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Investigation of green roof thermal performance in temperate climate: A case study of an experimental building in Florianópolis city, Southern Brazil

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ABSTRACT

Green roofs have been investigated as a bioclimatic strategy to improve the energy efficiency of buildings. Quantitative data on this subject are still needed for many specific climatic conditions. This paper deals with the investigation of the green roof thermal performance of an experimental single-family residence in Florianópolis (SC, Brazil), a southern city with a temperate climate. Field measurements during a warm period (01-March-2008–07-March-2008) and during a cold period (25-May-2008–31-May-2008) included internal air temperature of rooms, internal and external surface temperature of three types of roofs (green, ceramic and metallic), heat fluxes through these roofs, green roof's temperature profile, water volumetric content in substrate layer and meteorological data. During the warm period, the green roof reduced heat gain by 92–97% in comparison to ceramic and metallic roofs, respectively, and enhanced the heat loss to 49 and 20%. During the cold period, the green roof reduced heat gain by 70 and 84%, and reduced the heat loss by 44 and 52% in comparison to ceramic and metallic roofs, respectively. From the derived data it has been confirmed that green roof contributes to the thermal benefits and energy efficiency of the building in temperate climate conditions.

1. Introduction

Green roofs have been vastly investigated in the last decades in many cities around the world as a tool to solve many problems in the urban environment, such as storm water runoff management [1], mitigation of urban heat island effects [2] and increase of roof materials durability [3]. Moreover, research in thermal properties and energy performance of green roofs through experimental and mathematical methods gained importance in the recent years due to their potential to enhance the energy efficiency of buildings [4–16]. In general, researches suggest that contribute in reducing thermal fluctuation on the external and internal surfaces, lowering the energy consumption for maintenance of indoor comfort conditions.

Some of these studies proposed energy balance models to predict the thermal behavior of green roofs [6,12–14], but their reliability is still questionable due to several restrictions found therein (e.g. by excluding some biological processes). The accuracy of these models still needs to be improved for better practical results. Experimental measurements are still the most effective way to know the thermal performance of these devices under specific climatic conditions [4,5,8,11].

Just as the cool roofs, green roofs are also a method to reduce the urban heat island effects and improve the energy efficiency of buildings. On the cool roofs, the sensible heat flux is small because of the low net radiation by high solar reflectance. On the green roof surface, the sensible heat flux is small because of the large latent heat flux by evaporation, although the net radiation is large [2].

Cool roofs technology is more developed, inexpensive and widespread than green roofs, with rooftop materials commercially available characterized by high solar reflectance, ranging from 0.5 to 0.85, and high thermal emissivity values, measured to be about 0.9 [17–19]. Green roofs in turn have higher emissivity values than cool roofs, varying around 0.96, but smaller solar reflectance, with values ranging from 0.2 to 0.4 [20,21].

Although cool roofs appear more desirable, green roofs performance are associated with physical process like evapotranspiration and shading [12,16] that contributes fairly well for the energy efficiency of buildings and urban heat island mitigation issues [5,11]. Moreover, green roof will be more desirable and cost-effective because the great number of benefits for the building and the city context, including stormwater runoff mitigation [1], roof service lifetime extension [3], air quality improvement [22] and noise reduction [23], among others. Potential energy savings of green roofs has not been studied in much detail, still needing

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the accumulation of qualitative and quantitative data to support its dissemination [21].

Climatic conditions play an important role in the green roofs performance. Some quantitative data in the context of temperate climates are still needed, where the humidity level is high during most part of the year, thus lowering the evapotranspiration rate and cooling capabilities. This study presents an analysis of the influence of a green roof in the thermal performance of an experimental building thermally monitored in Florianópolis city, a southern Brazilian island with a temperate climate (http://www.eletrosul.gov.br/casaeficiente/en/home/).

The architectural project was based on solutions leading to the best usage of local climate conditions, aiming rational use of energy and environmental impact reduction. Some of the bioclimatic design strategies used were proper solar orientation of the rooms, natural ventilation, solar heat gain, thermal mass, thermal insulation of walls and roofs, external solar protection for windows, cool roofs and green roofs. Rainwater harvesting, grey water reuse, low water consumption equipment and photovoltaic-generated energy were also considered.

Besides its sustainability goals, the project also meets the operational flexibility and maintenance needs required for this building to works as a research lab and a technology showcase open for public visitation. During the years of 2007 and 2008, the building was subjected to an alternated biweekly use for public visiting and research activities (controlled experiments) to assess the thermal-energetic behavior of the building.

The research conducted using this building had the following objectives:

- to evaluate the influence of green roof in the temperature profile and heat flux across the roof;
- to compare the green roof thermal performance against ceramic and metallic roofs;
- to evaluate the influence of substrate water volumetric content in the thermal behavior of green roof.

2. Methodology: thermal monitoring

2.1. Description of the site and roof systems

The experimental building is located in Florianópolis, a southern Brazilian island (capital city, state of Santa Catarina) located at the latitude 27°36′19.81″ S, longitude 48°31′16.55″ W. The island is situated in a temperate climate region, sub-warm category with average temperature ranging between 15 and 18 °C during winter and 24 and 26 °C during summer. Annual average air temperature is 20.4 °C, with maximum 36.4 °C, and minimum 2 °C. Average air relative humidity is 83% [24].

The experimental building is a residential building for a family of four with living/dining room, kitchen, bathroom, laundry room, two bedrooms and a roofed utility room. The habitable area is 124 m^2. It has double walls with rock wool insulation (U = 1.06 W/m^2 K) with an absorptance of 60%. Windows are double glass panes (U = 2.84 W/m^2 K) with solar factor of 0.75 [25]. Fig. 1 shows a view of the North façade of the experimental building and an exterior view of the bedroom with green roof (bedroom 2).

The experimental building has three different types of roofs: ceramic roof, metallic roof and green roof. Figs. 2 and 3 show, respectively, the distribution of rooms and roofs in the experimental building. The rooms selected for monitoring (indicated in figures with underlined captions) were the living/dining room (66 m^2 of metallic roof surface), bedroom 1 (36 m^2 of ceramic roof surface), and bedroom 2 (20 m^2 of vegetated roof surface).

The ceramic roof consists of white roof tiles, wood battens, aluminized polyethylene radiant barrier, rock wool insulation and oriented strand board (OSB) wood ceiling. The metallic roof consists of solar photovoltaic panels, metallic panels of plate folded with white paint, rock wool insulation and OSB wood ceiling. The extensive type green roof (low cost, light weight, low maintenance) consists of *Bulbine frutescens* vegetation layer, soil substrate layer, geotextile filter, gravel and pebble drainage layer, reinforced mortar, extruded polystyrene insulation, no asphalt sealer and concrete slab. Figs. 4–6 show details of the aforementioned roofs, including the constructive components and respective thickness.

Table 1 shows the albedo (α) and emissivity (ε) values adopted for the roof materials. For the ceramic and metallic roofs, these values were obtained in Prado (2005) and in Brazilian standard NBR 15220-2 [26,27]. For the green roof, these values were obtained in OKE studies [20].

2.2. Description of equipment and measurement period

The thermal monitoring system of the experimental building was equipped with a data acquisition system, which scanned all sensors in the experimental building every 3 min and recorded the measured data in a microcomputer.

Internal monitoring of the experimental building was performed using two measurement points in each room: one located on the wall and one located on the ceiling. Similarly, each room had external measurement points on the roof and wall surfaces. The internal parameters registered by the system were air temperature (at 1.5 m height), ceiling surface temperature and heat flux between ceiling surface and interior air (heat flux transducer located in the internal surface). The external parameters registered by the system were the surface temperatures of walls and roofs. In the green roof, in addition to the exterior surface temperature (vegetation temperature), the temperatures of substrate and drainage layers and water volumetric content of substrate layer were also monitored. Figs. 4–6 show internal and external measurement points of the three analyzed rooms.

The meteorological parameters (solar radiation, air temperature, air relative humidity, wind speed and rainfall) were obtained with a weather station positioned near the experimental building. All experimental equipments used for the field measurements (monitoring system and weather station) and their specifications are presented in Table 2.

The measuring periods used for thermal analysis of green roof performance were a typical warm week in summer (01-March-08–07-March-08) and a typical cold week in autumn (25-May-08–31-May-08). The experimental building was not occupied during the analyzed periods.

3. Results and discussion

3.1. Thermal performance of green roof during the warm period

The warm period chosen for the analysis was a week in March 2008 (01-March-08–07-March-08), which is representative of a typical summer season in Florianópolis. Daytime is characterized by high loads of solar radiation (average value of 1.0 kW/m^2) with an average air temperature of 25.7 °C and an average relative humidity of 73.1%. Days presented winds with daily average value of 5.0 km/h, precipitation having occurred in the first three days with an accumulated value of 15.5 mm.

Our first analysis compared the external surface temperatures of the three roofs. As expected, the first effect observed in the behavior of the green roof is the reduction of the surface temperature and its daily amplitude, as illustrated in Fig. 12. Part of the incoming solar