International Journal of Agriculture, Environment and Bioresearch

Vol. 4, No. 03; 2019

ISSN: 2456-8643

MODULAR SYSTEM FOR COMPARISON BETWEEN GREEN ROOF AND ALUMINIUM ROOF

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http://doi.org/10.35410/IJAEB.2019.250258

ABSTRACT

The replacement of permeable areas by buildings and constructions, because of urbanization, has as result the increase of flooding and temperature in urban areas, which has led to excessive energy expenditure. The use of green roofs has been one of the alternatives to minimize these environmental problems. This study aimed to analyze the behavior of temperature on a green roof covered with Zoysia japonica grass and conventional roof on a small scale. The temperature of the green roof (GR), conventional aluminum roof (AR) and ambient was measured three times a day for nine days. The green roof was connected to an irrigation system in order to maintain the moisture content of the grass. In this system, it was added a known volume of water, and with the final volume in the end of the experiment, it was possible to determine the evapotranspiration rate of the GR. The results showed the thermal efficiency of the GR. Therefore, the green roof is an alternative approach to improve the thermal comfort in buildings promoting a reduction of temperatures and minimization of runoff flow

Keywords: Sustainable Drainage; Evapotranspiration; Temperature; Sustainable Construction, Green Roof.

1. INTRODUCTION

The increase of temperature in urban areas, such as the phenomenon of heat island, is a consequence of climate change and urbanization, which creates many problems to the environemtn as well as human health [1]. The green roof is an alternative that can mitigate or diminish the phenomenon of urban heat island, and can substantially reduce the surface temperature of the roof. The use of green roofs is becoming more concrete due to its several benefits. The advantages are already documented in the literature and are present in the filds of temperature, hydrology, acoustics, airquality and biodiversity areas [2].

Another major problem of urbanization is flooding caused by the increse of impermeable areas, which is a challenge for many cities and causes significant damage to property, people and the environment [3]. Green roof is also a mechanism used to manage urban runoff -because it mitigates floods from different return periods. In addition, some authors report that green roofs can solve the problems of acid rain with increasing pH from 5.6 to 6.5-7.6 [4].

Green roofs are characterized by the application of a vegetative cover on the buildings. Its planting is done mainly in flat roofs, however, there are modules available in the market that allow its installation in sloping roofs. The elements that make up this structure are a slab, a waterproofing layer, a thermal insulation, a draining layer, a filtering layer, soil and vegetation. In a broader perspective, there are three main types of green roofs, namely intensive green roof, semi-intensive green roof and extensive green roof. Green roofs are classified based on the thickness of the substrate layer and consequently due to vegetation variation [5].

Furthermore, the use of green roof can present better efficiencies with the advance of technologies. Building temperatures are cooled by green roofs due to plant cover and stomata opening to allow transpiration during the day. The vegetation stores the heat and cools down the air. Another characteristic of the green roofs is that they can clean the air and the runoff. Plants on the rooftops can purify the air; plants and soil can purify the runoff as well as delay the storm peak [6].

The vegetation is the base of the green roof construction. In order to make the best choice on which vegetation to choose, some parameters shud be taken into consideration, such as: climate of the region, whether the vegetation is native or exotic, height of growth, watering regime and period of maintenance [7]. Therefore, the selection of plants for different locations and climate requires a test on a multiple plant species in order to assess their suitability for green roofs.

A number of different species of vegetation are being employed for use on green roofs. Nagase and Dunnett [8] investigated the influence of 12 plant species on the amount of runoff from a simulated green roof. The study concluded that plants with larger dimensions of height, larger diameter and greater amount of biomass were more efficient in the reduction of runoff from simulated green roofs than smaller plant species. To better understand the relationship of water input on green roofs, it is necessary to verify that for any kind of soil, the flow of moisture occurs by several manners. This fact can be evidenced by the water balance equation in the soil:

$$I - ETP + P - RO - DPi + CR \pm \Delta SF \pm \Delta SW = 0 \quad (1)$$

where, I is irrigation, ETP is evapotranspiration, P is precipitation, RO is surface runoff, DPi is deep percolation, CR is capillary rise, ΔSF is the variation of subsurface flow, and ΔSW is the variation of soil water content.

The equation of soil water balance can also be applied to green roofs, which take into consideration soil, organic matter and vegetation. However, for this case, some simplifications can be taken into account (Eq. 1). Therefore, the mass balance of water in the simplified soils for green roofs can be used to calculate the evapotranspiration:

$$ETP = P - RO \pm \Delta SW \quad (2)$$

Another study evaluated the effectiveness of four green roof species at capturing particulate matter smaller than 10 µm (PM_{10}). The species tested were: *Agrostis stolonifera*, *Festuca rubra*, *Plantago lanceolata* and *Sedum album*. The study found that the species *A. stolonifera* and *F. rubra*, are more effective than others at PM_{10} capture [9]. Regarding green roof tests for temperature reduction, studies in Italy have shown a decrease of 0.57 to 0.63 times the temperature of green roofs comparing to conventional roof. In addition, there are reductions of the heat loss in internal spaces during winter [7].

Thus, this study aimed to analyze the behavior of green roof coverage in temperature using the specie *Zoysia japonica* of grass and conventional roof on a small scale. It was also evaluated the evapotranspiration of the vegetation used through a closed irrigation system installed next to the green roof.

2. MATERIALS AND METHODS

2.1 Area of study

This study was carried out at the Federal Technological University of Paraná in the city of Londrina, Brazil, at coordinates 23º18 'S and 51º 06' W. The climate of the region is classified as subtropical humid mesothermic with average annual temperature around 20ºC.

2.2 Roofs' construction

The development of this study consisted in the construction of two structures: one containing the green roof (GR), and the other containing an aluminum roof (AR). Both structures were made using concrete blocks (50x50cm and 3cm high) in order to simulate a construction (house or building) on a small scale. For the AR structure, it was place on the top of the construction a piece of aluminum tile (AT), 53x49 cm in size and a plastic container under the AT to give support to the roof (Figure 1i). The construction of the GR occurred in different layers. First, the same plastic container used in the construction of AR structure was placed right above the concrete blocks. Next, a bidim blanket (BB) was placed in order to avoid leaks through the structure. Then, the layers were as follows: fine gravel (FG), sand (SD), fertilized soil (FS) and, above all, the vegetation (VG) Zoysia japonica (Figure 1ii).

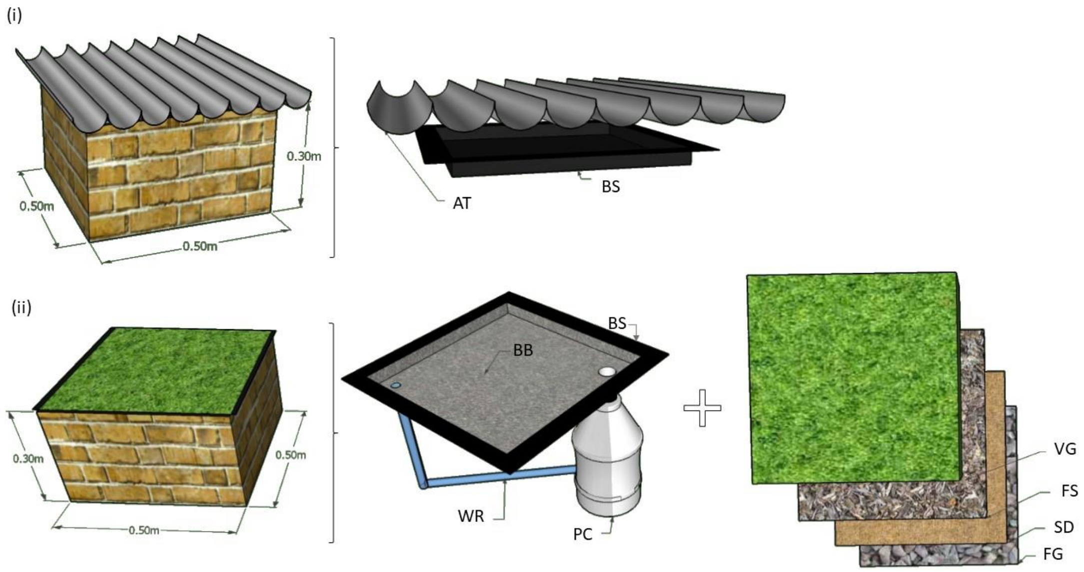

Figure 1: Construction of aluminum roof (i) and green roof (ii). NOTE: AT - aluminum tile, BS – black support, BB - bidim blanket, PC – plastic container, WR - water recirculation, VG – vegetation, FS - fertilized soil, SD – sand, FG - fine gravel.

The GR structure was placed on the concrete blocks at a 12° slope, as indicated by Schunck, Oster, Barthel and Kiessl [10]. The slope is an attempt to have a collection point of rainwater. Therefore, a 5L plastic container (PC) was used as a reservoir. In addition, a pump was place inside the reservoir to provide water recirculation (WR) in the system and consequently GR irrigation.

2.3 Temperature analysis and evapotranspiration

Both roofs were observed for a period of 9 days. During this period, the GR, AR and ambient temperatures were measured three times per day (10am, 12pm and 4pm). The temperatures' measurements of the GR and AR were collected with a skewer thermometer placed inside the structure. The ambient temperature was measured using an external thermometer located between the roofs.

Initially, 2 L of water was added to the GR reservoir for irrigation of the vegetation. The water recirculation pump was switched on once a day for a period of 20 minutes. As there was no rain during the analysis period, with the difference between the initial volume and the end of the experiment, it was possible to measure the evapotranspiration of GR.

3. RESULTS AND DISCUSSION

Regarding the temperatures measured at 10am, it was observed a variation between 25ºC and 35ºC on the ambient temperature, with a mean temperature of 27ºC (Figure 2a). Moreover, it was possible to observe that the internal temperature of the GR maintains an average of 26ºC, being more constant. However, the AR shows greater variations and the average temperature is 28ºC.

For the ambient temperatures measured at 12pm, it was obtained an average of 31ºC (Figure 2b). At the same time, the AT shows higher temperatures (average of 33ºC) in almost every day. Except for the sixth day, where the temperature in the GR and AR were the same, due to the cloudy weather conditions.

The maximum temperature inside the GR was 38ºC, maximum value also found at ambient temperature. The AR showed the highest temperatures, with maximum temperature measured at 42ºC in three days at 4pm (Figure 2c). The heat transfer occurs by conductive process in buildings. In this context, the heat flow through the roofs, along with the elevated temperatures on its underside is the main cause of the discomfort inside buildings, especially in the summer. The roof is the element of the building installation most exposed to external conditions and almost half of the heat gained is through it. On the other hand, the roof opens ample possibilities to dissipate the heat of the installation [11].

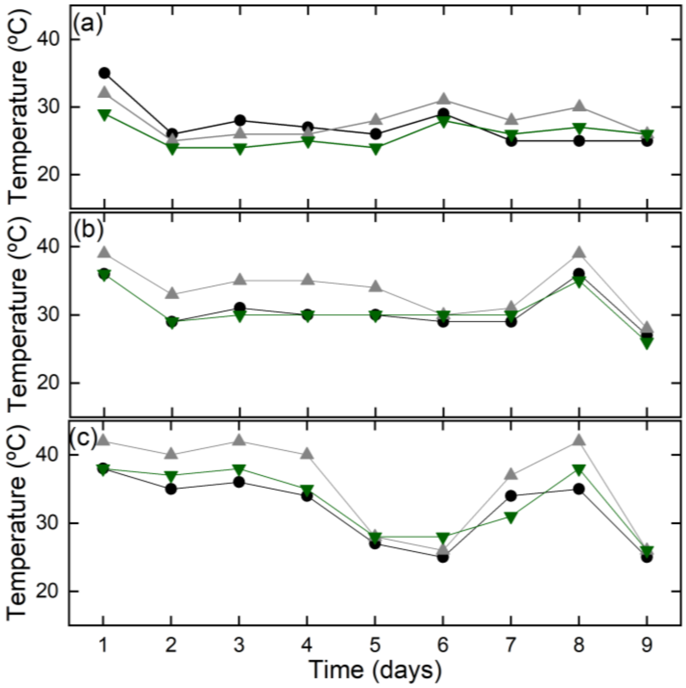

Figure 2. Temperature measured in the ambient (—●—), aluminum roof (—▲—) and green roof (—▼—), at the following times: 10h (a), 12h (b) and 16h (c).

The average temperature in all times (10am, 12pm and 4pm) in the AR was greater than the GR and ambient temperature. At 10am, average GR temperature was 25.9±1.8ºC, while ambient temperature was 27.3±3.2ºC and AR was 28.0±2.5ºC. During the nine days of experiment, the variation of the temperature at 10am is very small in GR (Figure 3).

At the 12pm temperature analyzes, the average between the GR (30.7±3.0ºC) and the ambient temperature (30.8±3.2ºC) were similar. In addition, the AR temperature was higher, with an average of 33.8±3.8ºC (Figure 3). However, at the same time of analysis, the temperature variation between the three measurements presented similar values.

For the period of 4pm, the average temperatures among the structures were even higher. At this time, the AR temperature presented a greater value of 35.9 ºC, with a variation of ±7.1ºC. In addition, the GR temperature (33.2±4.9ºC) was slightly above ambient temperature (32.1±5.0ºC).

In general, the results showed that the GR presented lower thermal amplitude compared to AR. Under the conditions evaluated, the GR reduced the temperature of the indoor environment, which has allowed the temperature to be maintained.

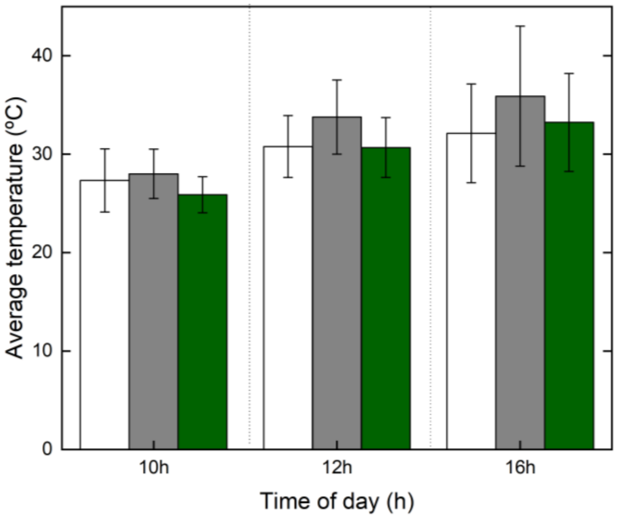

Figure 3. Average temperatures and their variations for: ambient (⬜), aluminum roof (◼) and green roof (🟩)

The highest temperature differences between GR and AR occurred on days when the ambient temperature was higher (Figure 4). On days when the temperature difference was zero or negative, they were consistent with cloudy weather. The thermal amplitudes were between 0 - 4ºC, 0 - 5ºC and -2 - 6ºC for the hours 10am, 12am and 4pm, respectively (Figure 4 - a, b and c, respectively).

After the field data collection of the temperature, it was possible to compare its variations in GR, AR and the ambient. The largest amplitude between the roofs was 6°C (Figure 4c). These results are in agreement with Parizotto and Lamberts [12], they found a variation of the thermal amplitude between green roof and ceramic and metal roof of 3.2ºC to 5.4ºC, respectively. On the other hand, for Spangenberg, Shinzato, Johansson and Duarte [13], the green roof is efficient in reducing the temperature of the roofs by 15ºC, giving the buildings users thermal comfort. As consequence, there is a decrease of air conditioning use and reduction of energy consumption.

The measured temperature of the GR remained smaller than the AR during the whole experiment, except for the sixth day at 4pm (Figure 4c). On this day, the weather was cloudy, and the average ambient temperature was 27.6ºC, which was one of the lowest value compared to the other days. For the Jim and Peng [14] in days with lower temperatures and presence of clouds, the results showed little variation between the analyzed temperatures. The green roof presented smaller thermal amplitude compared to other coverage systems.

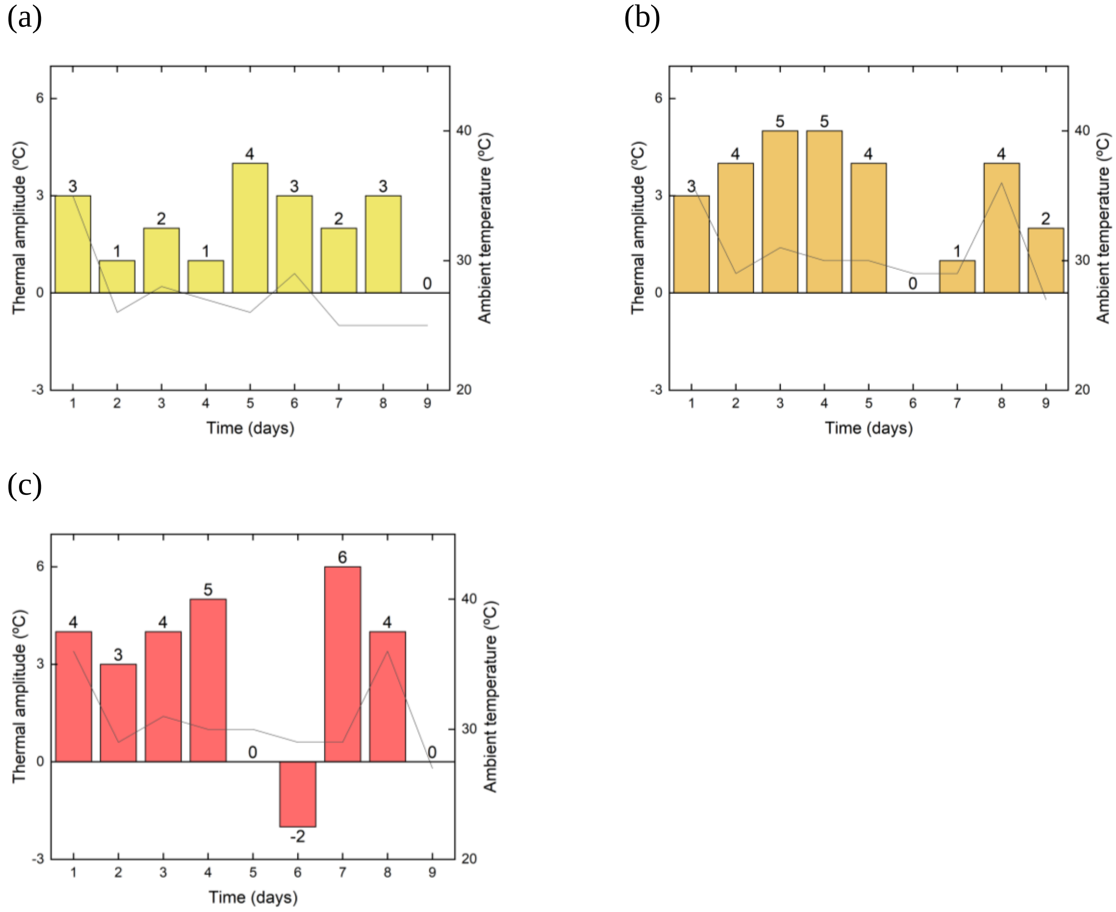

Figure 4. Thermal amplitude between the interior of the aluminum roof and the green roof, for the schedules: 10h (🟨), 12h (🟧) and 16h (🟥).

In respect of the determination of the vegetation evapotranspiration, simulations were performed with an initial known volume and with the collection of the flow rate. Regular watering was executed by the water recirculation mechanism. The natural precipitation was null in the analyzed period. At the end of the measurement, a reduction of approximately 45% of the initial volume of water was found, corresponding to a volume decrease of 1.1 L. This value corresponds to an attenuation blade of 3.6 mm.

Araújo, Squizzato, Costanzi, Baldin, Puzzi and Londrina [15] found, concerning the final water balance, 43.51% of evapotranspiration of the water intake in the system in the form of precipitation and irrigation. The implantation of this system in urban areas can reduce peak flows, as well as help increase the time necessary for the water to reach the conventional rainwater drainage system, corroborating to minimize floods in urban systems [16].

In relation to green roofs, the contribution of this technology lies in the vegetation's ability to retain rainwater and, due to its physiological action, allows the occurrence of transpiration and evaporation. Quantifying the evapotranspiration of a green roof becomes an important factor in measuring the actual contribution of this roof to minimizing rainwater runoff [6]

4.CONCLUSION

Green roofs are an alternative for the improvement of thermal comfort in buildings promoting the decrease of temperatures in the urban centers and contributing to positive impacts in the microclimate, causing potentially reduction of urban heat island. The decrease of temperature in regions with high solar incidence is an important factor for the adequacy of buildings to the thermal comfort.

In addition, the results of this study have brought advantages of the use of green cover in buildings associated to the minimization of runoff flow. Thus, this system can help reduce the volume of rainwater in the urban drainage system by retaining water in the soil and increasing evapotranspiration.

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