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# Energy and Hydraulic Performance of a Vegetated Roof in Sub-Mediterranean Climate

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**Abstract:** Widespread overbuilding, the prevalence of asphalt surfaces on green areas, and the use of building materials with low heat dissipation abilities are among the main causes of Urban Heat Islands. Within urban areas, evapotranspiration and shade from plants can significantly reduce the UHI phenomenon, help in stormwater management, and reduce building energy consumption. The goal of this work is to analyze the hydraulics and energy performances of an experimental extensive green roof at the University of Calabria (Italy) in Mediterranean area. This study confirmed that green roofs significantly mitigate storm water runoff generation in terms of runoff volume reduction and peak attenuation, and improve the thermal performance of buildings and the internal comfort of indoor spaces.

**Keywords:** green roof; energy-hydraulic performance; rainwater management

## 1. Introduction

Green roofs have been widely investigated in many cities around the world as a tool to solve many problems in urban environments. They can reduce the energy demands of air-conditioned spaces, and hence greenhouse gas emissions, through direct shading of the roof, evapotranspiration, and improved insulation values [1–4]. If widely adopted, green roofs could reduce the urban heat island [5,6] (an elevation of temperature relative to the surrounding rural or natural areas due to the high concentration of heat-absorbing dark surfaces such as rooftops and pavements) which would further lower energy consumption in urban areas. Moreover, based on the assumption that traditional approaches in urban stormwater drainage may be insufficient to manage water cycle changes associated with urbanization [7,8], green roofs, used as part of the storm water management strategy, represent sustainable solutions for mitigating runoff volumes and hydrograph peaks. Part of the rain is stored in the growing medium temporarily, to be subsequently taken up by the plants and returned to the atmosphere through evapotranspiration [9].

Integrated water and energy management in the urban context is one major route towards environmental sustainability and the reduction of carbon dioxide emissions. These objectives are also linked to the life cycle of infrastructures for the integrated management of these resources [10,11]. The understanding of mass (water) and energy fluxes between the building envelope and the surrounding environment is indeed a topical issue whenever sustainability and comfortable living conditions are addressed for urban areas [12].

From a hydraulic point of view, green roofs delay runoff into the sewage system, thus helping to reduce the frequency of combined sewage overflow (CSO) events, which is a significant environmental problem for many major cities in Europe [13]. Given the beneficial effects that green roofs produce on storm water retention, in the last years, several studies have been carried out. Some of them focus on the effects of the hydrological and physical parameters on green roof hydraulic efficiency; a review of those studies can be found in Garofalo et al. [14]. A study carried out in Portland has proven how ecoroofs can be considered an effective means for urban storm water management [15]. While Moran et al. [16], by monitoring two different green roofs in North Carolina, analyzed green roof performance on water quality improvement and runoff reduction. Carter and Rasmussen [17] have shown how green roof precipitation retention decreases with precipitation depth. In New York City, Carson et al. [18] analyzed three full-scale green roofs, obtaining retention values of 36%, 47%, and 61% respectively, and developed a characteristic runoff equation (CRE) for each green roof. Another study was focused on the evaluation of the survival, cover, roof cooling, and stormwater retention proprieties of 15 native species in coastal regions of Atlantic Canada in extensive green roof monoculture [19]. DeNardo et al. [20] and Spolek [21] have analyzed the effects of green roofs both on stormwater mitigation and thermal benefits.

The plants and the growing medium can also remove airborne pollutants picked up by the rain, thus improving the quality of the runoff. In addition, green roofs can improve air quality, provide additional green space in urban areas, and increase property value [4].

Vegetated roofs on the bare roofs of buildings can offer a good thermal protection that reduces the high thermal load from which the construction suffers during the summer period [22]. This is an acceptable ecological solution, which contributes not only to the reduction of the thermal loads of the building's shell, but also to the improvement of densely-built urban centers with little natural environment. Plants have an effect on the climate; foliage protects buildings from solar radiation and controls the temperature and humidity of the indoor environment. In closed spaces with planted roofs, the air temperature beneath the plants is lower than that of the air above. The difference between a vegetated roof and bare roof of a single building is both qualitative and quantitative [23]. The process of heat transfer into the planted roof is very different. Solar radiation, external temperature, and relative humidity are reduced as they pass through the foliage that covers the roof. Plants, owing to their biological functions like photosynthesis, respiration, transpiration, and evaporation, absorb a portion of solar radiation. The remaining solar radiation influences the internal climate as it passes through the building elements of the roof.

In general, researchers suggest that green roofs contribute to reducing temperature fluctuations on external and internal surfaces [24], lowering energy consumption for the maintenance of indoor comfort conditions [25]. Furthermore, vegetated roofs increase the thermal inertia of the building envelope, generating a time delay and attenuation of the external solicitation on the roof surface [26]. From the point of view of storm water management, a green roof system is able to significantly reduce storm water runoff generation in terms of volume, peak attenuation, and increase of concentration time [27].

This study presents an analysis of the energy and hydraulic performance of an experimental green roof in Cosenza, a Southern Italian city with a temperate climate. As part of the Research Project PON "Integrated and Sustainable Management Services for the Water-Energy Cycle in Urban Drainage Systems", a real scale model of a green roof was installed at the University of Calabria in order to evaluate the influence of green roofs on rainwater management and energy consumption for air conditioning in the Mediterranean area. The roof sections were instrumented to monitor temperature profiles within the roofing systems, solar radiation, relative humidity, soil moisture content, and storm water runoff. This set-up allows direct comparison of the performance and benefits of the green roof and the conventional roof.

The measurements for evaluating the energy performance of the green roof were conducted for each sector on a seasonal basis in order to assess the thermal behavior of the extensive green roof throughout a whole year.

The hydraulic performances were evaluated during the monitoring campaign in September–October 2015.

## 2. Methodology

### 2.1. Experimental Site

To fulfill the aims of the research project “Integrated and Sustainable Management Services for the Water-Energy Cycle in Urban Drainage Systems”, a scale model of the green roof was installed at the University of Calabria. A typical green roof stratigraphy has different layers of construction. A protection layer directly above the structural roof construction serves to protect the roof from moisture. This layer includes some combination of waterproof membranes and root barriers. A drainage layer that may include small moisture-retention reservoirs and voids resides directly above the protection layer to allow excess moisture to flow out of the green roof, either into waterspout or to some form of storage, and provide aeration to the vegetation roots. The growing medium (soil) layer resides above the drainage layer, which is usually separated by a geotextile filter layer. This medium layer is typically a light-weight combination of sand, aggregate, and organic matter. Finally, vegetation, chosen in accordance to the climate of the location, completes the installation.

In order to facilitate the comparison of different design solutions, the experimental site was organized into four sectors (Figure 1). Sectors 1 and 2 were vegetated with the same native Mediterranean species, but with different materials used in the stratigraphy. Sectors 1 and 3 had the same stratigraphy, but sector 3 was not initially vegetated. Sector 4 was left as a conventional roof, equipped with the classic dark waterproof membrane; for this reason, it was considered as the reference roof. The four sectors have a slope of 1% for correct water management, and are hydraulically independent.



**Figure 1.** Experimental green roof [28] at the Urban Hydraulics and Hydrology Lab at the University of Calabria, Italy.

The vegetation species used in the green roof are *Carpobrotus edulis*, *Dianthus gratianopolitanus*, and *Cerastium tomentosum*. These species were chosen for their particular features: high drought tolerance, low nutritional requirements, good ground coverage, rapid multiplication, short roots, and low maintenance. For their high drought tolerance, the water supply of sectors 1 and 2 is guaranteed by reusing the green roof’s outflow, collected in a specific storage tank and distributed through a drip irrigation system during drought periods.

This study was carried out in two main phases.

The first phase was focused on the analysis of the thermal performance of the vegetated roof in Mediterranean climate by comparing experimental data from three sectors.

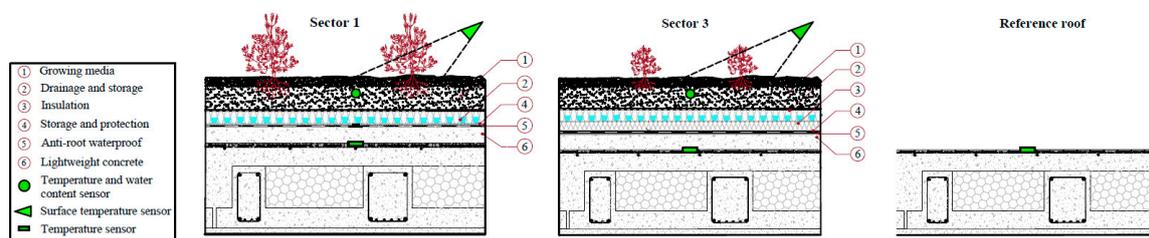
Finally, in order to evaluate the performance of the green roof in terms of storm water mitigation, the real runoff data from sector 1 were collected and compared with the real outflow from the reference roof. Thus, the hydraulic efficiency was analyzed by evaluating two hydrological indexes (Retained Volume and Peak Flow Attenuation).

## 2.2. Equipment and Measurement Period

The monitoring system of the experimental site was equipped with a data acquisition system which acquires sensors output at the experimental site every minute, and records the measured data in a computer.

Meteorological data are monitored by a weather station installed on the roof of the same building of the experimental set-up. This provides data of ambient air temperature, relative humidity, precipitations, atmospheric pressure, and wind direction and speed. The temperature sensor with a solar shield has an operative range from  $-40\text{ }^{\circ}\text{C}$  to  $+80\text{ }^{\circ}\text{C}$ , with an accuracy of  $0.4\text{ }^{\circ}\text{C}$ . The relative humidity sensor works in the range of 0–100%, with an accuracy of 3%. The wind speed sensor has an operative range from 1.5 m/s to 79 m/s, and an accuracy of 5%. The rain gauge sensor has a resolution of 0.2 mm. For the measurement of total horizontal solar radiation, a secondary standard EPLAB pyranometer is used.

In each plot, four probes simultaneously measure the temperature and volumetric water content (WC) in the substrate. The values presented in the following sections are obtained as the average of the four measures. Along the vertical profile, two resistance temperature detectors (RTD) were installed at the interface between the lightweight concrete and the root-barrier waterproof layer, and between the traditional roof surface and the lightweight concrete. A further RTD was placed on the top of the insulation layer in sector 3 (Figure 2). The soil probe has an accuracy of  $\pm 2\%$  for the measurement of soil moisture in an operative range from 0% to saturation, and an accuracy of  $\pm 1\%$  for measurements of temperature, with an output from  $-50\text{ }^{\circ}\text{C}$  to  $+50\text{ }^{\circ}\text{C}$ . The RTD sensors are four PT100 class1/3 wires with an accuracy of  $\pm 0.1\text{ }^{\circ}\text{C}$  at  $0\text{ }^{\circ}\text{C}$  and  $\pm 0.27\text{ }^{\circ}\text{C}$  at  $100\text{ }^{\circ}\text{C}$ . The green roof is equipped with a drip irrigation system managed by modules that operate activation and shut-down according to the values provided by adequate water presence sensors installed in the drainage layers. Irrigation is provided during hot months in summer to prevent water stress on the plants.



**Figure 2.** Sector 1 (left), Sector 3 (center) and Reference roof (right) sections with sensors location [23].

In addition, to analyze the hydraulic performance of one specific sector for two continuous months (September 2015 and October 2015), rainfall data was collected every minute by a tipping bucket rain gauge of 0.254 mm resolution, located on the experimental site. Specifically, for hydraulic parameters, the outflow rates from the conventional roof and from the green roof were recorded by flowmeters installed at the outlet of each compartment. The water level in each device was measured by a pressure transducer (Ge Druck PTX1830), and continuously recorded in a SQLITE database system with a resolution of 1 min. To describe the green roof hydraulic performance, two synthetic indexes—were evaluated. The first is the *Retained Volume (RV)*—calculated as the percentage difference between the total volume of rain and the total discharged volume—while the second is the *Peak Flow Reduction (PFR)*—evaluated as the percentage difference between conventional peak flow and the green roof peak flow.

A first analysis was conducted to evaluate the seasonal thermal behaviour of the two different layering solutions installed in the extensive green roof, and to compare the results with those of the traditional reference roof. For this purpose, in each season, two periods were selected according to the climatic conditions, chosen to be representative of the average seasonal conditions, considering one sunny week and one week with the presence of precipitations. In summer, only one sunny period was

selected because the analysis of thermal response can be extended to the whole period, considering the scarcity of rainfall that occurred in summer 2015. Data employed for this analysis were collected in year 2014 and 2015. A summary of selected days is reported in Table 1.

**Table 1.** Periods of analysis.

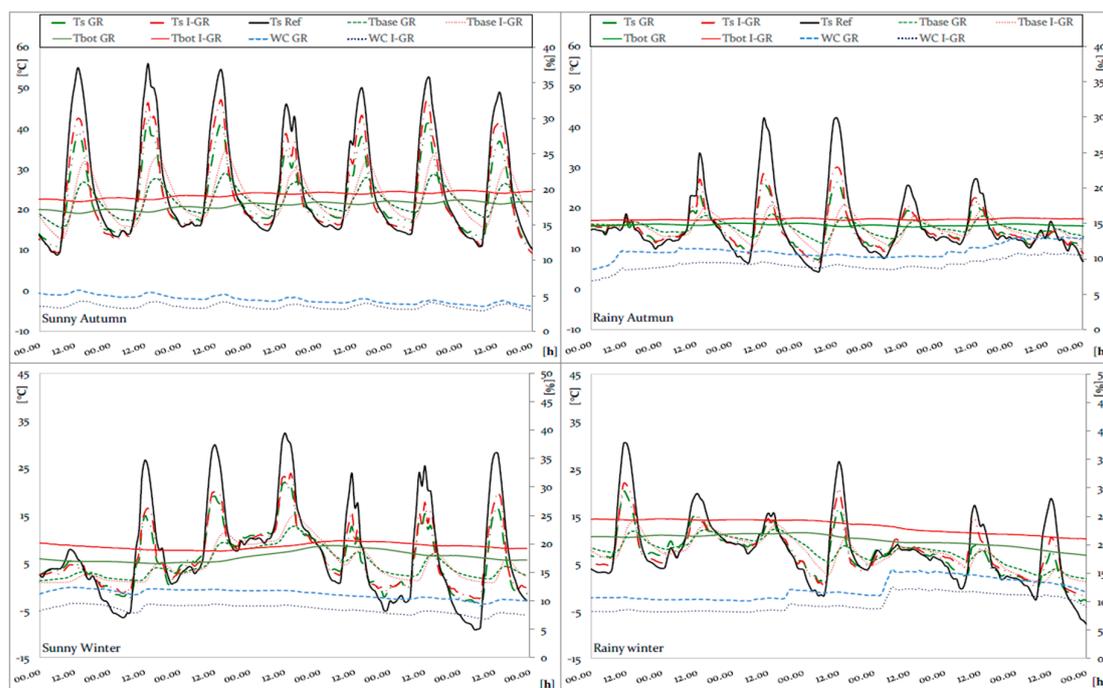
Dates	Condition	Season
13 October 2014–19 October 2014	Sunny	Autumn
7 November 2014–13 November 2014	Rainy	Autumn
1 January 2015–7 January 2015	Sunny	Winter
24 December 2014–30 December 2014	Rainy	Winter
11 April 2015–17 April 2015	Sunny	Spring
2 April 2015–8 April 2015	Rainy	Spring
16 July 2015–23 July 2015	Sunny	Summer

The variables considered in the following evaluations are:

- The green plots surface temperature;
- The substrate temperature;
- The temperature at the bottom of the of the green layering;
- The water content of the substrate;
- The surface temperature of the traditional reference roof.

### 3. Results and Discussion

In Figures 2 and 3 the trends of the monitored variables for the selected seasonal periods are reported. In particular, the figures report the trends of the plots' surface temperature, substrate temperature, temperature at the bottom of the green layering, water content of the growing medium, and the surface temperature of the reference roof. Since the thermal response of sectors 1 and 2 appeared to be very similar, the results are reported only for sectors 1 and 3, referred to in the following as "green roof GR" and "insulated green roof I-GR".



**Figure 3.** Green plots water content and surface, substrate base, and bottom temperatures, together with reference roof surface temperature in the sunny and rainy autumn and winter periods.

### 3.1. Autumn Thermal Analysis

In the sunny autumn week, the reference roof reached daily maximum temperatures greater than the green sectors, whereas the daily minimum values attained were very close to an almost-coincident nocturnal pattern. In the hours around noon, a rather significant difference is appreciated between surface temperatures of the green plots: the non-insulated green roof (sector 1) reached a maximum value of 42.4 °C, compared to 47.0 °C of the insulated one (sector 3). The minimum daily values were, conversely, very similar, resulting in a maximum daily surface temperature excursion for the non-insulated plot of 28.3 °C, and of 33.8 °C for the insulated plot. The lower presence of vegetation, the effect of the insulation layer that contained the heat flux towards the indoor environment, and the slight inferior water content of the substrate result in an increased surface temperature in this last plot. The reference roof showed considerably higher daily excursions, with a maximum of 46.2 °C, to be attributed to the superior temperature registered during the day in this plot, since the night values were instead very similar to those of the green plots. In sunny days, the effect of solar radiation is consistently greater because of the lower albedo of the dark bituminous membrane with a rapid and considerable temperature rise. The difference in surface temperature is also reflected in the values measured at the bottom of the substrate layer. In both green plots, a marked attenuation of the daily excursion is visible, and even though the thickness of the growing medium is much reduced, a time shift of the peaks is already appreciable. Moving down the layers, an almost steady trend of temperature was found at the interface with the structural roof. Here the overall effect of the overlying green roof is summarized in an average temperature of 21.0 °C in GR plot, and of 23.6 °C in I-GR plot. Evidently, the presence of the insulation layer in this plot led to a higher temperature level at the base of the green roof. For comparison, the average surface temperature of the reference roof in the week was 26.0 °C.

In the selected rainy period, two conspicuous rain events occurred, during which the trends of surface temperature of the green plots and of the reference roof tended to overlap almost completely. In these days, consequently, the temperature measured at the substrate base also showed almost identical values in the insulated and non-insulated green plots. As soon as solar radiation appeared on clear days, the surface temperatures tended to swiftly rise, reaching a maximum of 26.5 °C in GR plot, 30.1 °C in I-GR, and 42.4 °C in the reference roof. Again, the minimum daily values attained during nighttime were close for all the plots, but in this period, the increased water content of the growing medium allowed for moderate surface temperature in both plots and lower peak temperatures. Compared to the sunny week, the higher level of water in the substrate had the overall effect of strongly attenuating the daily temperature excursion that, in this period, reached a maximum of 19.1 °C in GR and 23.6 °C in I-GR. Again, at the base of the green roof layers, it is possible to appreciate an almost steady trend of temperature with mean values of 15.9 °C in the non-insulated plot and 17.3 in the insulated one. The average temperature of the reference roof was 15.6 °C.

### 3.2. Winter Thermal Analysis

Regarding the winter behaviour of the green roof, the extremely variable climatic conditions in the investigated years, along with the occurrence of several precipitation events during the winter months, made it difficult to make a marked distinction between sunny and rainy weeks. However, it was possible to select one serene period with the presence of a considerable amount of solar radiation during different days, while in the rainy selected period, abundant rainfall events occurred for a total precipitation of 60 mm (Figure 2). Because of the elevated water content in the substrate of both green roof plots, no significant difference in the daily maximum surface temperatures was detected. The slight higher values of I-GR that are appreciable from the graph were mainly due to the lower water content of this plot compared to the non-insulated one. Furthermore, the reduced solar radiation in winter period did not produce a sharp increase in surface temperature, helping to limit the difference between the two plots. The effect of the insulation layer was instead more visible at the base of the substrate, where I-GR reached a higher peak than GR almost every day, with a maximum difference in

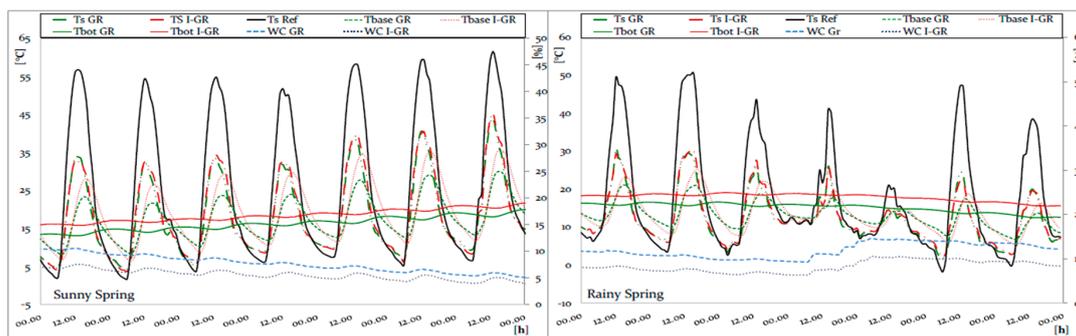
the week of 2.4 °C. At the bottom of the stratigraphy, the trend was again very stable around the mean value of 6.4 °C for the non-insulated green roof, and around the value of 8.5 °C for the insulated one. Considering the trend of the surface temperature of the traditional reference roof, it can be seen from the figure that this plot reached considerably higher daily peaks and lower night values compared to the green roof. The night temperature even dropped below zero in some of the selected days, especially in clear sky conditions, because the infrared thermal exchange with the sky intensively cooled the roof surface, causing a dramatic drop at night. The maximum and minimum temperatures were, respectively, 32.4 °C and −9.0 °C, around a mean weekly value of 7.2 °C.

In the rainy winter week, the precipitation events determined a rapid increase of the substrate water content that, however, did not result in significant surface temperature difference compared to the sunny week. In this sense, the limited evapotranspiration effect, because of the low level of solar radiation, low air temperature, and conspicuous level of relative humidity, did not produce considerably lower trends and daily excursions of the surface and substrate temperatures in insulated and non-insulated plots. However, the excursions of the reference roof were instead significantly reduced because of the limited climatic solicitations. It is interesting to note that the daily minimum temperatures attained by the green plots and the reference roof were markedly superior to those of the sunny week. This can be explained by considering that the greater sky covers consistently limited the night infrared cooling of the surfaces, and consequently the drops in temperature. It is interesting to note how, in cloudy and rainy winter conditions, the green plots were able to maintain considerably higher temperature levels at the base of the layering where a mean temperature of 10.8 °C was registered in GR and a mean of 13.0 °C in I-GR. In the reference, roof, in contrast, a weekly mean temperature of 6.5 °C was observed.

### 3.3. Spring Thermal Analysis

As expected, the overall thermal behavior of the selected spring weeks was quite similar to that of the autumn weeks. In this season, the maximum daily values of the green plots surface temperatures, conversely to those of autumn, were very close. This can be explained by the growth of colonizing species that germinate strongly in spring and early summer, modifying the surface thermal balance of the insulated plot that becomes similar to that of the non-insulated one. The reference roof again showed substantial higher peak temperatures, with a maximum of 61.5 °C registered during the last day of the period, and high daily excursions, with a maximum of 55 °C in the same day. The night surface temperature values were similar for the green plots, where minimum values reached 4.3 °C and 3.7 °C, whereas in the reference roof, a value of 1.7 °C was reached. Again, the effect of the insulation in I-GR is clearly appreciable at the base of substrate, where a marked difference in the daily maximum values is observed with a peak of 35.6 °C in I-GR in comparison with 30.0 °C of GR. The insulated plot was consequently able to provide a slightly higher temperature at the bottom of the green roof, with a mean value of 18.3 °C compared to the value of 16.2 °C in the non-insulated one (Figure 4).

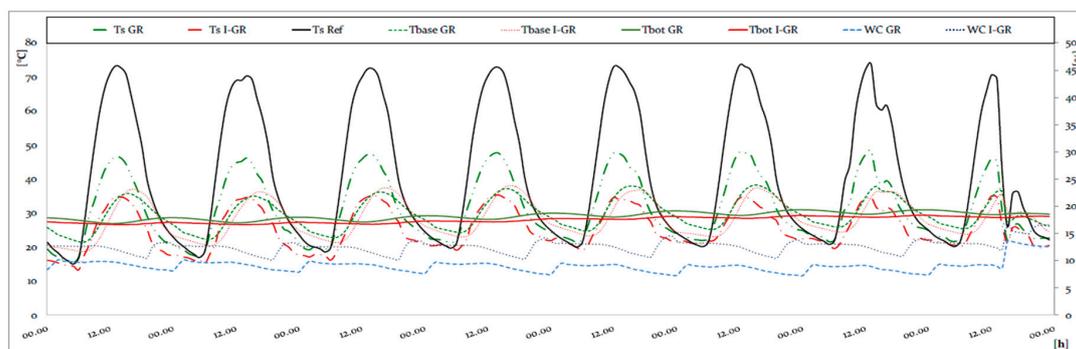
Also in the rainy week, the behavior was similar to the autumn week. When precipitation events occurred, the surface temperatures of the green plots and of the reference roof tended to assume similar values, while at the appearance of solar radiation, the reference roof temperature quickly rose to greater values, reaching a weekly maximum of 50.7 °C. In the green plots, the surface temperature trends were very close, with reduced daily fluctuations that did not exceed 24.3 °C. The base substrate temperature, similar to those of the other seasons, assumed lower peak values in the GR plot, whereas the daily minima were higher than I-GR, with overall lower daily excursions in the non-insulated plot that exhibited a maximum excursion of 11.0 °C compare to 17.0 °C of the insulated one. In the analyzed period, it is possible to appreciate that in the GR plot, the water level was always greater, reaching 14.6%, and being on average 3.6 percentage points higher than I-GR, thereby contributing to lowering the growing medium temperature. The bottom green roof temperature was again higher for the insulated plot, with a weekly mean of 17.9 °C compared to 15.2 °C of the non-insulated one (Figure 4).



**Figure 4.** Green plot water content and surface, substrate base, and bottom temperatures, together with reference roof surface temperature in the sunny and rainy spring periods.

### 3.4. Summer Thermal Analysis

Summer thermal behaviour needs to be discussed separately since the activation of the irrigation system strongly influenced the results in terms of temperature. Figure 3 clearly shows the typical asymmetrical bell-shaped trend of the reference roof and the conspicuously superior temperature value attained by it during the day, with peaks slightly higher than 70 °C. The minimum values were instead close to those of the green plots. In fact, the night cooling of the bituminous membrane was limited compared to the spring season, and did not reach the same minimum temperatures registered in the sunny spring period. In I-GR and GR, although the shape of the surface temperature pattern was quite similar, a substantial difference can be appreciated in the temperatures reached. In this period, in contrast to the others which were analysed, the non-insulated plot showed surface greater temperatures than the insulated one. The daily surface peaks of GR were never lower than 46.0 °C, whereas in I-GR, they were, at most, 35.3 °C. The minimum daily values were instead very close, even though the insulated plot could reach slightly lower values. In fact, to prevent plant stress due to water scarcity, in the critical summer period, the irrigation system is activated, providing water to the plots for one hour from 01:00 to 02:00 in GR, and for two hours from 20:00 to 22:00 in I-GR. For the last plot, in July 2015, the planting of lawn occurred, and consequently, in order to assist the growth of the vegetation, abundant irrigation was provided, resulting in a significant major level of water entering the substrate. As visible in Figure 5, average water content values of 9.0% in GR and 12.6% in I-GR were found. As a result, the excursion of surface temperatures was much more limited in the insulated plot, with an average weekly value of 17.7 °C compared to 28.1 °C of the non-insulated plot. For comparison, the average daily excursion of the traditional roof was 54.5 °C. At the base of the substrate, however, the difference between the two plots' trends is not strongly marked. Thanks to the additional water in the substrate, the insulated plot could generate slight lower temperatures, especially far from midday. However, daily peaks remained quite comparable, with a maximum of 38.0 °C in I-GR and a value of 38.2 °C in GR.



**Figure 5.** Green plots water content and surface, substrate base, and bottom temperatures, together with reference roof surface temperatures in the summer periods.

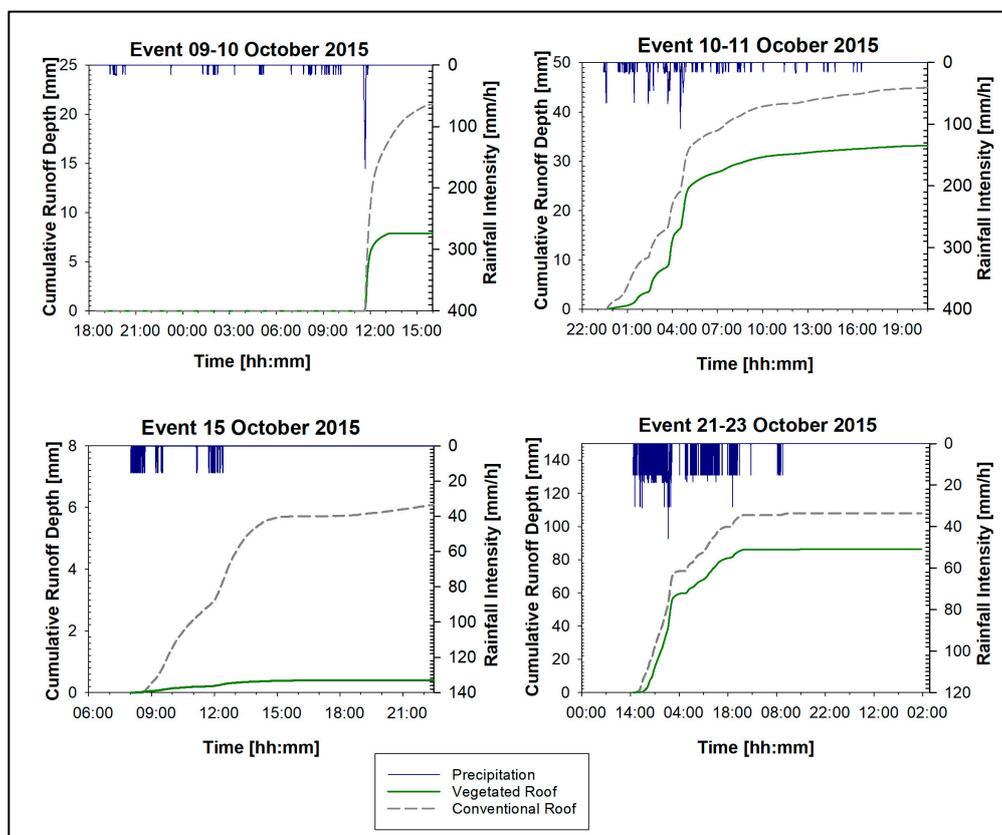
Finally, at the bottom of the green roof, temperature showed an almost steady trend in both plots, with average values of 29.2 °C in GR and 28.0 °C in I-GR. This result highlights how a proper watering strategy can be an effective means for temperature regulation in green roofs, enhancing the properties of the insulation into the stratigraphy. As demonstrated by the winter behaviour analysis, the presence of a thermal insulation layer yielded considerably higher temperature levels at the base of the green roof stratigraphy, resulting in consistent smaller heat fluxes toward the outdoor environment, and lowering the energy lost through the building roof cover. In summer, if irrigation is not provided adequately, the surface temperature of the insulated plot can easily reach huge values, consequently generating heat fluxes which are much more dramatic than those of the non-insulated plot [3].

### 3.5. Hydraulic Results

This study considers part of the monitoring campaign carried out at the experimental site of the University of Calabria, and is still in progress. It can be divided into two phases; the first concerns data collected from the whole Conventional Roof (outflows from the sector 4); the second studies the whole new Vegetated Roof system (outflows from the sector 1). The impervious system (conventional roof) serves as a reference for comparisons with the green roof's hydraulic performances.

Individual events were also defined as being separated by continuous dry periods of at least 6 h [29] and Rain Depth greater than 2 mm [30].

The selected rainfall data included seven events collected in the phase of the monitoring campaign for September and October 2015. The Cumulative Runoff Depth for the Vegetated Roof and for the Conventional one, and the corresponding hyetograph for four rainfall events with different Rain Depth, are illustrated in Figure 6.



**Figure 6.** Comparison of Cumulative Runoff Depth for the Vegetated Roof and for the Conventional one for four rainfall events: Rainfall Event 9 October 2015 (Rain Depth = 24.1 mm); Rainfall Event 10–11 October 2015 (Rain Depth = 48.3 mm); Rainfall Event 15 October 2015 (Rain Depth = 6.4 mm); Rainfall Event 21–23 October 2015 (Rain Depth = 120.1 mm).

Table 2 shows the hydraulic performance of the green roof in terms of Retained Volume (RV) and Peak Flow Reduction (PFR) at the event scale.

**Table 2.** Events observed at the green roof of the University of Calabria.

Event	Rain Depth [mm]	RV [%]	PFR [%]
9–10 September 2015	99.8	15	25
21–23 September 2015	2.8	100	100
7 October 2015	42.2	52.5	65.4
9 October 2015	24.1	55.5	17.9
10–11 October 2015	48.3	35.7	13.3
15 October 2015	6.4	93.9	92
21–23 October 2015	120.1	16.8	28.3
29–31 October 2015	63.3	26.6	52.6
Mean	-	57.5	72.3
Dev. Std.	-	35	43.4

By analysing the results shown in Figure 6, in which the Cumulative Runoff Depth from the Vegetative Roof is compared with the Conventional one, the ability of this specific extensive green roof to attenuate the stormwater runoff volume with respect to the impervious roof is evident.

Furthermore, the findings listed in Table 2 at the event scale show a high variability of the two performance indexes evaluated at the event scale. More in detail, the retained volume, ranging between 15% and 100%, and the peak flow reduction, ranging from 25% to 100%, denote, in agreement with other studies [14,29,31], that the weather conditions prior a rainfall event and the hydrological features of the rainfall events itself significantly affect the hydraulic response of a green roof.

On the other hand, by considering the results obtained in terms of mean values (Table 2), it emerges that the performance of this specific green roof as a device for storm water control in the Mediterranean area appears good. The mean retained volume value of 57.5% is, in fact, really close to that obtained by Palla et al. [32] for a green roof installed at the University of Genoa, another city in Mediterranean climate conditions. Garofalo et al. [14] have evaluated, from the analyses on different studies under various climate conditions and locations, a subsurface coefficient mean value ranging from 0.32 to 0.89. By considering that the subsurface runoff coefficient is the complementary index of the retained volume index, the mean value here obtained falls perfectly within this range of variation. Thus, by comparing these results with others studies, this specific green roof is able to reduce storm water runoff generation in the Mediterranean region.

On the basis of these findings, an extension of these to the spatial scale is needed. In this way, it would be possible to assess the role of green roof installations in preventing flooding phenomena in the urban areas and in limiting the impact of storm water on waste water treatment plants.

#### 4. Conclusions

Observations from the green roof installed at the University of Calabria allowed us to discuss the energy and water related performance of vegetated roofs within the specific climatic context of the Mediterranean region.

The dataset obtained during this study is useful to contribute to a deeper understanding of mass (water) and energy fluxes between the building envelope and the surrounding environment.

This is expected to support sustainable construction in urban areas, where the intrinsic interaction between energy and water plays a major role in the strategies towards sustainability and improved quality of life in cities.

The monitored performance was shown to be very promising in the Mediterranean context, where the characteristics of precipitation and the general climatic conditions are less favorable to the growth of vegetation on top of buildings. This applies to the attenuation of solar radiation through the vegetation layer, as well as to the thermal insulation performance of the green roof structure. The thermal

analysis was developed over one year in the four seasons in order to assess the performance of the green roof under the different climatic conditions of a typical Mediterranean locality. The results demonstrated how in winter in sunny conditions, the performance of the reference roof yielded slightly better results than the non-insulated green plot, but was always lower than the insulated green roof. In cloudy conditions, because the absence of solar radiation led to lower levels for the reference roof, this showed the worst performance of all the analyzed roof solutions.

In summer, thanks to the abundant irrigation provided to the insulated green plot, the excursions of surface temperature were much more limited, with an average weekly value of 17.7 °C compared to 28.1 °C of the non-insulated plot, and a value of 54.5 °C of for the traditional roof.

In intermediate seasons, the overall thermal behavior of the green plots was quite similar. In cloudy autumn conditions, at the base of the green roof layers, average weekly temperatures of 15.9 °C in the non-insulated plot and 17.3 in the insulated one were observed, with the reference roof at 15.6 °C. In sunny conditions, the average base temperature resulted respectively in 21.0 °C in the GR plot, 23.6 °C in the I-GR plot, and 26.0 °C in the reference roof. In sunny spring conditions, the insulated plot was able to provide a slight higher temperature at the bottom of the green roof, with a mean value of 18.3 °C compared to the 16.2 °C of the non-insulated one. In cloudy conditions, the bottom green roof temperature was higher for the insulated plot, with a weekly mean of 17.9 °C compared to 15.2 °C of the non-insulated one.

In addition, it was confirmed that green roofs significantly mitigate storm water runoff generation, even in a Mediterranean climate in terms of runoff volume reduction and peak attenuation. Results show a mean value of the Retained Volume for the two months considered of 57.5%. This finding confirms the good performance of the specific experimental green roof, and it is in agreement with other studies carried out in Mediterranean area. On the other hand, by observing the high variability of the same index evaluated at the event scale, it is possible to conclude that the weather conditions prior a rainfall event and the hydrological features of the storm water event itself significantly affect the hydraulic response of a green roof.

Green roofs are a solution to increase the energy and hydraulic performance and the sustainability of the building.

This study confirms that green roofs contribute to reducing thermal fluctuation on the external and internal surfaces, thereby lowering the energy consumption for the maintenance of indoor comfort conditions. From the point of view of storm water management, a green roof system is able to significantly reduce storm water runoff generation in terms of runoff volume reduction and peak attenuation.

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