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PERFORMANCE EVALUATION OF GREEN ROOF FOR THERMAL PROTECTION OF BUILDINGS IN REUNION ISLAND

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Abstract

Green roofs provide environmental benefits by protecting buildings against solar radiation and temperature fluctuations and by reducing building's energy consumption by direct shading. Our objective was to evaluate for the first time the performance of an extensive green roof in Reunion Island (Indian Ocean) influenced by a tropical humid climate. The green roof performance was explored by evaluating its effect on temperature fluctuations and heat fluxes during the summer season. The results showed that the presence of plants led to a decrease in temperature under the green roof. Plants also contributed to a lower heat flux exchange through the green roof. The determination of major parameters including U-value, R-value and k-value, demonstrated the thermal and energetic behavior of the green roof and helped to highlight *Sedum* plant benefits. To conclude, this study has demonstrated the thermal and energetic performance of a green roof based in an area under a tropical humid climate.

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Keywords: green roof, tropical humid climate, temperature fluctuations, energetic performance.

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I. Introduction

Natural cooling techniques have been used over the centuries and their application has started to spread throughout the world (Northern hemisphere). The introduction of mechanical air conditioning systems into the building, with their great energy expenditure, has become the standard alternative used to natural cooling.

The number of studies regarding this problematic are developed as ROOFSOL research project [1], which focused on the theoretical and experimental analysis of different roof solutions for cooling in the Mediterranean region, mainly based on evaporative and radiative cooling principles. In the case of Greece, the work of Niachou et al. [2] as well as the study of Spala et al. [3] on the analysis of the green roof thermal properties and energy performance can be considered.

The green roof technology is also able to reduce the energy consumption and to improve the internal comfort during the spring and summer seasons, in sites where the climatology is characterized by high temperature and irradiance values during the day [4].

There is a growing literature data regarding the green roof energy balance. An important work has been performed by both experimental and computational methods. For illustration, Cappelli et al. [5] analyzed the thermal behavior and effectiveness of vegetation covers with different average absorptance for solar radiation and diffuse properties through a finite difference simulation model. Several other studies also referred to the implementation of green roofs on the buildings [6-8].

Few studies were investigated in the Southern hemisphere where the green roof potential as a natural cooling is unknown or poorly known. Wong et al. [9,10] explored the thermal benefits of a green roof in Singapore through an experimental test done before and after the construction of a rooftop garden.

The objective of this paper is to propose a first experimental study of the green roof cooling in Reunion Island, located in the Indian Ocean and influenced by a tropical humid climate coming from the Southern hemisphere. An extensive green roof based on three kinds of vegetation was tested and compared to a reference bituminous roof during an experimental period of five months during the summer season. The green roof potential was explored through the determination of its effect on temperature fluctuations as well as on humidity rate in the soil and by evaluating its energy performance.

II. Experiment

II.1 Green roof description

The experimental green roof was established on August-September 2010 and is still in progress. The green roof is located in the South of Reunion Island, in Saint-Pierre town (21°19' S, 55°28' E) which is in an area under the wind and at 55 m above the sea level (Figure 1). There is a tropical humid climate along the coast and rather temperate in the mid – highlands (Figure 2). Due to Reunion Island location, solar energy is abundant (Figure 1). This region is also characterized by two seasons: winter and summer with a daily average temperature of ambient air from 19.1°C to 33.2°C ; a maximal average temperature at 17.2°C for the dry season during the winter time and at 35.8°C for the rainy season during the summer period.

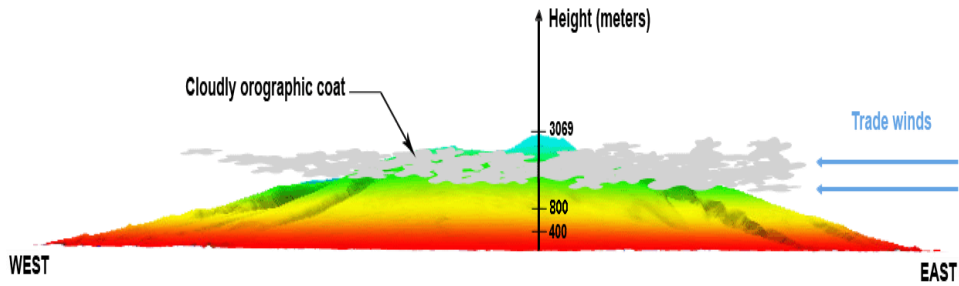


Fig. 1: The relief of Reunion Island

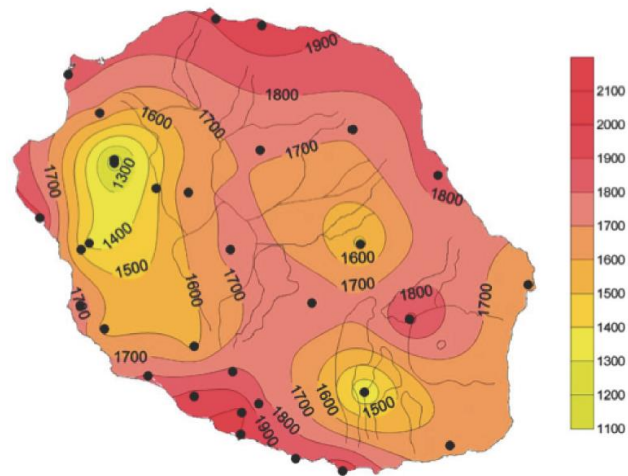


Fig. 2: Global solar irradiance (kWh/m^2) distribution in Reunion Island [11]

II.2 Structural composition of the green roof

The green roof system was provided by SAPEF Company, recognised for its expertise in green roof technology in the tropical environment [12].

The green roof composition is presented on Figure 3 and consists of a water-proofing membrane (SOPRALENE FLAM elastomer bilayer specially designed to resist root penetration), a drainage layer (SOPRALITHE Z 703 layer of 40 mm leading to facilitate the flow of water into storm drains while providing additional water retention), a filter membrane (SOPRAFILTRE nonwoven synthetic fiber layer preventing clogging of the drainage layer by fine particles of the substrate), a substrate layer (SOPRAFLOX X 701 layer of 80 mm, developed and produced in Reunion Island and adapted to tropical climatic conditions to provide optimal and constant permeability, resistance to erosion and density of green roofing) and plants from three species.

These plants correspond to *Plectranthus neochilus*, *Kalanchoe thyrsiflora* and *Sedum reflexum* species (Figure 4) which are succulents exhibiting a strong ability to store water in their leaves and to be highly drought resistant. These plants provided by SAPEF Company are known to easily grow and to lead to a dense green roof. During the measurement period (from October 2010 to February 2011), the average of plant cover was 30% of the whole roof area with *Sedum* as the major plant specie (38%) followed by *Plectranthus* (34%) and *Kalanchoe* (28%).

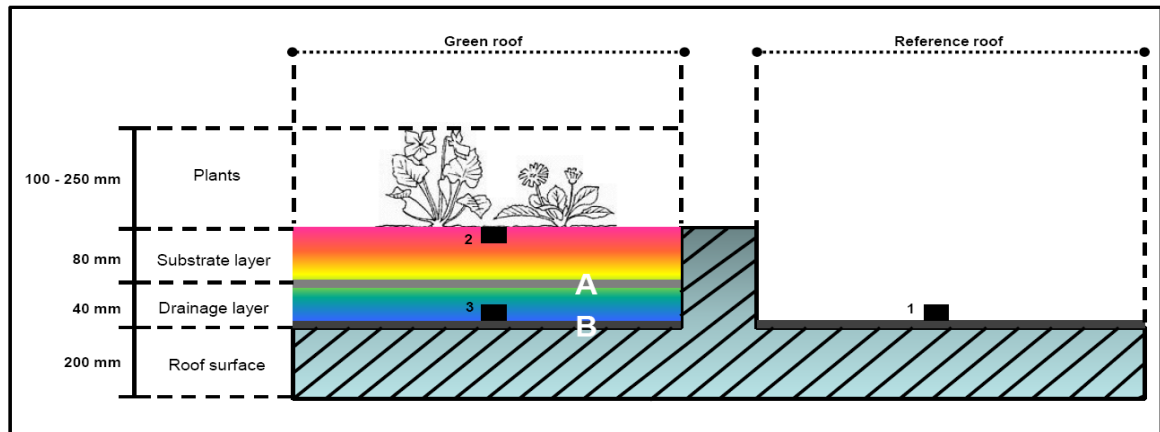


Fig. 3: Structural composition of the green roof

A reference bituminous roof is located nearby this experimental green roof. Both the reference roof and the green roof have no slope and the same area (54 m²). The green roof is also characterized by a maximal weight of 170 kg/m² and a water retention capacity reaching 40 L/m².

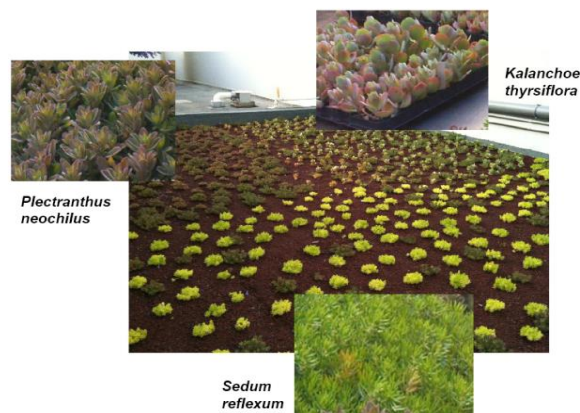


Fig. 4: Plants constituting the green roof

II.3 Sampling and analysis

All measurements were performed from October 2010 to February 2011 representing a five month-period from the end of the winter season to the summer time in Reunion Island. The site is equipped with a

meteorological station connected to a data acquisition system leading to monitor different major external parameters such as rain data, air temperature and relative humidity, wind direction and speed, global incoming solar radiation and air pressure. A set of sensors were also used to monitor the specific green roof parameters, namely type T thermocouples (Campbell Scientific) for measuring superficial temperature and temperature under the green roof (between drainage layer and water-proofing membrane; sensors type P) as well as a sensor to evaluate the heat fluxes through the green roof (HFP01 soil heat flux plate, Campbell Scientific). All sensors were connected to a data acquisition system (CR 3000, Campbell Scientific) supplied by a multiplexer (AM16/32B, Campbell Scientific), allowing the registration of each parameter value every 1 min. Then, data were transferred via a RS232 port on a computer and processed using MS Excel and MatLab.

III. Results and Discussion

As most of the temperature and heat flux values were normally distributed, parametric statistics were applied. Data were expressed as means \pm standard deviation values. The level of significance of $\alpha = 0.05$ was accepted in all cases.

III.1 Effect of the green roof on temperature fluctuations

During the experimental period, the maximum ambient air temperature was $28.7 \pm 0.4^\circ\text{C}$ and the maximum temperature of the reference roof reached $73.5 \pm 1.4^\circ\text{C}$. The presence of plants significantly decreased the temperature of the roof surface (between the RR surface and the GR Surface) whatever their species. Indeed, results obtained over the experimental five-month period showed that the maximum temperature measured under the three species of plants reached an average of $34.8 \pm 0.6^\circ\text{C}$. Accordingly, Wong et al. [9] reported that the maximum temperature measured under different kinds of vegetation in Singapore, which is also influenced by a tropical environment but under an equatorial climate, was closed to 36.0°C .

As shown on Table 1, plants were also able to induce a decrease in temperature fluctuations between the GR Surface and the GR at 120 mm. The average values of temperature differences were of $6.8 \pm 1.4^\circ\text{C}$ for *Plectranthus*, $6.5 \pm 0.9^\circ\text{C}$ with *Kalanchoe* and $6.7 \pm 0.3^\circ\text{C}$ for *Sedum*. Thus, the presence of plants resulted in an average value of temperature loss close to $6.7 \pm 0.1^\circ\text{C}$ under the green roof. A similar median fluctuation of $5.0\text{-}7.0^\circ\text{C}$ was previously reported [13]. Our results clearly demonstrate for the first time, the thermal performance of an extensive green roof developed in the Indian Ocean area under a tropical and humid climate. This study also shows that the three kinds of plants selected exhibit a significant ability to decrease the temperature at the green roof surface as well as inside the green roof.

Table 1. Temperature difference between GR Surface and GR at 120 mm ($^\circ\text{C}$)

MONTH	PLECTRANTHUS	KALANCHOE	SEDUM
Oct.	9.2 ± 2.1	8.0 ± 1.3	8.0 ± 2.5
Nov.	11.2 ± 0.5	9.0 ± 2.0	6.8 ± 0.6
Dec.	5.7 ± 0.5	4.6 ± 1.1	6.2 ± 0.9
Jan.	3.6 ± 1.0	4.8 ± 0.6	6.1 ± 0.6
Feb.	4.6 ± 0.2	5.9 ± 0.2	6.3 ± 0.5

III.2 Effect of the green roof on heat flux variations

Figure 6 illustrates the global solar radiation values (Figure 5A) and the comparison of heat flux transferred through the different green roof components according to the plant species (Figure 5B) on three typical days in January. Whereas the mean value of maximum global solar radiation on three days was $1165.7 \pm 43.3 \text{ W/m}^2$, the maximum heat flux transferred through *Plectranthus* green roof surface was $27.7 \pm 2.2 \text{ W/m}^2$, leading to determine a transmitted heat flux exchange of $2.4 \pm 0.2\%$. With *Kalanchoe*, the maximum heat flux reached a mean value of $28.8 \pm 2.7 \text{ W/m}^2$ that corresponded to a $2.5 \pm 0.3\%$ of transmitted heat flux. For *Sedum*, it appeared a mean value of heat flux at $16.6 \pm 1.7 \text{ W/m}^2$, resulting into a heat flux exchange of $1.4 \pm 0.2\%$ and suggesting that energy performance of *Sedum* is better than those of *Plectranthus* and *Kalanchoe*.

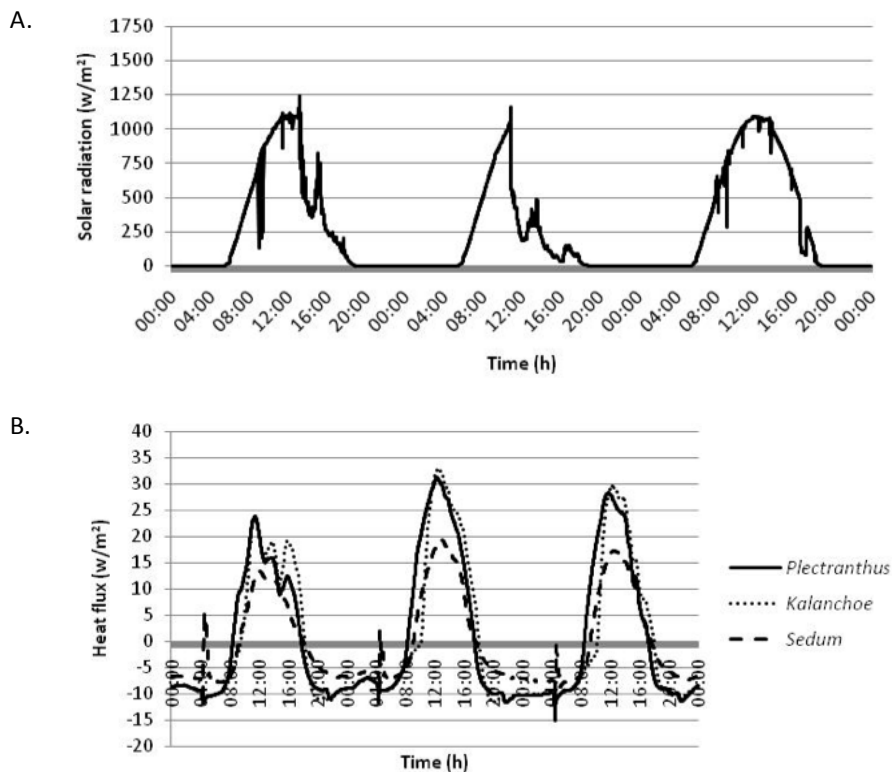


Fig. 5: Effect of the green roof on heat flux variations in January 2011. Global solar radiations (A) and heat fluxes (B) were measured on three typical days

During all the experimental five-month period, our study also shows that *Sedum* green roof presented an average heat flux exchange of $1.4 \pm 0.3\%$ as compared to *Plectranthus* ($2.3 \pm 0.2\%$) and *Kalanchoe* ($2.2 \pm 0.4\%$) green roofs. This result agrees with the data published by Feng et al. [14] establishing a heat flux exchange of 1.2% for *Sedum* green roof. Here, the higher performance of *Sedum* could be related to its higher sun-shading effect as well as its higher ability to grow more quickly than *Plectranthus* and *Kalanchoe*. Accordingly, in a three years study by the University of Michigan, the drought resistance of a

wide range of *Sedum* plants was compared to 18 native and non-native plants. It was concluded that *Sedum* plants were the most suited to unirrigated roofs in Michigan's climate, as all *Sedum* plants survived while other species had significant high mortality rates. Such a high drought resistance of *Sedum* plants is attributed to their ability, as succulents, to easily store water in their leaves [15]. Lazzarin et al. [16] compared the energetic exchange of a *Sedum* dry or wet green roof with a traditional roof in the north-east of Italy during the summer season and also reported a significant lower heat flux exchange for *Sedum* (0.4-1.8%) than for a traditional roof (4.4%). For Wong et al. [9], the thermal protection of plants also highly depends on their leaf area index (LAI) since lower temperatures were found under dense trees and shrubs as compared to sparse foliages.

As the green roof energy performance depends on its ability to reduce the heat gain, we measured the heat gain/loss per square meter over the five-month period. Considering that the total solar radiation did not significantly change during this period ($1215.9 \pm 32.0 \text{ W/m}^2$), it could be observed that the presence of the green roof was associated with an average total heat gain decreasing over the time. Indeed, from October to February, the total heat gain decreased from $1095.6 \pm 158.7 - 760.4 \pm 42.0 \text{ kJ/m}^2$ for the green roof with *Plectranthus*. For *Kalanchoe* green roof, the total heat gain reduced from $858.0 \pm 90.4 - 657.3 \pm 58.8 \text{ kJ/m}^2$. With *Sedum* green roof, the total heat gain also significantly decreased from $795.6 \pm 174.9 - 443.6 \pm 99.7 \text{ kJ/m}^2$. Such a decrease in the total heat gain value observed with the green roof can be explained by the growth of plants offering a higher coverage and a better roof membrane protection. Similarly, several literature data reported the ability of green roofs to reduce the proportion of solar radiation that reaches the roof structure as plants create a shadow effect on the soil layer [10,17,18]. Regarding the total heat loss, the experimental green roof was also able to efficiently reconstitute heat fluxes. Our data demonstrated that the green roof with *Sedum* led to a higher restitution of heat gain (63%) than the green roof with *Plectranthus* (54%) and *Kalanchoe* (51%).

III.3 Evaluation of the green roof thermal parameters

The addition of a green roof aims to improve the insulation properties of a building and thus to reduce annual energy consumption. In order to better characterize the energy performance of a newly developed green roof, it is required to determine three major thermal parameters, namely the conduction heat transfer coefficient (U-value), the thermal resistance value (R-value) and the thermal conductivity coefficient (k-value). Based on our previous results regarding temperature fluctuations and heat flux variations, we evaluated the thermal properties of the green roof. Table 2 reports the results obtained in February at the end of the experimental five-month period.

Table 2. Thermal properties of the green roof with a plant cover of 30% in February 2011

	U (W/M ² .K)	K (W/M.K)	R (M ² .K/W)
<i>Plectranthus</i>	5.46 ± 0.43	1.75 ± 0.05	0.19 ± 0.01
<i>Kalanchoe</i>	3.39 ± 0.59	1.25 ± 0.07	0.32 ± 0.06
<i>Sedum</i>	2.15 ± 0.22	0.47 ± 0.03	0.47 ± 0.05

It appears that the green roof with *Sedum* presents a U-value of $2.15 \pm 0.22 \text{ W/m}^2.\text{K}$ which is significantly lower than that measured with *Plectranthus* and *Kalanchoe* species. Consequently, we can also observe that *Sedum* shows the highest thermal resistance value as R-value is inversely proportional to U-value. To determine the thermal conductivity coefficient (k-value), it was essential to measure the total depth of the green roof (soil + plants) as k-value calculation depends on this depth value. Considering that the depth of

the substrate and drainage layers was 120 mm, the green roof presented a total depth of 320 mm for *Plectranthus*, 370 mm for *Kalanchoe* and 220 mm for *Sedum* in February. As shown on Table 2, k-values of the green roof differed according to the plant species with *Sedum* k-value which was 3 to 4-fold lower than that of *Kalanchoe* and *Plectranthus*. This coincides with the previous results and strengthens the view that *Sedum* presents the greatest energy performance as compared to *Plectranthus* and *Kalanchoe*. In order to clarify the thermal and energetic behavior of *Sedum* green roof, it will be of interest to carry out future studies investigating the main factors affecting the green roof performance. According to Alcazar and Bass [19], a green roof performance is more affected by the shading from solar radiation, evapotranspiration and plant physiological processes such as photosynthesis than by the increase in thermal resistance.

IV. Conclusion

This study aimed to evaluate for the first time the thermal and energy performance of an extensive green roof in an Indian Ocean area under a tropical humid climate. Our results showed that the green roof induced a significant decrease in temperature fluctuations between the green roof surface and the green roof at the depth of 120 mm ($6.7 \pm 0.1^\circ\text{C}$). Each plant also contributed to a low heat flux exchange through the green roof. *Sedum* presented an average heat flux exchange of $1.4 \pm 0.3\%$ as compared to *Plectranthus* ($2.3 \pm 0.2\%$) and *Kalanchoe* ($2.2 \pm 0.4\%$). As the energy performance of a green roof mainly depends on its ability to reduce the heat gain, we compared the values of heat gain/loss per meter square over all the five months of experimentation. It was found that *Sedum* green roof led to a higher heat restitution rate with 63%, than for *Plectranthus* (54%) and *Kalanchoe* (51%). Regarding the thermal parameters, the green roof with *Sedum* presented a U-value significantly lower than with *Plectranthus* and *Kalanchoe* species. Consequently, *Sedum* green roof was also characterized by the highest thermal resistance value. Finally, k-value of *Sedum* green roof was much lower than that for *Kalanchoe* and *Plectranthus*. To conclude, this study has evaluated for the first time the thermal and energetic performance of a green roof in an Indian Ocean area. Our results contribute to highlight *Sedum* benefits for a vegetated roof in such an area. Further investigations will be needed to assess if the green roof technology provides a very effective solution for building energy savings in cities under a tropical humid climate.

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