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ARCHITECTURE AND URBANISM

Green roofs and their contribution for the reduction of room temperature in buildings in Cascavel-State Paraná/green roofs and energy efficiency

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ABSTRACT. The objective of this study was to analyze a green roof by monitoring the variables that can influence it, comparing its effects to those of a conventional roof with clay tiles in Cascavel/State Paraná. The following parameters were compared in both prototypes: indoor temperature, outdoor temperature, relative humidity, wind speed and solar radiation. Temperature measurements were determined by sensors installed in the prototypes whereas the relative humidity was analyzed by wet bulb sensors. Data concerning to 30 days of experiment were collected and tabulated in Microsoft Excel. The green roof remained for 7 days within the relative humidity range considered comfortable whereas the conventional roof remained for 4 days. The green roof caused a mean reduction of 4.96°C, proving that green roofs contribute to reducing indoor room temperature and thermal lag promoted by the green cover, where the heat input takes longer to occur when compared to the conventional roof. Regarding the behavior of the vegetation cover and substrate, the larger the green cover, the lower the substrate temperature transmitted to the indoor environment.

Keywords: sustainable roofing; energy conservation; thermal gains.

Telhado verde e sua contribuição para a redução da temperatura ambiente em construções para a cidade de Cascavel-PR/telhado verde e eficiência energética

RESUMO. O objetivo deste estudo foi analisar o telhado verde, monitorando as variáveis que podem influenciá-lo, observando seus efeitos, comparados a um telhado com de telha de barro, na cidade de Cascavel/PR. Medidas de temperatura interna, ambiente, temperatura externa, umidade relativa do ar, velocidade do vento e radiação solar foram comparadas em dois protótipos. As medidas de temperatura foram determinadas por meio de sensores instalados nos protótipos, e a umidade relativa do ar por meio de sensores de bulbo úmido. Após coletados os dados, durante 30 dias, foram tabulados em planilhas do *software Excel*, e o telhado verde apresentou sete dias dentro da faixa considerada confortável para umidade relativa do ar enquanto o telhado convencional, quatro dias. Observou-se redução média de 4,96°C no telhado verde, apontando a contribuição dos telhados verdes para a diminuição da temperatura interna do ambiente, e o atraso térmico promovido pela cobertura, onde o aporte de calor ocorre em horários mais tardios comparados ao telhado convencional. Quanto ao comportamento da cobertura vegetal e do substrato, quanto maior for a cobertura verde, menor será a temperatura do substrato transmitida ao ambiente interno.

Palavras-chave: coberturas sustentáveis; racionalização de energia; ganhos térmicos.

Introduction

For being warmer than the rural areas that surround them, cities suffer from a phenomenon known as urban heat islands (Li, Bou-Zeid, & Oppenheimer, 2014). This phenomenon has been studied for decades and may be caused by many factors, such as the extensive use of asphalt and concrete in urban areas, which causes evapotranspiration reduction and higher heat concentration (Grimmond, 2007).

Considering the increase in the world's urban population, urban heat islands have direct implications on energy issues and environmental health (Grimm et al., 2008) and have drawn more and more attention of scientists and planners. Recent studies on how heat islands interact with the urban environment have shown that they might become longer and more frequent in heated atmospheres, causing impacting heat stress to humans (Li et al., 2014).

European countries such as Germany, France, Austria, Norway and Switzerland have invested in roof gardens, also known as green roofs (Wong, Chen, Ong, & Sai, 2003). Currently, in order to minimize effects such as heat islands by creating a micro climate, the ecological function of green roofs has become more important than their aesthetic function, promoting energy efficiency and thermal insulation through their surfaces, bringing benefits for the building and the urban scale (Kumar & Kaushik, 2005; Santamouris et al., 2007; Fioretti, Palla, Lanza, & Principi, 2010; Susca, Gaffin, & Osso, 2011). Green roofs can also reduce energy consumption in buildings with low insulation levels, providing cooling in summer and heating in winter (Castleton, Stovin, Beck, & Davison, 2010).

Green roofs can be classified as intensive, semi-intensive and extensive, and their depth may vary according to the type of vegetation used (Banting, Doshi, & Missios, 2005). Green roofs show significant differences from conventional roofs with no vegetation in what concerns to the reduction of surface temperature and heat input (Wong et al., 2003). In this sense, the objectives sought with a focus on energy efficiency and environmental thermal comfort are justified and can be applied in the region of Cascavel, in western Paraná State, which is suitable for agriculture for having fertile soil and a large amount of wastes that can be used as other sources of renewable energy. As stated by Galinkin and Bley (2009), changes can occur from the smallest to the largest, from the micro to the macro.

The aim of this experimental research was to study green roofs. It highlights the effects of heat input and heat loss to the environment. The objects of study were a green roof prototype and a conventional roof prototype with clay tiles.

Material and methods

The validation of the research was done by the comparison of data collected during the daily monitoring of both prototypes from October 1, 2015 to October 31, 2015. Systematizing the rules and procedures for data collection is the purpose of the data collection protocol, which works as a tool (Yin, 2003).

The following procedures were adopted: First stage - Literature review. It covered the definitions of sustainable development, energy efficiency and its guidelines by briefly linking architecture, bioclimatology, green roofs and their benefits and technical aspects, as well as the climate in Cascavel/State Paraná.

Second stage - Field Experiment. This stage consisted of the project design and implementation of the green roof and conventional clay tile roof prototypes, as well as the installation of sensors for data collection.

Third stage - Experimental data collection and results. Observations and recording of daily data were conducted every five minutes by the sensors, which were connected to a Contemp A202 data logger[1], which automatically transfers the data to the data logger interface in the computer. Then, the same data were tabulated in Excel spreadsheet software.

Fourth stage - Data analysis. A correlation between the two prototypes was made, showing which type of roof had the best level of temperature reduction in the indoor environment and which had the highest heat input.

As for the data analysis method, a standard was established for the evaluation of the following indicators: outdoor temperature, wind speed and solar irradiation. These data were compared and related to the daily temperature means collected by the sensors. In order to design the graphs, the warmest and coolest days of the monitored period were selected based on the daily outdoor temperature means and data comparison was performed. The day which presented the highest solar radiation level was also used for the presentation of graphs in order to verify the influence of solar radiation on the substrate, vegetation cover and consequently on the temperature and humidity of the environment inside the prototype.

According to Koppen's classification, the climate in the city of Cascavel/State Paraná is described as Cfa: subtropical. The average temperature in the coldest month of the year is below 18°C (mesothermal) and the average temperature in the warmest month is above 22°C, with hot summers, infrequent frost and trend of rainfall concentration in the summer months, however, there is no defined dry season. In 2015, which was the year when data were collected for this experiment, Cascavel was influenced by the El Niño, which is an oceanic-atmospheric phenomenon characterized by the warming of the Equatorial Pacific Ocean waters. The impact caused by the El Niño in 2015 was considered the strongest since 1997/1998. The experiment was conducted at Unioeste (State University of Western Paraná), Cascavel, State

[1]The A202 is a highly versatile standard data collector that enables the recording and monitoring of analogue variables on a computer or on the instrument itself, typically being done through a supervisory system or the accopanying Masterlogger software.

Paraná, Brazil, in the Center of Analysis of Alternative Energy Systems - Casa.

Two roof prototypes were built, one with a green roof and the other with a conventional roof with clay tiles in order to analyze and compare their efficiency. The prototypes consisted of side locks, concrete slab and timber for the application of roofing (Figure 1 and 2). To mount the green roof experiment, the following layers were placed in sequence: geotextile fabric, expanded clay, substrate (produced with humus from cattle manure) with a depth of 0.10 m, and *Axonopus Compressus* grass. The nutritional composition of the substrate was 79 humus, 20 coal dust, 0.5 NPK 04-14-08 and 0.5% calcite calcium.

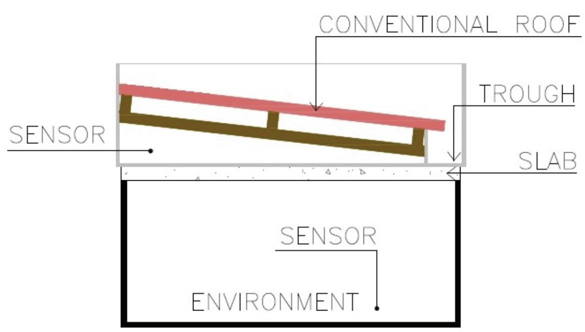

Figure 1. diagrammatic section – sensors in the conventional roof. Source: copyright.

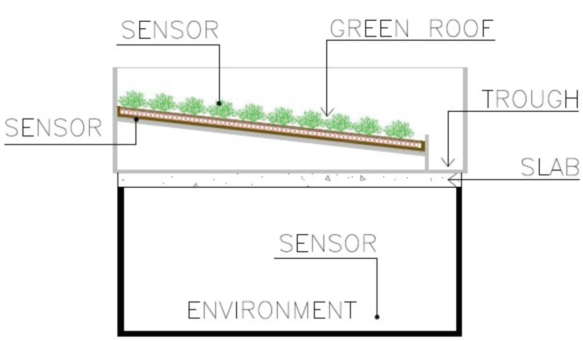

Figure 2. diagrammatic section – sensors in the green roof. Source: copyright.

Two temperature sensors were installed in the conventional roof prototype, one between the tiles and the waterproofing material, and the other inside the room. One wet bulb humidity sensor (%) was also installed inside the room. Three temperature sensors (°C) were installed in the green roof, one on the surface of the vegetation, the second below the substrate and the third inside the room. A wet bulb humidity sensor (%) was also installed inside the room. The instruments that monitored variables in both prototypes were a digital anemometer (m s^{-1}) to monitor wind speed, and a pyranometer (kW m^{-2}) to monitor solar radiation. The collection started at the beginning of October and ended after 30 days of data monitoring for 24 hours a day.

Results and discussion

The experimental results allowed the assessment and comparison of the thermal behavior of the two roofing systems during the month of October in the city of Cascavel/State Paraná. The period of data collection corresponds to the spring (01/10/15 – 6:00 a.m. to 30/10/15 6:00 a.m.) and the thermal comfort range used was that of summer (between 24.8 and 19.2°C), due to the proximity of the station change, in accordance with the method of Olgyay (1973), as the average temperature for the warmest month of the year in 2015 (February) was 22°C. Figure 3 depicts the behavior of solar radiation (kW m^{-2}), outdoor temperature (°C) and wind speed (m s^{-1}) of the two prototypes after 30 days of collection.

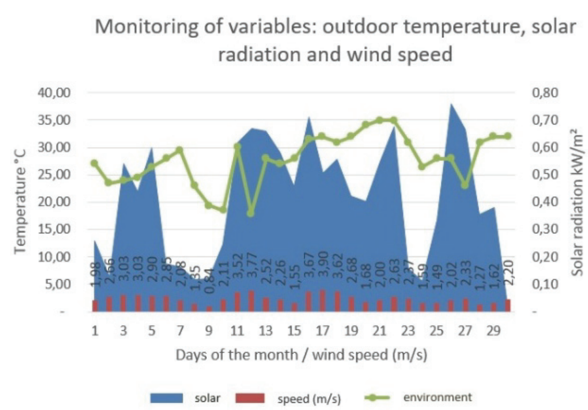

Figure 3. Graph of the daily monitoring of the variables (using the daily means). Source: copyright.

Relative humidity (RH) (%) is the most common measure of water vapor. When comparing the indoor relative humidity of both prototypes it is noticed that the green roof had RH levels lower than that of the conventional roof and closer to the comfort range, which is between 40 and 60% (Olgyay, 1973). The green roof presented RH levels within the comfort range for seven days, whereas the conventional roof presented it for four days. The lowest RH levels coincided with the days on which the lowest temperature was recorded during the monitoring period. Figure 4 and 5 shows the behavior of the variables assessed in the two prototypes, as well as the values of solar radiation during the period of 30 days.

The temperature reduction of the green roof prototype is given by Δt (outdoor temperature subtracted from the indoor temperature of the green roof prototype combined with the solar radiation for the period). It presented a mean reduction of 4.96°C, which means that the indoor temperature of the green roof prototype was lower than the outdoor temperature. The highest outdoor temperature (35°C) was observed on 22/10/2015. On the same day, the indoor temperature was 30.51°C and the solar radiation 0.634 kw m^{-2}, which corresponds to a Δt = 4.49°C.

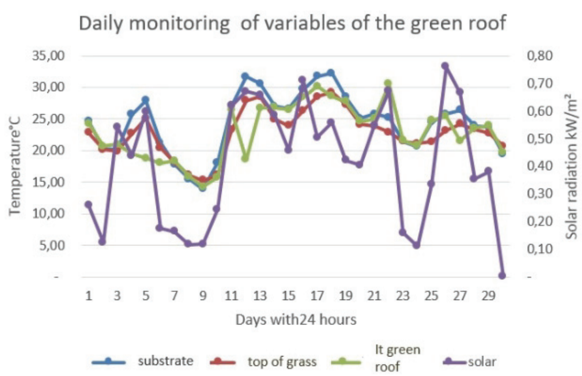

Figure 4. Graph of the daily monitoring of the variables of the green roof (using the daily means). Source: copyright.

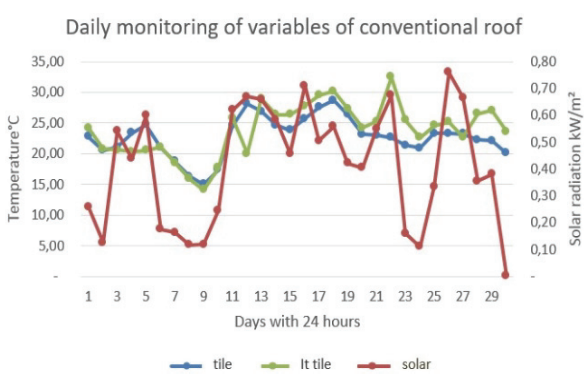

Figure 5. Graph of the daily monitoring of the variables of conventional roof (using the daily means). Source: copyright.

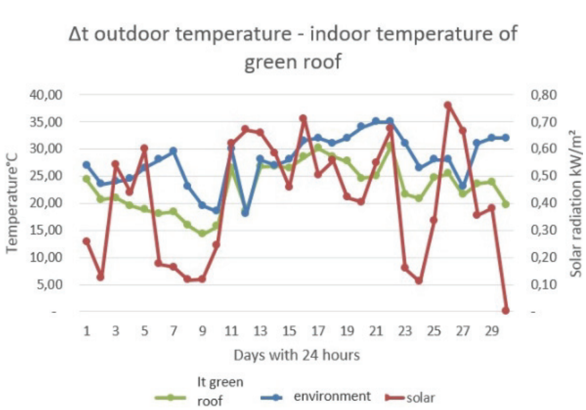

Figure 6. Graph of the variation of the temperature of the green roof prototype. Source: copyright.

Temperature reduction was also observed in the conventional roof prototype (Δt = 4.03°C, where Δt = outdoor temperature subtracted from the indoor temperature of the conventional roof prototype), however, it was 0.93°C lower than that of the green roof. The indoor temperature of the conventional roof prototype and the solar radiation observed on 22/10/2015, the day with the highest outdoor temperature (35°C), were 32.49°C and 0.634 kw m^{-1}, which correspond to a Δt = 2.51°C (Figure 7). Such data indicate that the green roof prototype had a higher temperature reduction level.

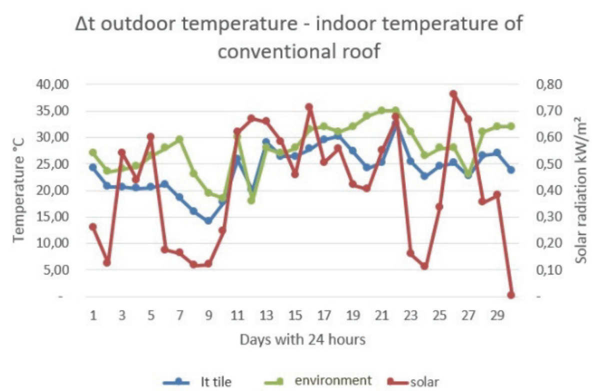

Figure 7. Graph of the variation of the temperature of the conventional roof prototype. Source: copyright.

Figure 8 shows the behavior of solar radiation on 13/10/15, which was selected for being a sunny day. Peaks of indoor temperature were observed at 1:00 p.m. in the conventional roof prototype and at 3 p.m. in the green roof prototype. The average outdoor temperature was 17.01°C. The relative humidity observed was 77% in the green roof prototype and 92% in the conventional roof prototype.

The negative temperature peaks in the green roof prototype occurred posterior to those in the conventional roof prototype every day throughout the experiment. The indoor temperature was higher than the outdoor temperature for 5 hours in the conventional roof and for 4 hours in the green roof prototype.

In order to assess the temperature behavior of the two prototypes, in addition to the sensors that monitored the temperature variation on the surface of the grass and tiles, infrared photos were taken on 16/10/2015 (31.5°C average temperature) with an infrared camera, model IRISYS 4000 Series Imager. Figure 9 and 10 presents the photos.

The infrared photo of the green roof was taken at 2:10 p.m. There are four different temperature variation points, which are represented by cursor 1: 42.0; cursor 2: 54.9; cursor 3: 44.7 and cursor 4: 40.4°C. The green roof presented a variation of 19.6°C among the visible temperatures, average temperature of 44.3°C, hottest spot of 55.4°C and coldest spot of 36.3°C. Lower temperatures were observed where the grass was green, whereas higher temperatures were observed where the grass was dry, which is due to the lack of evapotranspiration. For this study, the same substrate depth of 0.10 m reported by Beatrice and Vecchia (2011) in a study on the assessment of three different substrate depths for the development of a green roof cover was kept.

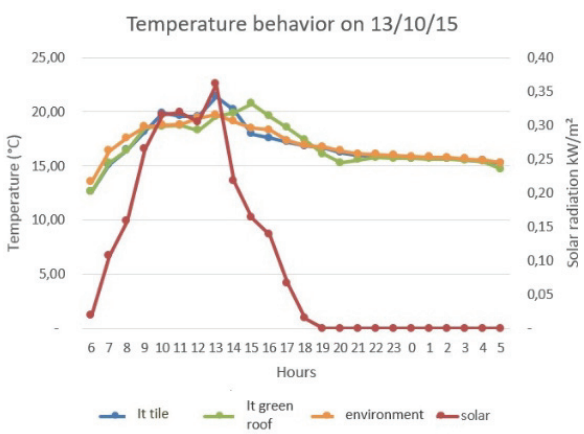

Figure 8. Graph of temperature behavior on 13/10/2015. Source: copyright.

The infrared photo of the conventional roof was taken at 2:24 p.m. and the four variation points are represented by cursor 1: 41.8; cursor 2: 50.5; cursor 3: 49.3 and cursor 4: 46.4°C. The conventional roof presented a variation of 19.5°C among the visible temperatures, average temperature of 43.8°C, hottest spot of 51.4°C and coldest spot of 31.9°C. Lower temperatures were observed on the overlaps of the tiles, as wind blew through them.

Based on the temperature differences shown in the photos, the average temperatures on the surface of the grass were lower than on the substrate, what is in agreement with Araújo (apud Velazquez, 2005), who states that green roofs work as thermal insulation due to their layers and thickness, acting as barriers for solar energy transmission.

Figure 11 shows the thermal behavior of the green roof on 16/10/15. It was observed that on sunny days the temperatures were lower on the surface of the grass and higher on the substrate. According to Krusche, Althaus, and Gabriel (1982), 27% of the solar radiation is reflected, 60% is absorbed by the vegetation and substrate through evapotranspiration and 13% is transmitted to the support base. On cloudy days or during night, the temperatures on the surface of the grass are higher than on the substrate, which according to Dimoudi & Nikolopoulou (2003) happens because vegetation maintains physical and physiologic processes that contribute to reducing the heat sensation, such as transpiration, shading and solar radiation absorption.

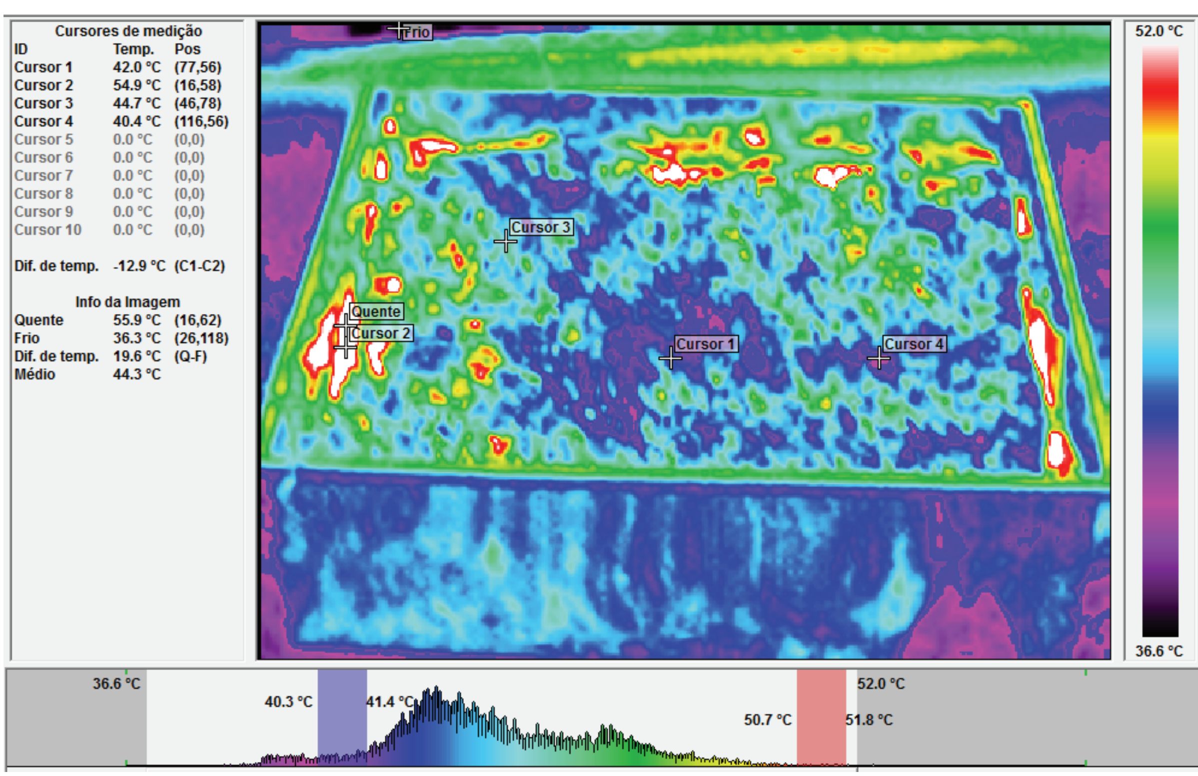

Figure 9. Infrared photos of the green roof. Source: copyright.

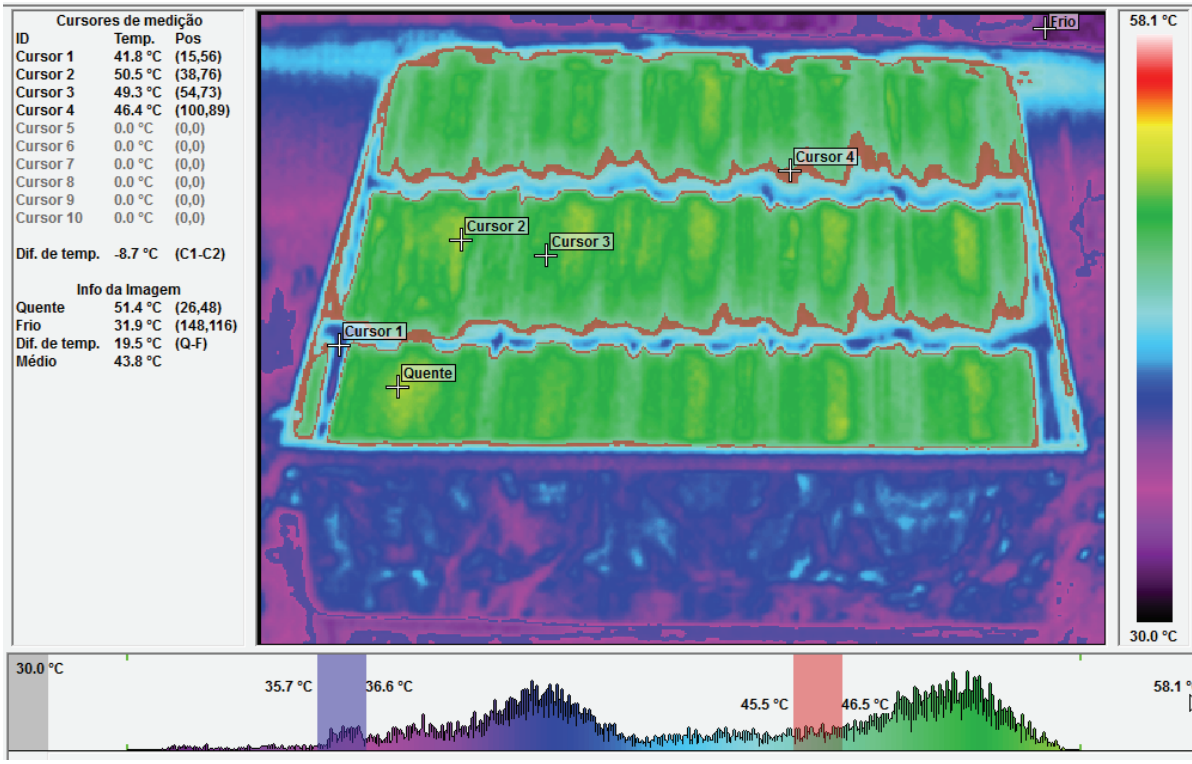

Figure 10. Infrared photos of the conventional roof. Source: copyright.

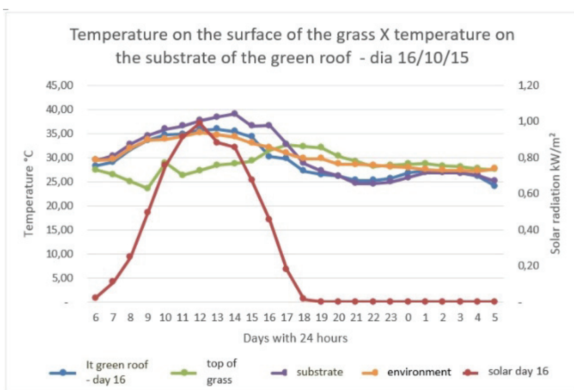

Figure 11. Comparison of the mean temperatures on 16/10/2015. Source: copyright.

When analyzing the relationship between the substrate temperature and the indoor temperature of the green roof prototype, it was observed that the substrate temperature has a direct relationship with the indoor temperature, that is, the higher the substrate temperature, the higher the indoor temperature. However, this relationship was not observed between the indoor temperature and the temperature on the surface of the grass, that is, the green cover had no direct influence on the indoor temperature of the prototype. Similarly, when analyzing the relationship between the temperature on the surface of the grass and the indoor temperature of the green roof prototype on the warmest days, which presented R^2 values of 0.073 (16/10/15) and 0.01 (22/10/15), the green cover had no direct influence on the indoor temperature of the prototype. On the days with lower outdoor average temperatures, the temperature on the surface of the grass was less dependent on the radiation, with R^2 values of 0.634 (12/10/15) and 0.442 (27/10/15).

Conclusion

The experiment with green roof showed the relative humidity inside the comfort range (40 and 60%) for seven (07) days, whereas the conventional roof showed it for four (04) days. The reduction of indoor temperature using green roof was 4.96°C, compared with the conventional roof. This indicates its contribution in the reduction of the indoor temperature of the prototype through the thermal lag, what serves as a good strategy to minimize the effects of external agents on buildings and contributes for their sustainability.

During the assessment of the relationship between the substrate temperature and the indoor temperature of the green roof prototype, it was observed that the substrate temperature has a direct relationship with the indoor temperature, that is, the higher the substrate temperature, the higher the indoor temperature, it was found a determination coefficient of 0,93.

The infrared photo of the green roof shows lower temperatures where the grass was green, whereas higher temperatures were observed where the grass was dry, which shows the influence of the green in the reduction of substrate temperature and consequently in the indoor temperature.

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