. In the dry period, between April and September, the frequency of rain decreases considerably and is constituted by a winter area markedly drier in the State of Sao Paulo. It is when the Tropical Continental (mTc), Tropical Atlantic (mTa) and Polar Atlantic (mPa) air masses dominate over the region, presenting low precipitation, little cloudiness, low relative humidity and average temperatures lower than those of rainy periods. The rainy season occurs from October to March, due to the incursions of the Continental Equatorial mass (mEc) and the dynamism of the Atlantic Polar Front over the Tropical Atlantic, which correspond, in a large way, for the rain genesis it produces during the performance of the frontal systems in this period of the year (MONTEIRO, 1973; BARBOSA, 2009).

The low rainfall totals in the dry period are associated with the performance of ASAS (High Subtropical from South Atlantic), because in this season this system reaches its westernmost position on the continent, extending itself to the southeast region of Brazil. Rain events occur when the frontal systems, subtropical and extra-tropical cyclones manage to overlap ASAS (REBOITA, 2010). In the summer, the persistent rainfall in the regions of Southeast, south of Northeast, north of Paraná and central Brazil is related to the South Atlantic Convergence Zone (ZCAS), a typical phenomenon in this period in South America. It's characterized by a band of convective cloudiness which, when settled up, extends from the South of the Amazon towards the Southeast until the Subtropical Atlantic Ocean. (QUADRO, 1994).

The missions to obtain the thermographies were conducted nearby the Laboratory of Technology and Information Systems (LTIS), inside an air space of approximately 8.000 m², as shown in Figure 2.

Figure 2 – Aerial image with indication of the area and direction of the flights.

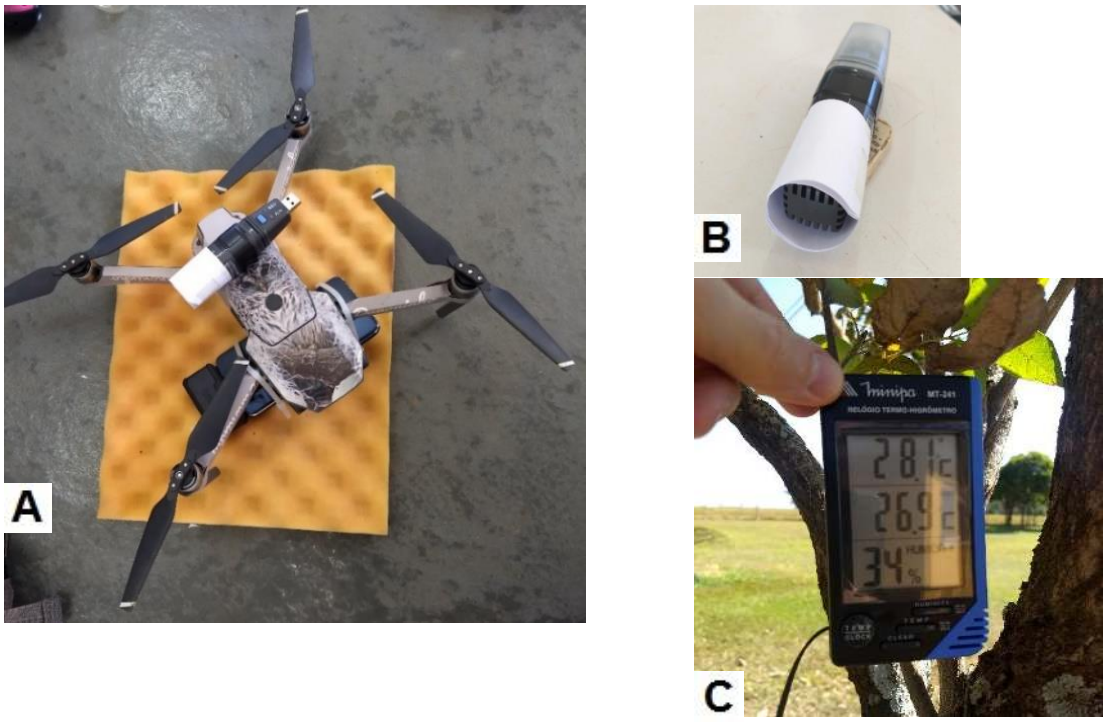


Source: Elaborated by the authors (2021). Adapted by Google Earth, 2021.

2.2. Instrumentation and data acquisition

For the development of the study, a UAV quadcopter DJI Mavic was used, in which a FLIR One thermal camera connected to a smartphone was loaded to get the surface temperature data through thermographies. The camera captures RGB image and thermal image, where each pixel of the image has a temperature value, with a resolution of 640x480 pixels. A portable thermohygrometer with a Minipa EZ Temp10 datalogger was also shipped to obtain the temperature and humidity values at altitude. In order to know the maximum and minimum temperature and humidity values of the environment, a Minipa MT241 digital thermohygrometer was used. The equipment loaded in the UAV had their weighing checked in order not to overload it and maximize the use of its battery during the missions. Figures 3A, 3B, 3C and 3D show the equipment used for data acquisition.

Figure 3 – (A) UAV with embedded sensors and termal camera; (B) portable thermohygrometer with direct solar radiation protection and (C) digital thermohygrometer for recording environment temperature and humidity.

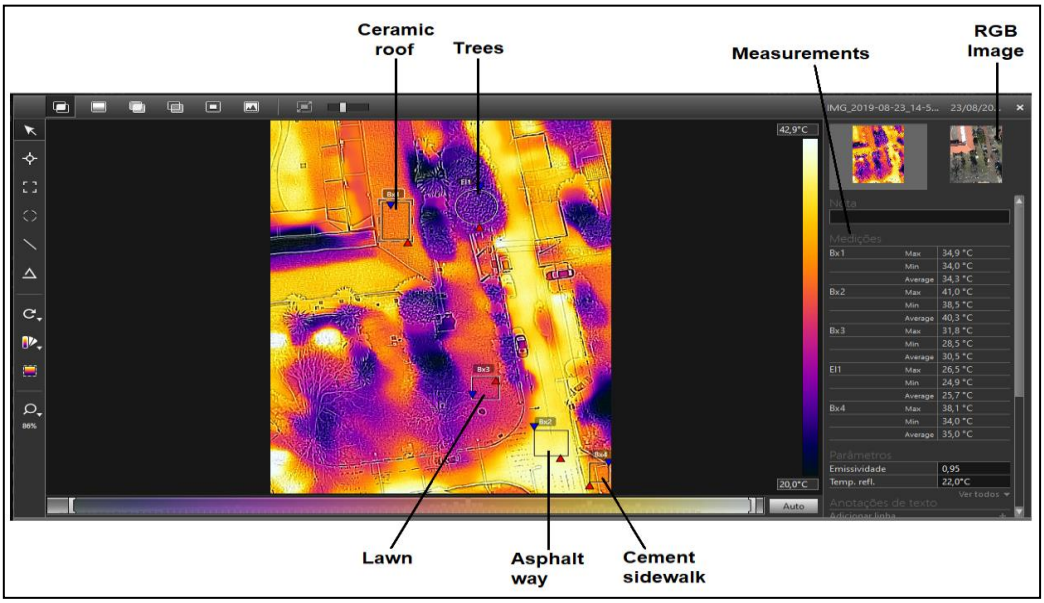


Source: Elaborated by the authors (2021).

The experiment consisted of three missions with the UAV during the winter, on 08/23/2019, lasting 5 to 7 minutes each one. The first mission started at 12h40, the second at 14h50 and the third at 18h20, approximately 40 minutes after sunset. The flights, kept at an average height of 50 meters from the ground, made it possible to obtain the thermographies of the surfaces selected for the study, such as the asphalt, cement sidewlak, vegetation cover (lawn and trees) and building cover (ceramic roof and cement tile), allowing the analysis of the temperature variation of each typologie of surface at different times.

The thermal camera was programmed to get images every 15 seconds, using a controller app downloaded on the smartphone. The thermographies were analyzed with the FLIR Tools software (Figure 4), which allows checking the temperature values of each pixel of the image, calculating the average temperatures of a specific area and also exporting these values to a spreadsheet.

Figure 4 - Image of the Flir Tools software, used to analyze the thermographies, showing in the example the maximum, minimum and average temperatures of some selected surfaces.



Source: Elaborated by the authors (2021).

The reference digital thermohygrometer was kept throughout the hole experiment at a height of 1.5 meters from the ground and protected from direct solar radiation. The data were recorded manually at four different times. The portable thermohygrometer was programmed to record measurements every 30 seconds. Before starting each flight, the UAV was maintained at a height of 1.5 meters from the ground for one minute to allow the sensor to stabilize in relation to the external environment.

3. DEVELOPMENT

3.1. Weather analysis for data acquisition

In the recognition of the active air masses, analyzes of the technical bulletin provided by the Weather Forecasting and Climate Studies Center of the National Institute for Space Research (CPTEC-INPE) were used, with verification by the GOES-16 satellite images (Figures 5A, 5B and 5C). During the day of the experiment, the advance of a dug in medium levels of the atmosphere left the weather unstable between the east of Sao Paulo, south of Minas Gerais and Rio de Janeiro (INPE, 2019), inducing rain in the Pirassununga region of low intensity in the early morning.

Figure 5 - Satellite images of the southeastern region, with emphasis on the location of Pirassununga, showing the presence of cloudiness by the action of the dug on the experimental day: (A) at 12h30; (B) at 15h00 and (C) at 18h30.



Source: INPE (2019).

3.2. Analysis of meteorological data

On the day of the experiment, the configuration of a dug, an area of relatively low atmospheric pressure, favored the formation of cloudiness and precipitation in the morning, however, with wind stability and little cloudiness in the afternoon, which made it possible to carry out of flights. Table 1 shows the values of the reference thermohygrometer, which recorded the variation in maximum temperature and of the relative humidity during the study period.

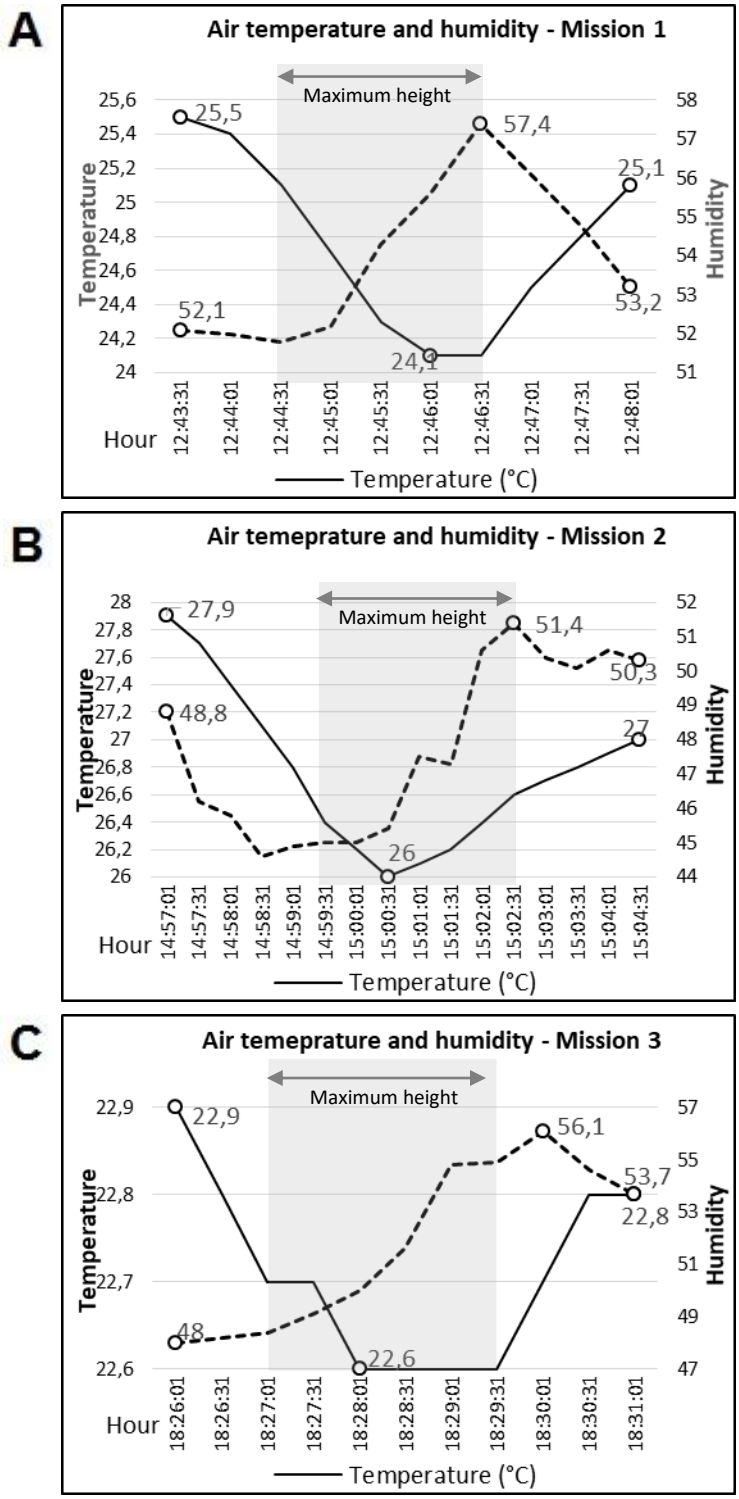
Table 1 - Maximum temperature and relative humidity values registered at the respective times.

Indicators	**12h30**	**14h50**	**17h50**	**18h20**
Air Temperature (°C)	26,9	28,3	21,5	20,1
Relative Humidity (%)	34	27	41	45

Source: Elaborated by the authors (2021).

The values got by the portable thermohygrometer embedded in the UAV were exported to a spreadsheet, allowing the graphs to be generated for better representation and analysis of the temperature and relative humidity of the air at different altitudes. Figures 6A, 6B and 6C and Table 2 show the values obtained during the three missions with the UAV.

Figure 6 - Graphics of air temperature and relative humidity, highlighting the period of time that the UAV remains at the maximum programmed altitude during the mission 1 (A), Mission 2 (B) and Mission 3 (C).



Source: Elaborated by the authors (2021).

Table 2 - The atmospheric thermal amplitude, maximum and minimum temperature values, besides the relative humidity recorded in the respective missions with the UAV.

Indicators		Mission 1	Mission 2	Mission 3
Temperature (°C)	Max.	25,5	27,9	22,9
	Min.	24,1	26	22,6
	ΔT	1,4	1,9	0,3
Relative Humidity (%)	Max.	57,4	51,4	56,1
	Min.	52,1	48,8	48
	ΔU	5,3	2,6	8,1

Source: Elaborated by the authors (2021).

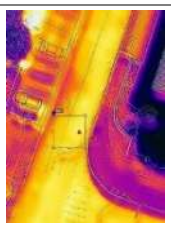
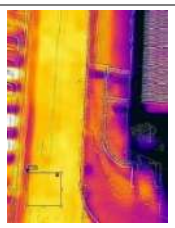
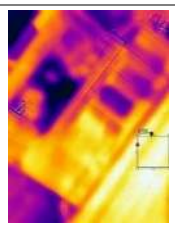
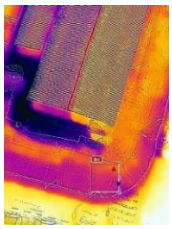
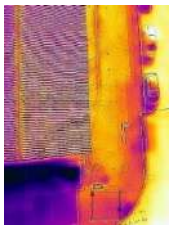
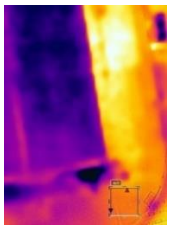
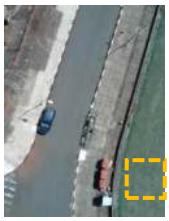
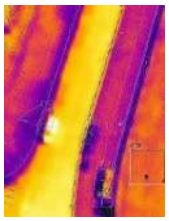
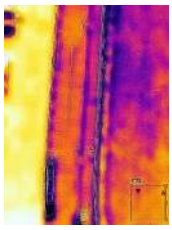
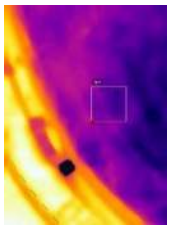
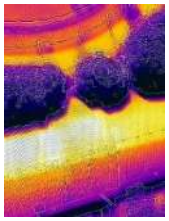
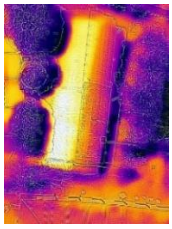
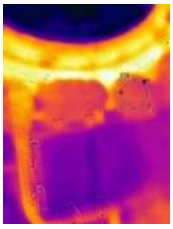
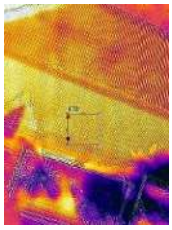
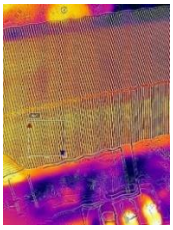
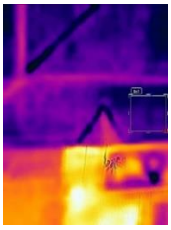
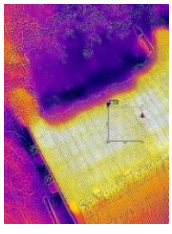
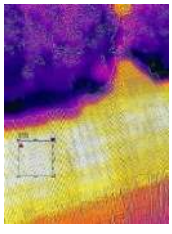
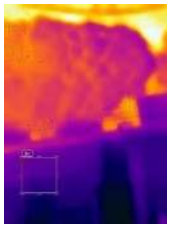
In the three missions, it was found that the air temperature values were lower in the higher layers, varying 1.4°C in mission 1, 1.9°C in mission 2 and 0.3°C in mission 3, being this last one inside the equipment's error range of ± 0.5°C. The relative humidity values, on the other hand, behaved in the opposite way, becoming higher as the UAV reached higher altitudes, varying 5.3% in mission 1, 2.6% in mission 2 and 8.1% in mission 3.

It was observed in mission 3 that, although the amplitude of humidity was greater when the air temperature was the lowest, it was during mission 1 that the humidity of the air was highest both at ground level and at maximum altitude of the UAV, considering the influence of the precipitation that occurred just before it started.

3.3. Thermographies analysis

To analyze the thermographies, the images obtained from the UAV at stabilized altitude were selected, allowing the smallest possible variation from the distance among the camera to the surfaces. The types of surfaces analyzed were separated into two groups: ground cover (asphalt, cement sidewalk, lawn and trees) and building cover (ceramic roof and cement tile). In each typology a sample area of the thermography was selected at the three different times, using the following criteria: sample area with the same size, which had not been shaded during the day and without puddles. Then, the average temperature of each sample area and its thermal amplitude (difference between the highest and lowest average temperature between the three missions) were analyzed, as shown in Table 3.

Table 3 - RGB image and thermographies of the typologies analyzed in each mission, indicating the average temperatures of the sample areas and the thermal amplitude.

	Thermographies and average temperatures			
RGB Image	Mission 1	Mission 2	Mission 3	**ΔT**
 **Asphalt**	 38,1ºC	 41,8°C	 23,7ºC	18,1°C
 **Sidewalk**	 27,4°C	 32,8°C	 21,8°C	11°C
 **Lawn**	 33,7°C	 38,5°C	 12,5°C	26°C
 **Tree**	 22°C	 25,8°C	 17,3°C	8,5°C
 **Ceramic roof**	 36,7°C	 36,3°C	 15,2°C	21,5°C
 **Cement tile**	 37,3°C	 52°C	 14,4°C	37,6°C

Source: Elaborated by the authors (2021).

Among all typologies of soil cover, the asphalt was the surface with the highest temperature during mission 1 and also during mission 3, at night. The second lowest temperature was the cement sidewalk during missions 1 and 2, underneath only of the temperature of the top of the tree, and remained below the temperature of the asphalt during mission 3. Still, the temperature values of the lawn were higher than the cement sidewalk and lower than the asphalt during missions 1 and 2, but during mission 3 it was the lowest temperature among all the analyzed surfaces. The top of the tree was the surface with the lowest temperatures during missions 1 and 2 and it was also the surface that suffered the lowest total thermal amplitude.

In the group of roofs buildings, the ceramic roof was the only surface whose temperature dropped between missions 1 and 2, even if slightly. Besides, the cement tile was the surface with the second highest temperature during mission 1, only lower than the temperature of asphalt, reaching the highest temperature between all surfaces, during mission 2, and also suffering the greatest total thermal amplitude.

In the analysis of the sample areas of the thermographies it was found that, in all surfaces occurred an increase in temperature, between missions 1 and 2 with a subsequent decrease in mission 3, except for the ceramic roof, whose temperature suffered a decrease of 0.4 ° C between the first two missions.

Analyzing the types of soil cover without vegetation (asphalt and cement), asphalt proved to be the surface with the greatest capacity to retain heat during the day and release it at night. The cement sidewalk is lighter than asphalt and have greater reflectivity, accumulating less heat and remains at a lower temperature than asphalt at night. Both asphalt and cement sidewalk remained with temperatures above the air temperature during the night, showing that they are materials with the capacity to continue heating the air in contact with these surfaces even after the solar radiation has finished at the end of the day.

The lawn vegetation reduces its rate of transpiration during the hottest hours of the day, and the foliage, with an intermediate reflectivity to the two previous surfaces, ends up absorbing less heat than asphalt and starts to release it at times with lower atmospheric temperature. It happens through transpiration, which allows the vegetable to lose energy and remain with the lowest temperature during the night, in addition to the evaporation of water from the soil. On the other hand, the arboreal vegetation, whose crown stays higher

in relation to the soil, maintained the lowest total thermal amplitude among all the analyzed surfaces.

The roofs of the analyzed buildings showed a significant difference. The temperature of the ceramic roof was reduced slightly during mission 2, which wasn't the case with any of the other surfaces. This reduction may have been a result of the fact that the ceramic tiles were porous and have accumulated moisture with the rain that occurred in the morning, which, when evaporating, removes heat from the roof. This favors a lower total thermal amplitude in comparison to the cement tile, which was registered as the highest temperatures between all surfaces during missions 1 and 2, the lowest temperature during mission 3 and the highest total thermal amplitude, showing to be a material with low thermal insulation capacity.

The atmospheric stability along the study provided safe flights with UAV and definite images, optimizing the time of the missions and without needing to recharge the battery, which is consumed more quickly on windy days, which can compromise the missions and the quality of the images.

4. FINAL CONSIDERATIONS

In this study, the surface thermal behavior of some typologies of soil cover in buildings was analyzed using thermal images obtained with the help of a UAV.

The results founded in this research showed that, among the types of vegetation soil cover, there was a greater heat retention by asphalt cover, where the highest temperature was registered during the day and also at night, followed by the cement sidewalk. Both were the only surfaces with a temperature higher than the air temperature at night, contributing to the phenomenon of urban heat island formation. On the lawn, the temperature remained high during the day, reaching above that of cement sidewalk, however, at night it was the surface with the lowest temperature among all analyzed. The top of the tree, on the other hand, proved to be the surface with the lowest temperature variation, that is, it accumulates less heat during the day and takes longer to lose at night.

On the roof surfaces of buildings, the temperature variation was quite different. While the temperature of the ceramic roof suffered little variation during the day, that one of the cement tile suffered a high variation, showing that it's not a good thermal insulator.

These results are in agreement with those found by Oke (2017), that demonstrated each material used to construct cities (e.g. concrete, asphalt, stone, brick, wood, metal, glass, tile) plus natural materials (e.g. soils, vegetation, water) has its own distinct mix of radiative, roughness, termal and moisture properties, so the climatic behaviour of an urban surface, which comprises a variety of materials in different proportions, is unique.

These data can be used in the planning of strategies in order to minimize the effects of urban heat islands. When it's necessary to decrease the surface thermal amplitude, it's possible, for example, to adopt an urban afforestation plan that can prevent the incidence of solar radiation directly on asphalt and sidewalks and, where it's not possible to plant trees, prioritize floors with lighter shades. At the same time, roofs with low insulation capacity, such as cement tile and dark tones, should be avoided for roofing of buildings, where green roofs should be a priority, with lighter tones of porous materials and green roofs, when conventional roofs give way to a system with vegetation, providing better thermal insulation. Since the heat of the surfaces warms the air in contact with them, using materials and techniques that favor less heat accumulation, this avoids an increase in atmospheric temperature in the urban environment.

The use of UAV on a micro scale for the study of urban heat islands proved to be a very satisfactory tool, as it made possible to quickly obtain the thermographies of the selected targets and into the programmed period. The weather analysis was a determining factor in order to identify the active air mass and choose the best period to carry out the missions with the necessary atmospheric stability.

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