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ORIGINAL ARTICLE

Green roofs as passive system for energy savings in buildings during the cooling period: use of rubber crumbs as drainage layer

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Abstract The building sector is responsible for most of today's energy and materials consumption. Construction systems such as green roofs can improve the energy performance of buildings, but meanwhile, they themselves should be more sustainable. This research focuses on the study of the benefits, in terms of energy consumption, of an extensive green roof (without insulation layer) in comparison to a conventional flat roof solution (with insulation) under Mediterranean continental climate. Moreover, in order to improve the sustainability of this system, the use of recycled rubber instead of traditional stone materials as drainage material is evaluated as well. For this purpose, the electrical energy consumption of the cooling system and thermal behaviour of three identical experimental cubicles, with only differences on the roof composition, was evaluated during summer period. The results show that a simple extensive green roof 9 cm thickness provides a reduction of 5 % in case of rubber crumbs and 14 % in case of pozzolana, in terms of electrical energy consumption, than a conventional flat roof with an insulation layer of 3 cm polyurethane, even when only the 20 % of the surface is covered by plants. Furthermore, small differences in thermal behaviour were observed when replacing volcanic gravel by recycled rubber crumbs as drainage material.

Keywords Green building · Building envelope · Extensive green roof · Energy consumption · Passive system · Recycled rubber crumbs

Introduction

The houses and building sector account for 40 % of total primary energy consumption (Directive 2010/31/eu) in the European Union (EU). Therefore, the reduction of energetic demand in this area is a priority in the framework of the objectives "20-20-20" in energy efficiency. The Energy Performance of Buildings Directive forces us to rethink our processes and constructive systems in the quest for higher energy efficiency and better integration of renewable energy. It is well known that the thermal performance of a building is a key aspect to consider during its design phase.

In addition, almost half of materials used in the European Union are for the construction and maintenance of buildings. For this reason, the choice of materials and constructive systems with low environmental impact becomes an important factor to achieve a more sustainable building and to comply with the raised objectives.

This paper focuses on a new study about green roofs. In the last years, green roofs have been consolidated as a sustainable constructive system that offers interesting advantages over traditional flat roofs. Some of these advantages are the water retention capacity (Villareal and Bengtsson 2005), the reduction of surface runoff in large cities (Getter et al. 2007), the improvement of

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the urban environment (Alexandri and Jones 2008; Li et al. 2010), the reduction of the heat flux through the roof (Palomo Del Barrio 1998; Lazzarin et al. 2005; Kumar and Kaushik 2005; Wong et al. 2007), a lower heating of the external surfaces in the summer period (Niachou et al. 2001), a higher capacity to absorb most of the thermal load which it receives during summer periods (Theodosiou 2003), a lower solar heat is irradiated and reflected by green plants compared to bare roofs (Wong et al. 2003), the reduction of the annual heating and cooling loads (Santamouris et al. 2007; Castleton et al. 2010), and the increase of the durability of internal membranes (Kosareo and Ries 2007).

In this study, the variations in thermal performance and energy consumption when the extensive green roofs are implemented as passive energy saving systems have been analysed. Moreover, to show the potential implementation of these systems, a comparison with a common flat roof used in Mediterranean continental climate has been performed. This research consists of a comparison between an extensive green roof (without insulation layer) and a conventional flat roof solution used in this climatic zone (with an insulation layer) in terms of final energy consumption by the installed heat pumps. The simple and sustainable green roof system used in this experimental facility (9 cm depth) is based on a conventional extensive green roof and has the following layers from bottom to top: waterproofing layer, drainage layer (4 cm), substrate layer (5 cm), vegetation layer (Fig. 3). Neither insulation layer nor filter layer have been used in this system. The substrate is a commercial one, special for extensive green roofs, and the drainage material is volcanic gravel. The species planted were a mixture between *Sedum* sp. and *Delosperma* sp.

Since the vegetation was in a growth phase, only the 20 % of the total roof area was covered by plants during the studied period. Shortage of vegetation cover is usual in extensive green roofs, especially in the first years after installation, which makes the study of thermal behaviour of substrate and drainage layers more interesting.

Furthermore, in order to add a plus of sustainability, the same green roof system was studied but using recycled rubber crumbs as drainage layer instead of volcanic gravel (Fig. 3). This solution contributes to the reduction of the extraction and utilization of natural materials, such as expanded clay, pumice, or natural pozzolana, which require large amounts of energy in their transformation process (Bianchini and Hewage 2012).

In previous studies, the possibility of using rubber crumbs was confirmed in hydraulic conductivity, infiltration rate, cumulative infiltration, better aeration, and reduction in weight on the constructive system as demonstrated Vila et al. (2012). In addition, the first studies about the thermal behaviour of this system, without plants, showed that the substrate has an important effect on the indoor temperature of the building as demonstrated by Pérez et al. (2012) in real-scale experimentation.

For these purposes, three identical house-like cubicles where the only difference is the roof constructive system were used to carry out the experiment. Two of the cubicles had 9-cm depth extensive green roofs without insulation (comparing rubber and volcanic gravel as drainage material) while the reference cubicle had a conventional flat roof with insulation.

The aim of this paper is to compare the thermal performance and electrical energy consumption by the heat pumps of the three cubicles above mentioned in an experimental facility during the cooling period.

Methodology

The experimental set-up consists of three house-like cubicles (Fig. 1) located in Puigverd de Lleida, Spain, with the same internal dimensions (2.4×2.4×2.4 m). Their bases consist of a mortar base of 3×3 m with

Fig. 1 Experimental cubicles in Puigverd de Lleida, Spain

crushed stones and reinforcing bars. The walls present the following layers from the inside out for all three cubicles (Fig. 2): gypsum, alveolar brick (30×19×29 cm), and cement mortar finish. No additional insulation was used in these cubicles (Cabeza et al. 2010; de Gracia et al. 2011)

The only difference between the three cubicles is the construction system of their roofs:

(a) Reference cubicle: A conventional flat roof (precast concrete beams and ceramic floor arch 25 cm) with 3 cm of polyurethane insulation layer above, concrete relieved pending formation of 2 %, double waterproofing membrane, and finished with a single layer of gravel of 7 cm thickness (Fig. 2).
(b) Volcanic cubicle: A conventional flat roof (precast concrete beams and ceramic floor arch 25 cm), concrete relieved pending formation of 2 %, double waterproofing membrane, and 4 cm of volcanic gravel directly below the substrate layer of 5 cm thickness (Fig. 3).
(c) Rubber cubicle: A conventional flat roof (precast concrete beams and ceramic floor arch 25 cm), concrete relieved pending formation of 2 %, double waterproofing membrane, and 4 cm of recycled rubber crumbs directly below to the substrate layer of 5 cm thickness (Fig. 3).

According to the recommendations given by the commercial company (Soprema, SOPRANATURE®. web page: http://www.soprema.fr/metiers/produit/1497/971/SOPRANATURE), the extensive green system used here requires no filter layer between the substrate and the drainage layer.

As shown in Fig. 4, the *Sedum* sp. and *Delosperma* sp. planted were in the growth phase due to this fact, the coverage was still scarce and the solar radiation protection was poor.

In order to evaluate the thermal performance of the different roof systems, the following data were registered for each cubicle at 5-min intervals:

- Internal ceiling surface temperatures
- Internal ambient temperature and humidity (at a height of 1.5 m)
- Electrical consumption of the heat pump for cooling demand
- Solar radiation
- External ambient temperature and humidity

The heat pumps used in all the experiments are Fujitsu Inverter ASHA07LCC. All temperatures were measured using Pt-100 DIN B probes, calibrated with a maximum error of ±0.3 °C. The air temperature and humidity sensors were ELEKTRONIK EE21FT6AA21 with an accuracy of ±2 %. The electrical consumption of

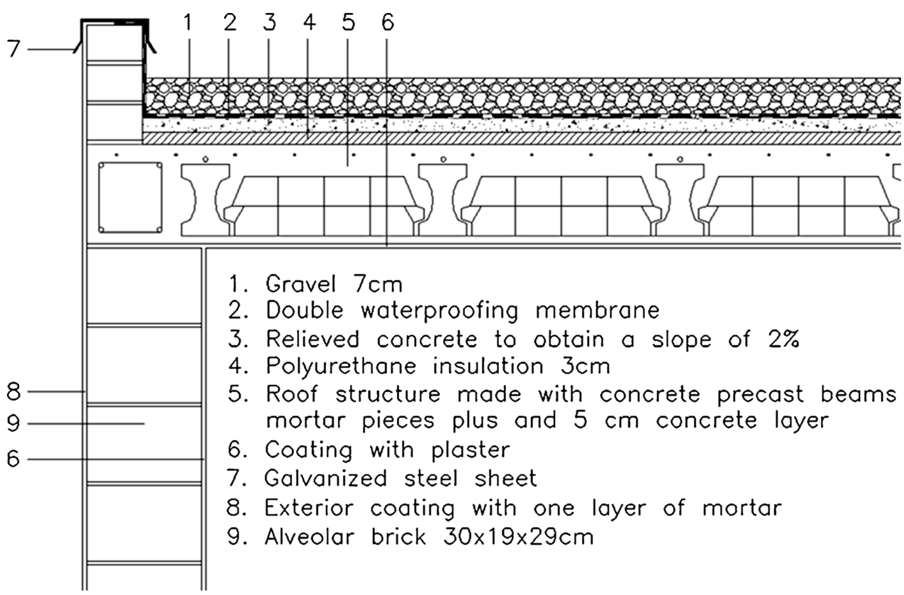

Fig. 2 Constructive sections of the reference cubicle

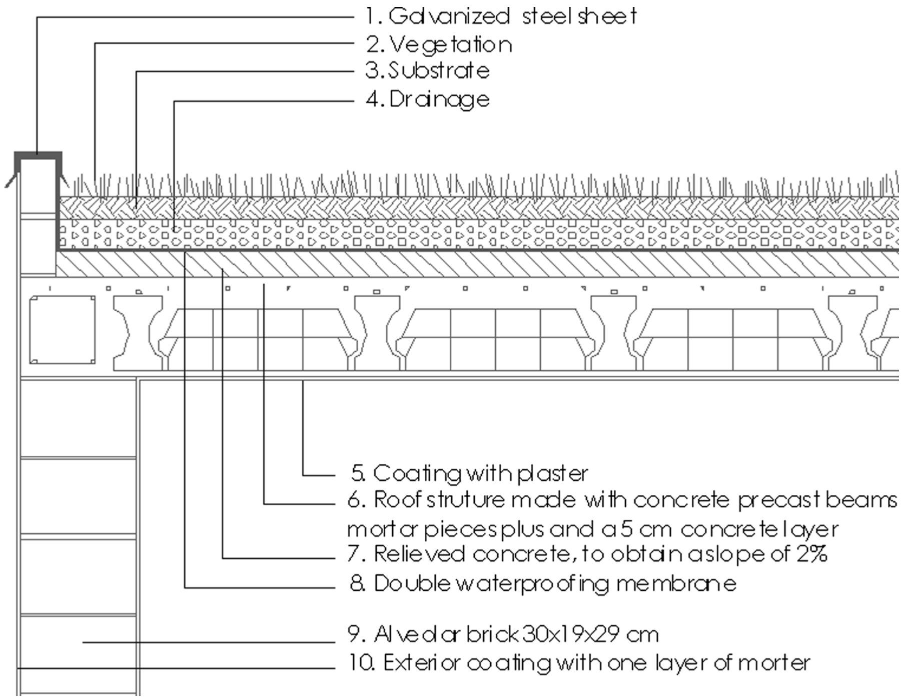

Fig. 3 Constructive sections of the green roofs cubicles

the HVAC systems was measured using an electrical network analyser (MK-30-LCD) with class 1 accuracy. Middleton Solar pyranometer SK08 was used to capture the horizontal global solar radiation.

Experiments were carried out during summer period (from 21 June to 20 September), but here only weekly periods are presented and discussed. These selected weeks represent the behaviour of different analysed periods.

The experimental set-up offers the possibility to perform two types of tests:

(a) Experiment 1, under controlled temperature, where a heat pump is used to set the internal ambient temperature of the cubicle. To span the spectrum of results, some experiments were done using set points below the comfort range (experimental range, 16–24 °C; comfort range, 23–26 °C for summer). Results presented of the experiment 1 are from the first week of July 2011 under controlled temperature at 24 °C. Figure 5 shows the climate conditions during this period. Due to the warm temperatures in summer, the heat pump was used only for cooling.

(b) Experiment 2 under free floating temperature, where no heating/cooling system is used. The thermal evolution of the inner environment of the different cubicles is compared. Results presented of the experiment 2 are from the first week of

Fig. 4 Experimental roofs with 20 % coverage of plants

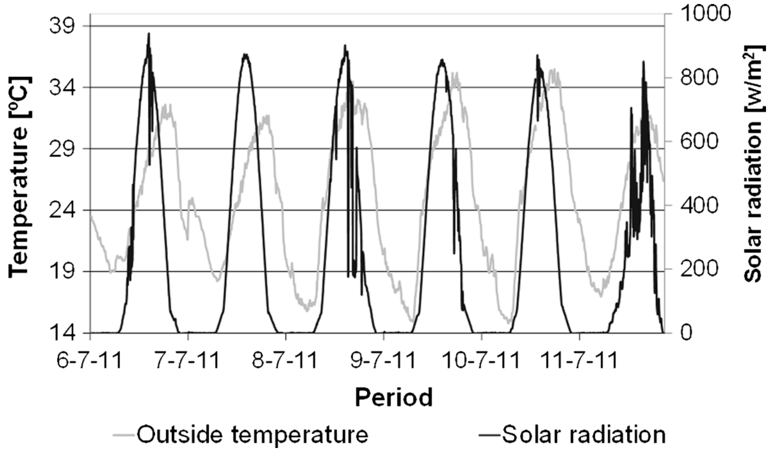

Fig. 5 Outside temperatures and solar radiation during the first week of July 2011

September 2011 and the third week of September 2011. Figures 6 and 7 show the climate conditions during these periods.

The experimental results allow evaluating and comparing the thermal behaviour and final electrical energy consumption by the heat pumps of the three constructive systems described above during summer period.

To understand the climate zone of experimental facility in Puigverd de Lleida (Spain) is important to note that it is classified as dry Mediterranean continental, characterized by its great seasonal variations. It has low rainfall divided in two seasons, spring and autumn, and it has a thermometric regime with large differences between a long winter (160 days) and a very hot summer. The average annual rainfall is between 350 and 550 mm, and the mean annual temperatures oscillate between 12 and 14 °C, with thermal amplitudes of 17–20 °C. A special mention must be made to the fog, typical of the region in the months of November, December, and January that can be given a period of up to 55 days in the absence of sunlight. Note that cooling period in this climate correspond to summer period which begins on 21 June and ends in 20 September.

Results and discussion

Experiment 1

This experiment shows the cumulative electrical energy consumed by the heat pumps installed in the three cubicles during the first week of July 2011 can be seen in Fig. 8. In this experiment, a set point of 24 °C was used. The heat pump of the reference cubicle has the highest electrical energy consumption followed by the rubber crumbs cubicle and finally the volcanic gravel cubicle with the lowest consumption. Compared to the reference, the cubicle with volcanic gravel had 14 % less electrical energy consumption, while the one with

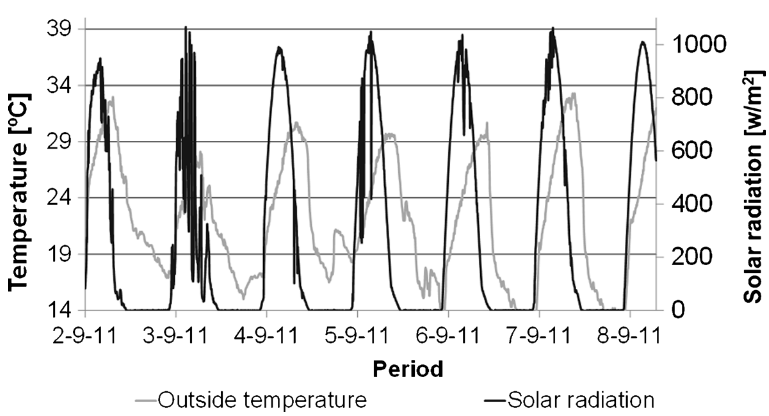

Fig. 6 Outside temperatures and solar radiation during the first week of September 2011

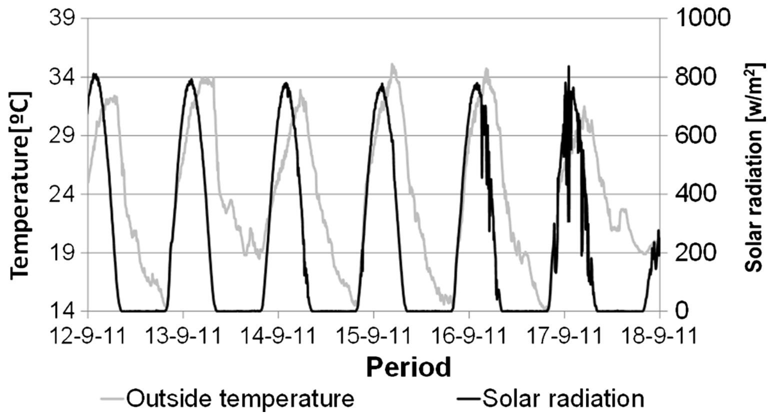

Fig. 7 Outside temperatures and solar radiation during the third week of September 2011

rubber crumbs consumed 5 % less during the first week of July 2011.

Since the substrate is the same in both studied green roofs, the thermal improvement in green roofs is produced by the drainage layer. In the case of pozzolana, it may be due to the porosity of the stone which was macro porous and micro porous. On the other hand, the rubber crumbs have more density compared to pozzolana but they have small particles that were less macro and micro porous.

Taking to account that coverage of plants on the green roofs was only 20 % of the total area, the effect of shade provided by plants was low. For this reason, the layers located below the plants (substrate and drainage) provided the major insulation on the green roofs.

An important issue of the paper is how to analyse the benefits of the green roof system when the complexity to analyse the thermal conductivity of the disaggregated materials (substrates, rubber crumbs, pozzolana, and plants) is really difficult as Theodosiou (2003) mentioned in his studies.

After reviewing all the literature, one can find that there are no real data about thermal properties of disaggregated materials. Some authors (Niachou et al. 2001; Sailor 2008) show approximations of thermal values of these materials from the simulation programs like TRNS YS or EnergyPlus.

Therefore, the obtained results are really interesting to obtain the contributions of the internal layers of the whole green roof system compared to a traditional flat roof because they allow quantify the savings as electrical energy consumption of the heat pumps.

In a future real scenario with the vegetation grown at 90–95 %, the energy savings would be even more evident. In Mediterranean continental climate, there is

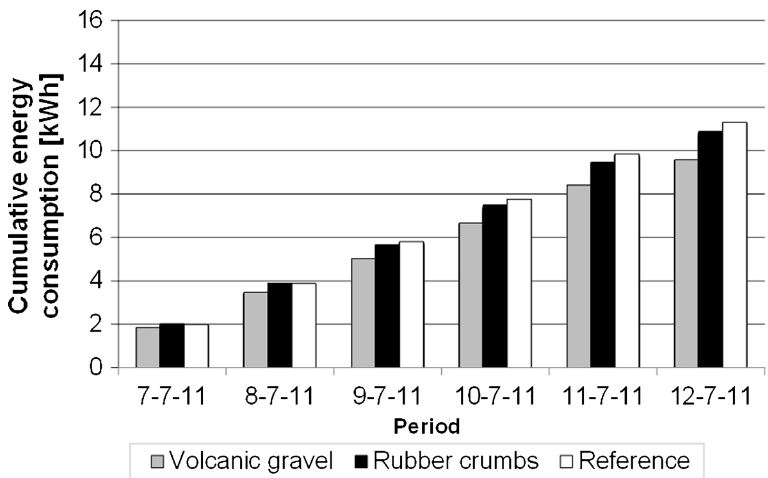

Fig. 8 Cumulative electrical energy consumption by the heat pumps. Controlled temperature (set point 24 °C), first week of July 2011

low rainfall, and for this reason it is difficult to achieve the 100 % of plant coverage.

Experiment 2

In order to compare the insulation effect of the green roofs (without insulation layer) with the reference roof (with insulation layer), tests under free floating conditions were performed. First of all, the outside temperatures and solar radiation are shown in Figs. 6 and 7 to understand better the Mediterranean continental climate during summer period, when experiment 2 was conducted.

Figure 9 shows that the internal ceiling temperatures in volcanic gravel and rubber crumbs cubicles present similar thermal behaviour, being 1 °C lower than the thermal behaviour registered in the reference cubicle. The behaviour of the internal ceiling temperatures (Fig. 9) through the week period follows the same pattern as the behaviour of the outside temperatures (Fig. 6). But, the internal ceiling temperatures for the green roofs remained 4 °C below the outside temperatures, and the reference roof were 3 °C lower.

More results of internal ceiling temperatures from the free floating experiments are shown in Fig. 10. Small significant differences could be observed between the three different cubicles during the third week of September 2011. Both the rubber crumbs and volcanic gravel cubicles show 1.5 °C lower in internal ceiling temperatures than the reference cubicle.

In this period of experiment 2, the difference between the internal ceiling temperatures of the green roof cubicles and the reference cubicle was bigger compared to the first week of September 2011. This difference may be due to the fact that the third week of September (Fig. 7) was warmer than the first week of September 2011 (Fig. 6).

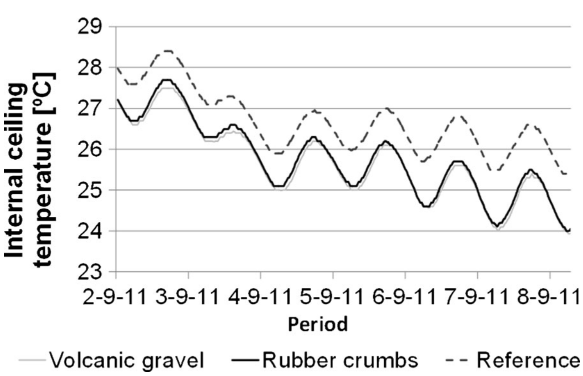

Fig. 9 Internal ceiling temperatures of different cubicles under free floating conditions, first week of September 2011

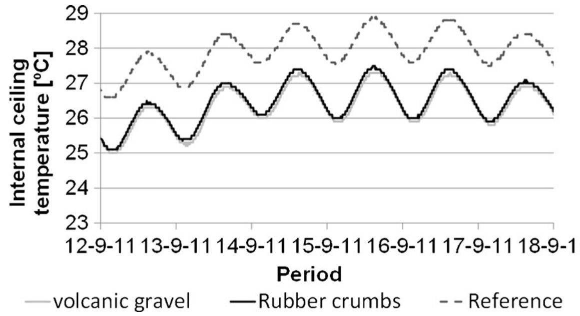

Fig. 10 Internal ceiling temperatures of different cubicles under free floating conditions, third week of September 2011

As in the previous experiment, experiment 2 shows the good thermal behaviour of the internal layers (substrate and drainage materials) of the green roofs compared to the reference roof.

Conclusions

In this paper, the benefits of this simple and sustainable extensive green roof solution (without insulation layer) in comparison to a conventional flat roof solution (with insulation) in terms of electrical energy consumed by the heat pumps are experimentally evaluated. Data was recorded during the summer period, under Mediterranean continental climate, when the plants were in a grow phase and therefore only 20 % of the roof surface was covered by them. In order to improve the sustainable approach of this constructive solution, replacement the volcanic gravel as drainage material by recycled rubber crumbs is studied and thermally evaluated as well.

After performing the experiments in the experimental cubicles, it can be concluded that:

– With constant internal ambient temperatures of 24 °C, the extensive green roofs (without insulation) reduce the electrical energy consumption (kWh) by the heat pumps during cooling demand, in comparison to 3 cm polyurethane insulated conventional flat roof. This reduction was 5 % when using recycled rubber crumbs and 14 % when using volcanic gravel as drainage layer.

- Under free floating conditions, in order to check the thermal evolution of the inner environment without any HVAC system, reductions of about 1.5 °C of internal ceiling surfaces temperatures between green roofs cubicles and reference cubicle during those periods were observed.
- No big differences were observed in terms of thermal performance on the green roofs when using recycled rubber crumbs instead of volcanic gravel as drainage material.
- In this study, it is demonstrated that a simple extensive green roof 9 cm thickness provides better performance during cooling periods, in terms of electrical energy consumption by the heat pumps, than a conventional flat roof with an insulation layer of 3 cm polyurethane, even when only the 20 % of the surface is covered by plants.

The results show that internal layers of green roofs (substrate and drainage) provided better insulation capacity compared to a conventional flat roof in Mediterranean continental climate.

Future research should study in more depth the composition of the internal layer materials of the green roofs in order to improve their thermal properties; in addition, it is important to take into account the water content of the substrate which can vary the final thermal response of the green roof system.

On the other hand, the shadow effect of the plants is really important as Kumar and Kaushik mentioned in their study (2005), even better performance in reduction of cooling demand is expected when plants cover 100 % of roof area.

Furthermore, the possibility of replacing the traditional materials (pozzolana) used in the drainage layer by others coming from recycled materials (rubber crumbs), without decreasing the thermal benefits of the green roof, is demonstrated.

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