

Article

The Role of the Extensive Green Roofs on Decreasing Building Energy Consumption in the Mediterranean Climate

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Abstract: Buildings portion in global energy consumption is 40%, and in the building envelope, the roof is a crucial point for improving indoor temperature, especially in the last and second last floors. Studies show that green roofs can be applied to moderate roof temperature and affect the indoor temperature in summer and winter. However, the performance of green roofs depends on several parameters such as climate, irrigation, layer materials, and thickness. In this context, the present research deals with a comprehensive experimental analysis of different thermal impacts of green roofs in summer and winter in a Mediterranean climate. Measurements carried out in one year in three different types of green roofs with different thicknesses, layers, and with and without the insulation layer. The analysis determined the possible period that indoor cooling or heating might be required with and without green roofs and demonstrated the positive impact of green roofs in moderating the roof temperature and temperature fluctuations, which in summer was remarkable. In conclusion, since in the Mediterranean climate, the thermal differences between green roofs and conventional roofs in summer are much higher than winter, it seems that the green roof without an insulation layer would show better performance.

Keywords: green roof; sustainability; heat flux; building energy consumption; roof temperature

1. Introduction

Buildings are responsible for about 40% of global energy consumption [1,2]. The green roofs known as a natural cooling system have a high potential in reducing energy consumption and mitigating the heat island effect through different mechanisms such as a decrease in solar radiation since a significant portion is absorbed for the biological functions of the plants, decreasing roof temperature, and decreasing surface temperature fluctuations [3]. The studies show the critical impact of water content on the cooling performance of green roofs. However, during the summer in a dry climate, water demands cannot rely on precipitation, and in some cases, irrigation might be required [4]. The impact of green roofs is not only for cooling in summer but also for heating performance in winter. In winter, the use of precipitation by the system can also be useful in urban runoff or flood management [5–9].

Green roofs are classified into two major categories, including extensive (soil layer less than 200 mm) with minimal maintenance and intensive (soil layer more than 200 mm) and with longer root

length plants [7]. The studies showed the significant impact of green roofs in moderating temperature fluctuations, mainly during the warmest hours of the day [10]. The roof surface temperature can decrease significantly by green roofs in summer. The analysis of an extensive green roof in a tropical and humid climate proved a notable decrease in roof temperature. The maximum temperature of the bituminous roof reached 73.5 ± 1.4 °C, while the maximum average temperature in the green roof reached 34.8 ± 0.6 °C, [11]. Green roofs can also decrease the thermal load of the buildings [12,13]. The analysis showed that green roofs could decrease the energy consumption for cooling purposes. The reduction of the load for the floor under the roof could be up to 58% and for the whole house between 15 and 39%. For heating purposes in the winter, the reduction of the load could be between 5% and 17% for the floor under the roof and whole house between 2% and 8% [14]. The results of another study showed that the green roof decreased the heat and cooling load by about 45% while the insulated roof 0–9% [3]. The evapotranspiration of the plants plays an essential role in energy reduction by green roofs. The analysis showed the significant impact of the water content and irrigation on the cooling performance of green roofs in summer. Moreover, the amount of energy reduction by latent heat can also be among 6% to 13% of the incident solar radiation [15]. The analysis of an irrigated, non-vegetated green roof with a depth of 80 mm showed daily temperature reduction of up to 8 °C in the summer by the evaporative cooling effect of the green roofs. The values for the non-irrigated scenario was about 4 °C [16]. The analysis showed that the green roof layers decrease the impact of sunshine and can be used as thermal insulation since it could absorb heat at the roof slab [17,18]. The studies showed that many factors are essential in the operation of green roofs in the Mediterranean climate, such as plant density [19], the height of the plants, soil thickness, insulation [20,21], and irrigation level [22].

The analysis showed that among all sections in the building envelope, the roof of a building is a key point for improving the indoor temperature since the surface temperature generally is the highest in that place, and the heat transfer of the roofs is maximum in the summer, [10]. The analysis showed that the role of green roofs on cooling load reduction was at a maximum (about 60%) for the last floor and the second last floor (about 58%), in results in the whole building about 2 to 39% of the total load depends on the number of floors, and less in high-rise buildings [14,23,24].

The insulation of the roofs can reduce heat transfer and improve the indoor temperature and therefore counted as a valuable strategy for building sustainably [25]. The analysis of thermal insulation in different types of green roofs show an energy reduction of about 20% in an extensive, 60 to 70% in a semi-intensive and 45 to 60% in an intensive [20]. The hypothesis of buildings with poor thermal insulation combined with green roofs in a humid-tropical climate showed that the roofs with poor thermal insulation but low substrate thickness, and low density planting could not achieve a high amount of indoor cooling. Therefore, the insulation, plant density, and thickness of the layers all are essential in optimizing the passive cooling by green roofs in a humid-tropical climate [26]. The use of cork insulation, natural material for insulation instead of polymeric insulation, shows that the natural material can be used for insulation of the green roofs besides improving the drainage performance of the green roofs [27–30]. Moreover, the analysis showed that the cork insulation could lose thermal capacity after wet, counting as an advantage in summer [31].

The elements that receive and transfer heat or cold in the building are the walls and roof and depend on the material used or insulation. Moreover, the roofs also expose to solar radiation and can absorb or reflect the thermal energy by long-wave radiation heat [32]. During summer, daily solar radiation is the highest, and there are negative heat fluxes through the roof, which means from the outside to inside. During winter, the heat fluxes through the roof are generally positive and upward, which means from inside to outside [33].

In the energy consumption of the buildings, one of the vital factors is thermal comfort that shows the occupants' satisfaction [34,35]. The suggested minimum indoor temperature to protect the health presented by the World Health Organization (WHO) for cold climates is 18 °C [36]. The suggested thermostat heating set point, according to the Energy Star recommended by the United States Environmental Protection Agency (EPA), is about 21 °C for heating in winter and 25.5 °C for

cooling in summer [37]. The ideal indoor temperature depends on several factors such as the climate, air temperature, relative humidity, seasons, mean radiant temperature, air velocity, type of cloths and activity level (metabolic rate), and the usual thermal comfort range from 18 to 25 °C [38–41].

The background study shows in summer, the direct solar radiation to the roof causes high roof temperatures and is one of the main causes of high indoor temperatures. In winter, low roof insulation can cause the loss of heat and decrease the indoor temperature. By changing heat transfer from the building's roof, the indoor temperature will change. The usual methods for this purpose are insulation, green roofs, and change in roof color. In this regard, the green roof as a natural system to decrease the thermal requirement of buildings has been analyzed in this research. In this context, since the green roof can be in different layers, thicknesses, with and without the insulation layer, the present research deals with a comprehensive experimental analysis of different impacts of green roofs in summer and winter in a Mediterranean climate. Measurements carried out in one year to determine the impact of three different types of green roofs on average roof temperature and indoor heating or cooling periods. In fact, the main difference of this study from the other similar documents is its consideration of temperature analysis in three different types and three layers of green roofs under the same climatic conditions. Moreover, it has attempted to investigate the monthly average differences between roof temperature in conventional roofs and green roofs and the impact of green roofs in maximum and minimum roof temperatures and temperature fluctuations. In addition, the advantages and disadvantages of using the insulation layer with green roofs in the Mediterranean climate have been investigated.

2. Materials and Methods

The method is based on the experimental data of 2016 and by comparison between temperatures of a conventional roof as a reference, three types of green roofs, and ideal temperature in summer and winter. The gathered data is per minute and from an extensive green roof. Furthermore, the impact of different thickness in green roof layers has been analyzed. The ideal indoor temperature for different seasons in the current study is according to Table 1.

Table 1. The Ideal Indoor Temperature for Winter and Summer [34–41].

Northern Hemisphere	Start	End	Ideal Indoor Temperature [T]
Spring	1 March	31 May	23
Summer	1 June	31 August	26
Autumn	1 September	30 November	23
Winter	1 December	28 February	20

2.1. Case Study

The experimental site situated in the south of Italy and on the roof of one of the buildings at the University of Calabria, Figure 1.

The green roof areas are different in order to cover completely the room volumes located beneath the floor. However, in this analysis, since the central thermal system for all the floor is the same, the comparison among different plots has been done. The type of green roof is extensive, with a soil layer equal to 80 mm covered with native Mediterranean plant species. The layers in three green roofs and the places where temperature sensors were considered are shown in Figures 2–4. In all three plots, lightweight concrete with a density of 400 kg/m³ and a thickness of 75 mm has been added to the conventional roof to create a 1% sloop on the roof for the rainfall collection system.

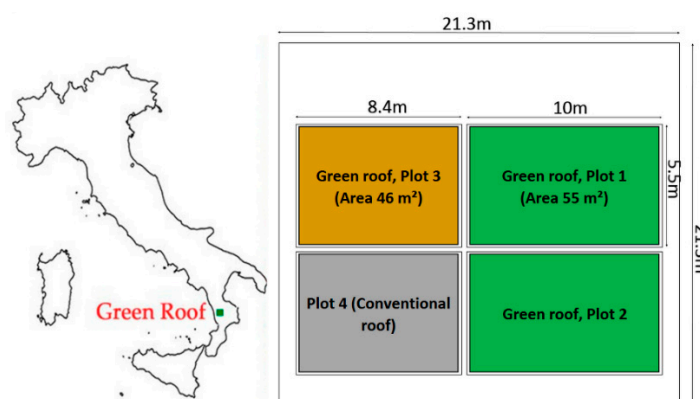


Figure 1. The Experimental Green Roofs Located at the University of Calabria in a Mediterranean Climate.

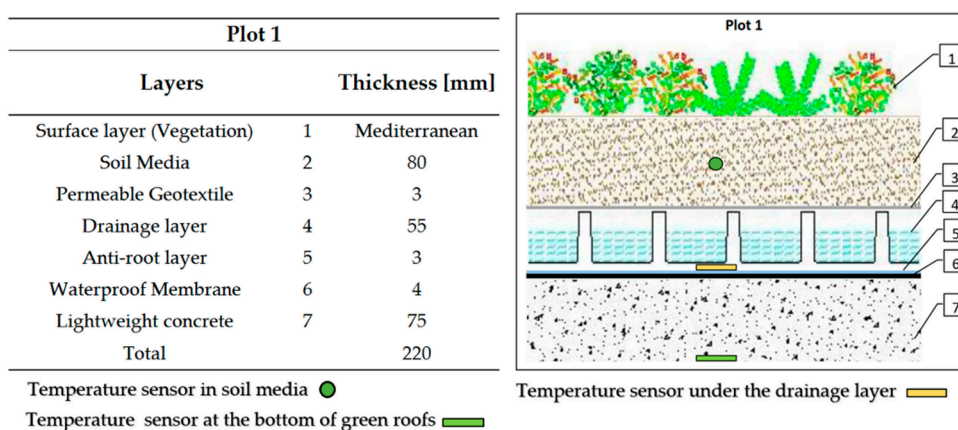


Figure 2. The Different Layers in Plot 1 (P1) and the Places of the Considered Sensors.

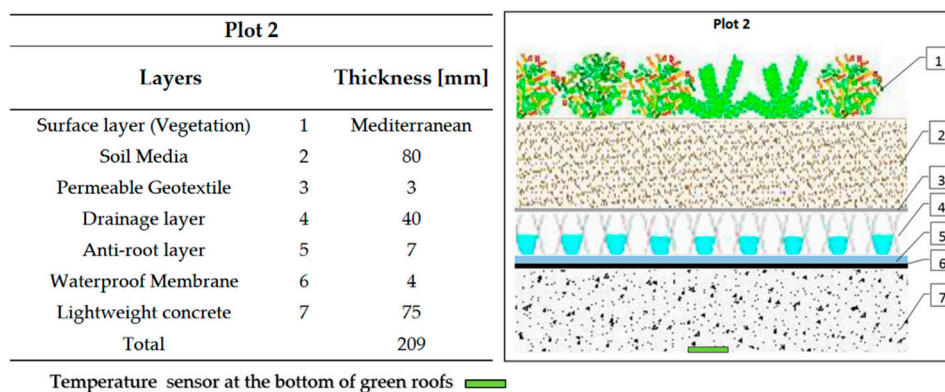


Figure 3. The Different Layers in Plot 2 (P2) and the Places of the Considered Sensors.

In plot 1, the total thickness of the layer is about 220 mm, and in plot 2 with different types of a drainage layer, it is about 201 mm. Plot 3 is similar to plot 1, but under the drainage layer, an insulation layer added, and the total thickness of the layer is 248 mm. The vegetation of plot 1 and plot 2 is Mediterranean types, and plot 3 is spontaneous plants. These two plots have received the same number and typology of plants; moreover, the surface temperature, detected by pyranometers, has shown the same mean temperature values denoting the same vegetation composition. Plot 4 is used as a reference, and it is a conventional roof, and the temperature of this plot has been compared with other plots. The employed temperature sensors include four wires RTD PT100 class1/3 with an accuracy of ± 0.1 °C at 0 °C and ± 0.27 at 100 °C installed inside the soil and different layers.

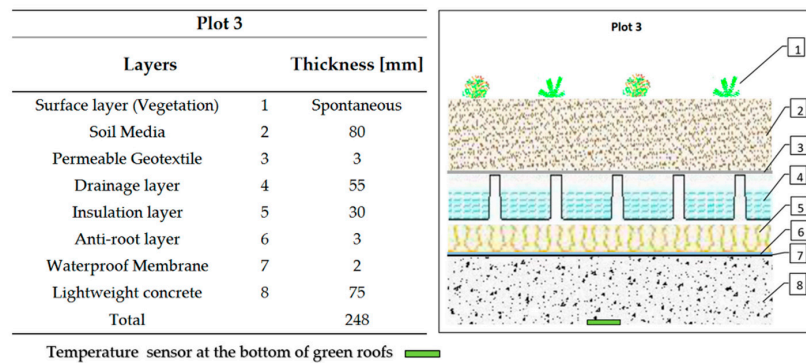


Figure 4. The Different Layers in Plot 3 (P3) and the Places of the Considered Sensors.

2.2. Assumptions

Since the role of roofs in indoor temperature is essential, the comparisons have been made by considering the roof temperature with or without green roofs. It must be mentioned that the indoor temperature is not equal to the temperature of the roof, but the indoor temperature is also affected by the interface temperature; therefore, the reduction of the gap between the last two values (indoor and interface) denotes the achievement of better comfort conditions.

- According to the ideal indoor temperature, as presented in Table 1, the use of heating or cooling has been suggested.
- The role of the heat island is not the topic of this paper and not considered in the analysis.
- Since all of the comparisons have been made for three green roofs situated in the roof of one building, therefore, the impact of the roof type under the green roof on the heat transfer between outdoor and indoor is the same, and is not considered in the analysis.
- Green roofs mostly affect the temperatures of the last and second last floors; therefore, it is not correct to refer the results to the whole building fabric, such as tall or high-rise buildings.

3. Results and Discussions

3.1. The Impact of the Green Roof on Average Roof Temperature

The temperature at different green roof layers in plot 1 has been shown in Figure 5. The average daily temperature in the conventional roof and at the bottom of green roofs (green layers) in the summer and winter of 2016 has been shown in Figures 6 and 7.

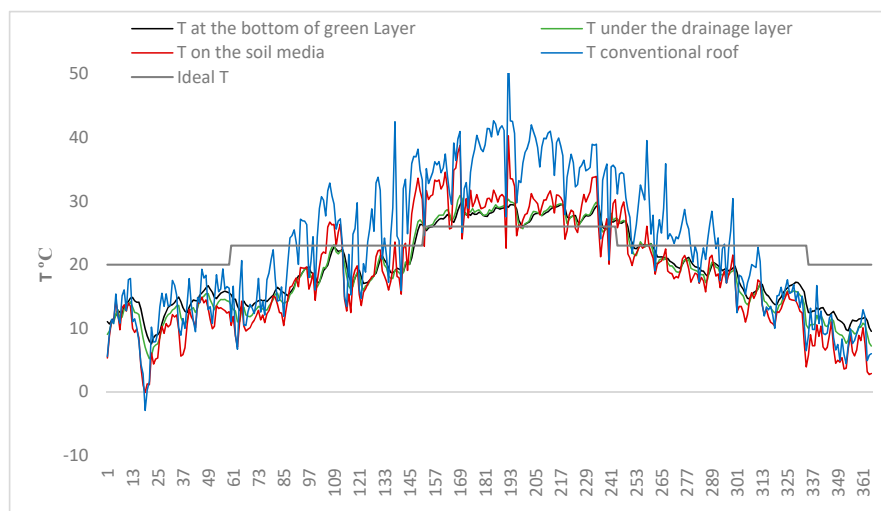


Figure 5. Average Daily Temperature in Different Layers of Green Roof Plot 1, 2016.

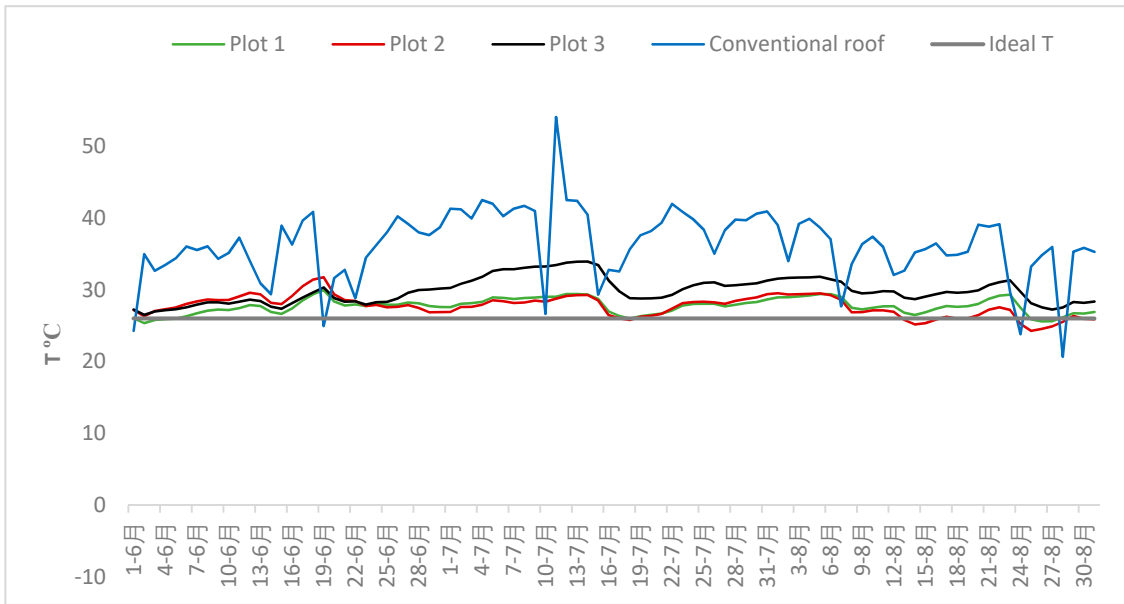


Figure 6. Average Daily Temperature in Conventional Roof and under Green Roofs, Summer 2016.

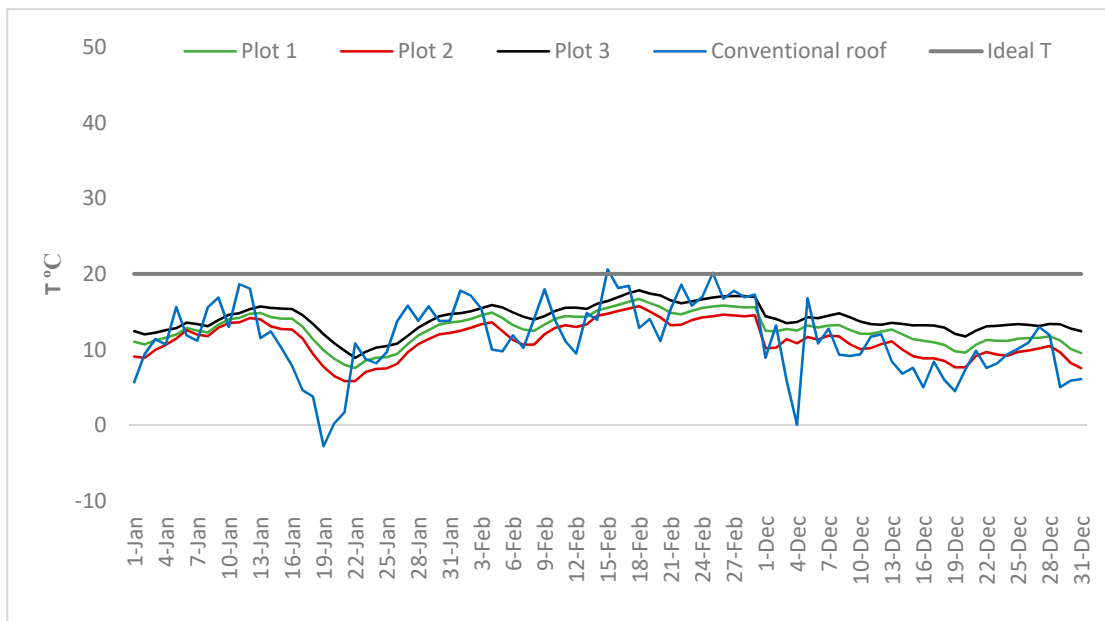


Figure 7. Average Daily Temperature in Conventional Roof and Green Roof, Winter 2016.

The analysis shows temperature differences among different layers in the green roof. The differences are more in the inner layer and maximum at the bottom of the green roof. The analysis of the summer and winter determined that using the green roof would change the roof surface temperature in a way to be closer to the ideal indoor temperature, especially in summer.

3.2. The Impact of the Green Roof on Indoor Heating or Cooling Period

By analysing the differences among the temperature under green roofs and ideal temperature (Ideal T) as presented in Table 1., and since the impact of roof temperature on indoor temperatures is important, the period that cooling or heating might be required has been determined and shown in Figure 8. As can be seen from the graph, the impact of all three green roofs in moderating the roof

temperature in summer is remarkable. However, even in winter, the green roofs moderated severe cold weather waves.

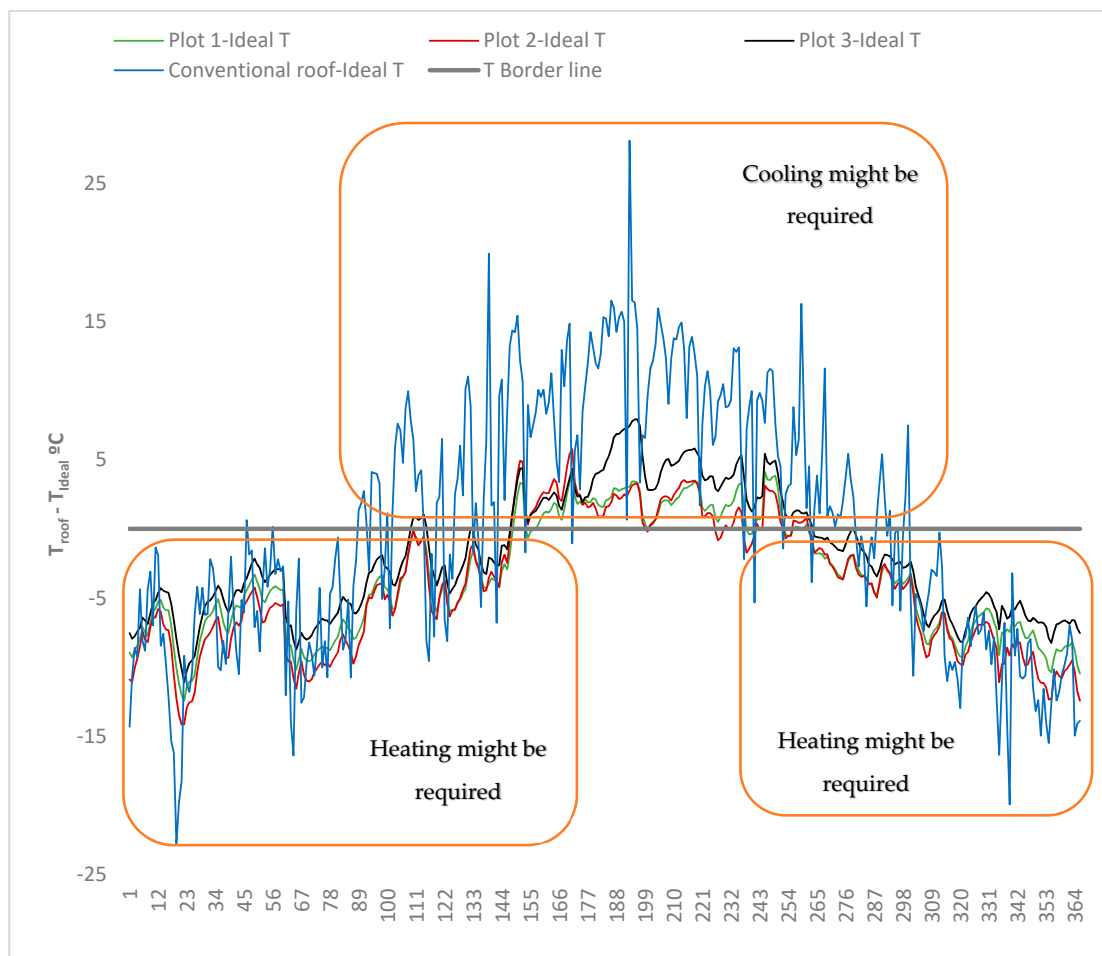


Figure 8. The Periods that Indoor Cooling or Heating Might be Required.

3.3. The Monthly Average Differences between the Green Roof and Conventional Roof

The monthly average roof temperature differences between the green roofs and the conventional roof have been presented in Table 2. The values show that in winter, the temperature under the green roof was higher, and differences varied from 4.6 to 0.2 °C. In summer, the temperature under the green roof was lower and differences varied from 5 to 11.3 °C

Table 2. The Monthly Average Differences between the Green Roof and Conventional Roof ($T_{Plot} - T_{Conventional Roof}$).

Month	Differences [T °C]			Month	Differences [T °C]		
	P1	P2	P3		P1	P2	P3
January	1.1	-0.2	2.2	July	-11.2	-11.3	-7.9
February	-0.3	-1.5	1.0	August	-7.1	-7.9	-5.0
March	-1.5	-2.8	0.1	September	-4.9	-5.0	-3.6
April	-5.3	-5.6	-3.8	October	-3.1	-3.2	-1.6
May	-7.9	-7.5	-6.4	November	0.3	-0.4	1.5
June	-7.4	-6.5	-6.4	December	2.9	1.1	4.6

The differences among temperatures under three types of green roofs have been shown in Figure 9. As it is clear, the impact of plots 1 and 2 in summer are similar and perform better in comparison with

plot 3. In winter, the impact of the green roof in plot 1 was better than plot 2. However, plot 3 shows better results in winter.

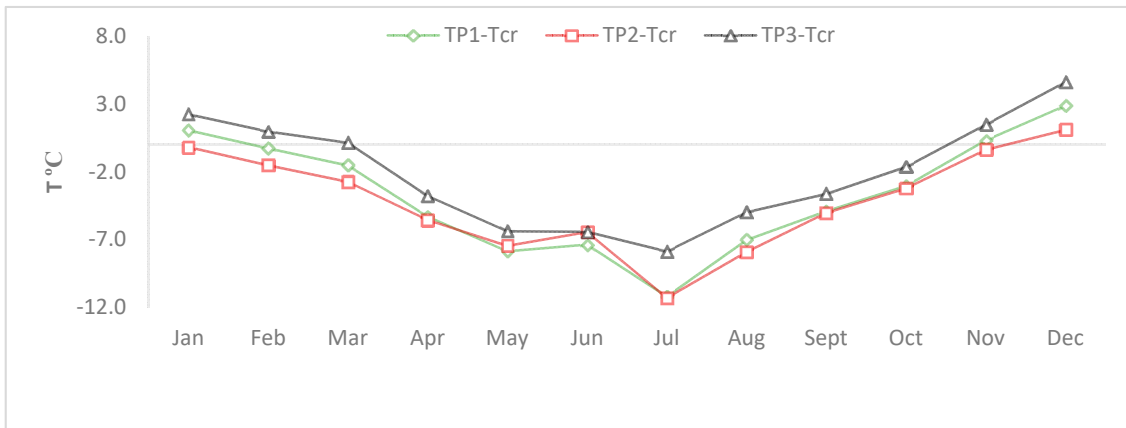


Figure 9. Monthly Average Differences between the Green Roofs and Conventional Roof.

3.4. The Role of Green Roof in Maximum and Minimum Roof Temperature

The maximum and minimum daily temperature in the conventional roof and three types of green roofs have been presented in Figure 10. The first clear trend is the temperature fluctuations in conventional roofs in comparison with green roofs. The second important point is the maximum roof temperature on the conventional roof that measured 72.2 °C while under the green roofs are less than 35 °C, which means a difference of about 37 °C. The minimum temperature on the conventional roof was -8.6 °C while under the green roofs, it was about 7.3 °C that shows a difference of about 16 °C.

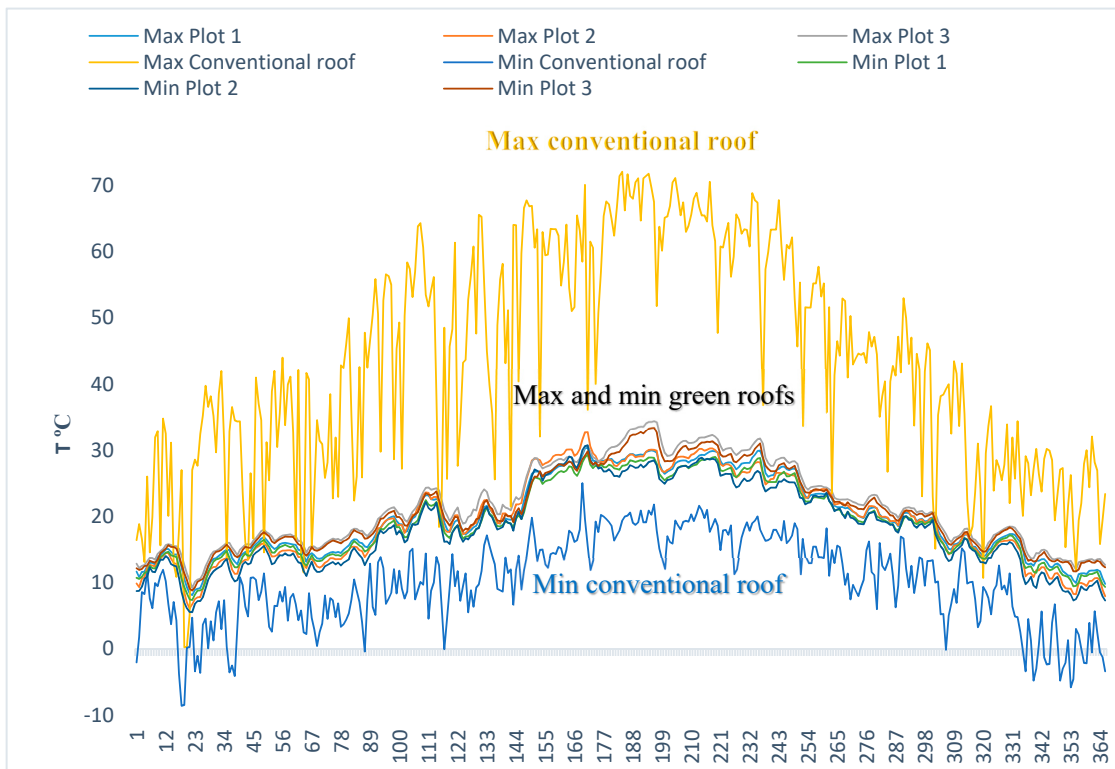


Figure 10. Maximum and Minimum Daily Temperature Differences between the Conventional Roof and Green Roof, 2016.

The comparisons among average monthly temperature fluctuations in conventional and green roofs have been shown in Figure 11. As can be seen from the graph, the average roof temperature fluctuations decreased significantly by green roofs, and the temperature fluctuations in all three green roofs are less than 2 °C.

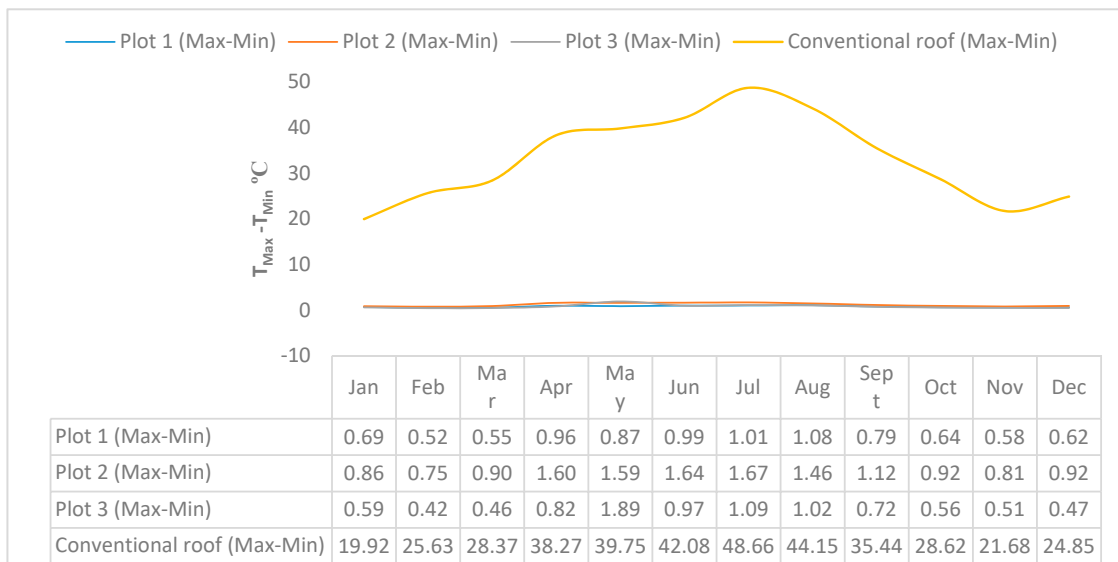


Figure 11. The Differences between Maximum and Minimum Temperatures in Conventional and Green Roofs.

The differences among maximum and minimum roof temperatures after using three types of green roofs have been shown in Table 3, and Figure 12. The graph shows the same trend for all three green roofs. The green roof in plot 3 shows better results in min temperature, but the impact of plot 1 and plot 2 was more in maximum roof temperature. However, the differences among them are less than 4 °C.

Table 3. Differences among Maximum and Minimum Roof Temperatures after Using Green Roofs.

Month	Max P1–Max cr	Max P2–Max cr	Max P3–Max cr	Min P1–Min cr	Min P2–Min cr	Min P3–Min cr
January	11.37	12.48	10.25	−7.86	−6.58	−9.08
February	16.46	17.57	15.28	−8.65	−7.31	−9.92
March	18.81	19.82	17.19	−9.00	−7.65	−10.71
April	28.02	27.92	26.60	−9.28	−8.74	−10.85
May	30.87	30.07	28.91	−8.01	−8.09	−8.94
June	30.63	29.34	29.70	−10.46	−11.10	−11.41
July	38.76	38.52	35.37	−8.89	−8.46	−12.20
August	33.47	34.16	31.44	−9.60	−8.53	−11.69
September	25.87	25.83	24.62	−8.78	−8.49	−10.10
October	20.54	20.54	19.16	−7.44	−7.16	−8.89
November	13.45	14.00	12.33	−7.65	−6.88	−8.85
December	12.69	14.3	11.05	−11.53	−9.61	−13.33

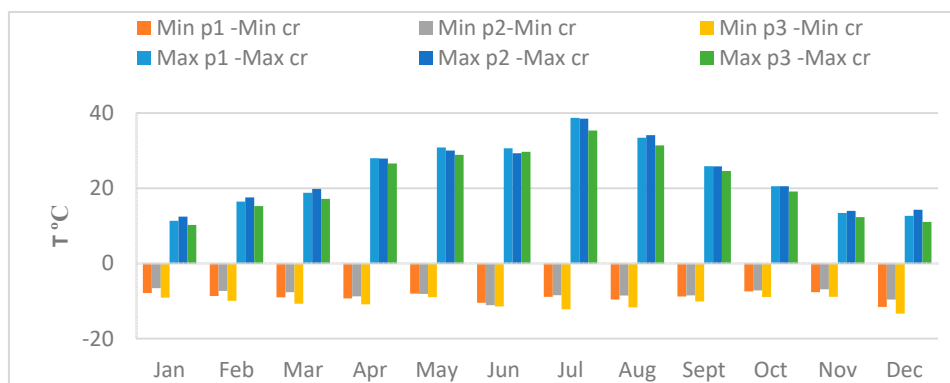


Figure 12. The Amount of Maximum and Minimum Temperature Differences after Using Green Roofs.

3.5. The Impact of Green roof Thickness, Layers, and Insulation on Roof Temperature

The differences among the temperature of the conventional roof, soil media, under the drainage layer and under the lightweight concrete are apparent in both summer and winter, as presented in Figure 5. However, in summer, the temperature under the drainage layer and under the green roof with adding a 7 mm membrane plus a 75 mm lightweight concrete is close together. It represents that the role of evapotranspiration in cooling the temperature is significant in summer, and the temperature of layers under the drainage layer is nearly equal to the roof temperature. In the winter, the temperatures under the drainage layer are less than the temperature under the lightweight concrete (under the green roof), and the temperature was increasing by going downside toward the roof surface. These differences show the heat transfer of indoor and outdoor temperatures by the roof in the winter.

In summer, as it is clear from Figures 6 and 9, the differences among plot 3 with adding a 30 mm insulation layer and plot 1, and plot 2 without an insulation layer, are distinct, and the insulation layer negatively affected the performance of the green roof in decreasing roof temperature. The opposite trend exists in winter, as shown in Figure 7, and after adding a 30 mm insulation layer, the performance of the green roof improved in comparison with plot 1 and plot 2 and the temperature of the roof surface in the winter increased. The result shows the remarkable impact of the insulation layer with a thickness of even 30 mm. Moreover, plot 1 with higher thickness than Plot 2, due to the use of a different drainage layer with lower thickness shows better thermal performance

As a result, the experimental data demonstrate that in the Mediterranean area, the lack of insulation layers improves the energy performance in summer, and this effect prevails despite a slight worsening of the heating demands in winter. Therefore, in the Mediterranean area, by not using insulated green roofs, the evapotranspiration would help cool the structure passively. Moreover, the favorable outdoor air temperatures in winter would not increase the heating demand significantly.

4. Conclusions

The results show the positive performance of green roofs in moderating roof surface temperature that in summer is more remarkable than winter, and as a result, the reduction of the gap between the indoor and interface (roof) denotes the achievement of better comfort conditions. By comparing the differences among the roof temperature and ideal temperature, the times that indoor cooling or heating might be required have determined and demonstrated that by using the green roof without an insulation layer, the roof temperature in summer would be near a comfortable temperature. The impact of green roofs in moderating the roof temperature in the winter was less than in summer. However, even in the winter, the green roof moderated cold weather waves.

The investigations of the monthly average values show that in winter, the temperature under the green roof was higher, and differences varied from 4.6 to 0.2 °C. In summer, the temperature under the green roof was lower, and differences varied from 5 to 11.3 °C. The observed roof temperature fluctuations in the conventional roof were among 20 to 48.5 °C, and the analysis shows the average

roof temperature fluctuations decreased significantly by green roofs, and the temperature fluctuations in all three green roofs are less than 2 °C. Moreover, the maximum roof temperature in 2016 on the conventional roof measured 72.2 °C while under the green roofs were less than 35 °C that means a difference of about 37 °C. The minimum temperature on the conventional roof was −8.6 °C while under the green roofs, it was about 7.3 °C that shows a difference of about 16 °C.

The analysis of green roofs in the summer shows that adding the thickness of green roofs by layers such as a lightweight concrete would have a limited effect on the thermal result. However, adding just a 30 mm insulation layer affected the performance of the green roof in decreasing roof temperature negatively. The analysis of green roofs in the winter shows indoor and outdoor heat transfer by the roof without an insulation layer, and the thermal performance of the green roof in winter improved by adding a 30 mm insulation layer. Moreover, the green roof plot 1 with a higher thickness shows better thermal performance than plot 2 with lower thickness. It must be mentioned that the main differences between plot 1 and plot 2 were the type and size of the drainage layer.

In conclusion, the experimental analysis shows the positive impact of green roofs on decreasing the energy consumption of the building. Moreover, since in the Mediterranean climate, the differences between green roofs and conventional roofs are much higher in summer, it seems that the green roof without an insulation layer would show better performance.

5. Recommendations

One solution to improve the performance of green roofs in both summer and winter might be the use insulation of type, whose thermal capacity due to wet and dry situations can change such as natural insulation, and is therefore recommended for future investigations.

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Conflicts of Interest: The authors declare no conflicts of interest.

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