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Use of rubber crumbs as drainage layer in green roofs as potential energy improvement material

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ABSTRACT

Today, green roofs are a building system which provides interesting benefits over traditional roof solutions. The most important advantages are the reduction of surface runoff in cities, improvement of the urban climate, biodiversity support, improvement of the durability of roofing materials, and, especially, energy savings. This paper has the aim of studying the performance of green roofs as a passive system for energy savings, within a wider objective of seeking constructive solutions suitable for sustainable and environmentally friendly architecture. This idea is tested at an experimental installation available at the University of Lleida, with several cubicles testing the energy performance of different construction solutions. This work raises the possibility of using recycled rubber from tires as a drainage layer in green roofs, substituting the porous stone materials currently used (such as expanded clay, expanded shale, pumice, and natural puzolana). This solution would reduce the consumption of these natural materials, which also require large amounts of energy in its transformation process to obtain their properties. Moreover it would provide a solution to the problem of waste rubber from the tires, known as rubber crumbs. Since the purpose of the drainage layer is the optimum balance between air and water in the green roof system, first the ability for draining of recycled rubber granules was studied and was compared with the offered by stone materials. The new solution using rubber crumbs is also studied to test if it would keep the same insulating properties that the green roof with stone materials presented in previous studies. Early results show that this extensive green roof system can be a good passive energy savings tool in Continental Mediterranean climate in summer, and that rubber crumbs can be an interesting substitute for stone materials used as drainage layer in this type of green roofs.

1. Introduction

Green roofs have been consolidated in recent years as a construction system that offers interesting advantages over traditional solutions. Some of these are the reduction of surface runoff in large cities, the improvement of the urban environment, the support to biodiversity, the improvement of the durability of waterproofing materials, and especially energy savings [1–21].

The green roofs are usually formed by the following layers [22,23]:

- Vegetation layer.
- Substrate layer: Usually topsoil or garden soil. It is the physical support for the plants. Moreover, it provides nutrients and should have capacity to retain water.
- Filter layer: Usually polypropylene or polyester geotextiles membranes. It allows the water to cross but not of the substrate small particulates that could clog the cavities in the drainage layer.
- Drainage layer: Its objective is to obtain an optimal balance between air and water in the green roof system. Drainage layer must be able to retain water when it rains, while it should also ensure good drainage and aeration of the substrate and roots. Currently being used mainly two types of drainage layer:
  - Polyethylene or polystyrene nodular panels, in which water accumulates, while allow evacuating the water excess, ensuring good ventilation.
  - Layer made of porous stone materials with some water retention capacity, such as expanded clay, expanded shale, pumice, and natural puzolana.
- Protection layer: Usually geotextiles polypropylene or polyester membranes. It provides mechanical protection of lower layers, especially for the waterproofing layer.
- Root barrier and waterproofing layer: It protects the building from the roots and water. Usually bitumen or PVC membranes, reinforced with polyester, fiberglass, plastics, and mineral granules. There are also some made with synthetic rubber or polyethylene.

They can either be extensive green roofs (thin substrate layer, light weight, without irrigation, and resistant species) and

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intensive green roofs (larger substrate thickness, larger weight of the system, with irrigation, and species typical of traditional gardening) (Fig. 1) [23,24].

Green roofs are a constructive solution designed with the goal of building more sustainable and environmentally friendly buildings. However the design is still based on conventional materials such as polypropylene or polyester geotextiles membranes, polyethylene or polystyrene panels, expanded clay, natural puzolana, and bitumen or PVC membranes.

Thus, besides studying their functional benefits, also study the goodness of the construction system itself should be considered. This work follows this idea, focusing on the materials used in the drainage layer.

The work raises the possibility of using rubber crumbs from tires as drainage layer in green roofs, substituting the porous stone materials currently used (such as expanded clay, expanded shale, pumice, and natural puzolana). Several actions were carried out:

(a) Since the purpose of the drainage layer is the optimum balance between air and water in the green roof system, first the ability for draining of recycled rubber granules was studied and compared with the offered by puzolana (comparison of hydraulic conductivity in lab and experimental green roofs in trays).
(b) Second, the new solution using rubber crumbs is also studied to test if it would keep the same insulating properties that the green roof with stone materials presented in previous studies in Continental Mediterranean climate (experimental green roofs in cubicles).

The study took place in Lleida, near Barcelona, in Spain. Lleida has a climate 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 (between the spring and the last frost may take more than 160 days) and a very hot summer. The average annual rainfall of between 350 and 550 mm, and the mean annual temperatures oscillates 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. This is a very similar climate to that of the area of Madrid, while taking this more annual rainfall and fewer days of fog per year.

The system used corresponds to an extensive green roof with a drainage layer of 4 cm of natural puzolana directly below to the layer of substrate (5 cm thickness) [25]. According to the recommendations given by the company commercializing the reference system used here between these two layers no filter layer was placed. In this type of climate and for extensive green roofs, irrigation during the summer months is also recommended.

2. Materials and methods

2.1. Drainage ability of the materials

In order to compare the drainage ability of the recycled rubber with the natural puzolana, hydraulic conductivity of these materials was studied with a constant load permeameter in lab [26].

The materials used as drainage layer in this first work were puzolana, a volcanic porous gravel (P) with a particles sizes of 4–12 mm, and recycled rubber of tires (R) with three different particles sizes, between 2 and 7 mm (R-Big), between 2 and 3.5 mm (R-Half), and between 0.8 and 2.5 mm (R-Small) (Fig. 2). For the substrate layer a commercial substrate was used [25].

The experiments were done individually for each of the four drainage materials (drainage layer), and later with those materials with a layer of substrate on top of them (drainage layer + substrate layer).

On the other hand, in order to further study the behavior of the analyzed green roof system, and observe what happens when the puzolana is replaced by rubber crumbs as drainage layer, several experimental trays were installed and studied during summer and autumn of 2009 (Fig. 3) [26].

In these trays the same system of green roof was installed, that is, 4 cm for the drainage layer and 5 cm for the substrate layer. The materials used as drainage layer were the same as in the laboratory study of hydraulic conductivity, puzolana (P) and rubber crumbs (R-Big, R-Half, R-Small).

The plants studied were Mesem Pendulina (*Lampranthus* spectabilis (Haw.) N.E.Br. = M*esembryanthemum* spectabile Haw.), and Rosemary (*Rosmarinus* officinalis L. var. *postratus*).

The analyzed parameters were the water retention capacity of the system, and the plants development.

2.2. Experimental green roofs in cubicles

The aim of this experiment was to study the insulation effect of extensive green roofs in Continental Mediterranean climate.

The first steep was the installation of one provisional extensive green roof on an existing experimental cubicle in a large installation that the research group GREA has in Puigverd de Lleida (Lleida,

Fig. 1. Left: Intensive green roof, Singapore 2007. Right: Extensive green roof, Lleida 2010.

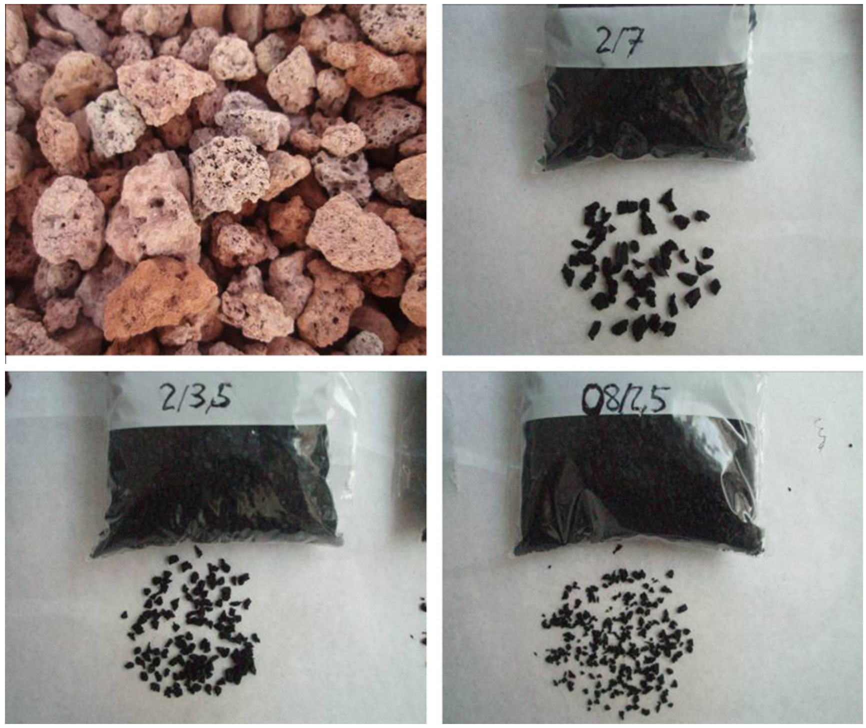

Fig. 2. Drainage layer materials. Puzolana and three different particles sizes of rubber of tires.

Fig. 3. Experimental green roofs in trays.

Spain) [27,28]. In this cubicle only the evolution of the internal temperature could be measured. This action took place during summer and autumn of 2009.

Again the system used corresponded to an extensive green roof with a drainage layer of 4 cm of natural puzolana directly below to the layer of substrate, of 5 cm thick, without filter layer [25]. Plants used were *Sedum* sp. and *Delosperma* sp. (Fig. 4).

The cubicle dimensions are $3 \times 3 \times 3$ m, built with bricks and insulated with polyurethane. The results obtained in this cubicle was compared with other two of equal size, also built with bricks, but with different insulation, one with polystyrene and the other without insulation (reference).

As the first interim extensive green roof results were positive three new cubicles were built raised to build (Figs. 5 and 6).

The experimental set-up consists of three house-like cubicles located in Puigverd de Lleida, Spain, with the same inner dimensions ($2.4 \times 2.4 \times 2.4$ m). Their bases consist of a mortar base of 3×3 m with crushed stones and reinforcing bars, and the walls present the following layers from the inside out; gypsum, alveolar brick ($30 \times 19 \times 29$ cm), and cement mortar finish.

The only difference between the three cubicles is the composition of the roof:

(1) Reference cubicle: With a conventional roof formed by a single layer of gravel of 10 cm thickness.
(2) Puzolana cubicle: With an extensive green roof with a drainage layer of 4 cm of puzolana directly below the substrate layer, of 5 cm thickness.
(3) Rubber cubicle: With an extensive green roof with a drainage layer of 4 cm of rubber crumbs directly below to the substrate layer, of 5 cm thickness.

To evaluate the thermal performance of each roof system the following data were registered for each cubicle at 5 min intervals:

- Internal wall temperatures (east, west, north, south, roof and floor) and also external south wall temperature.
- Internal ambient temperature and humidity (at a height of 1.5 m).
- Heat flux at the south wall (inside and outside).

Fig. 4. Provisional extensive green roof in experimental cubicle.

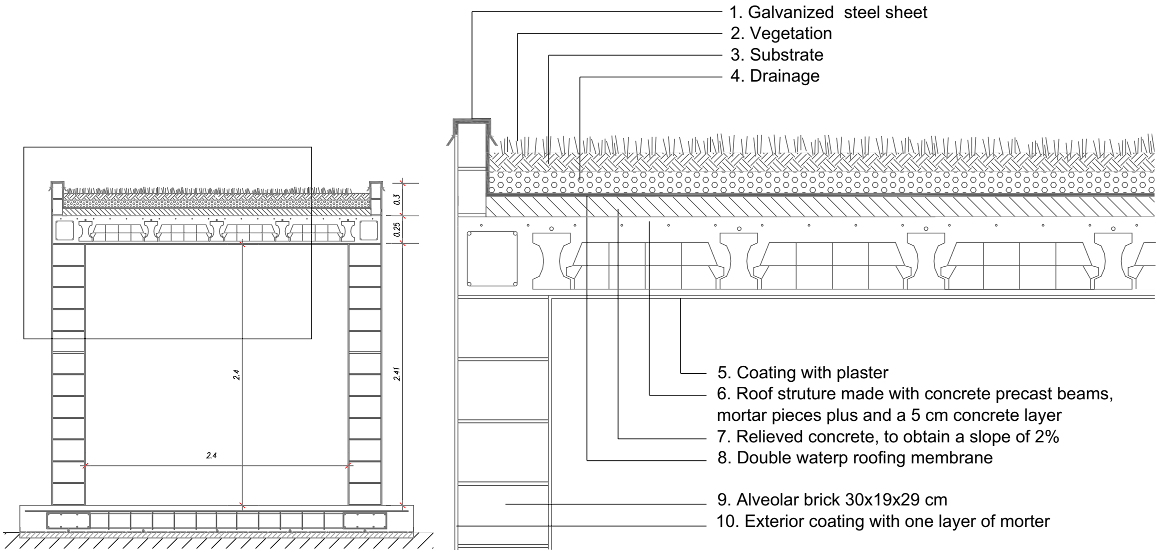

Fig. 5. Constructive section of the new experimental cubicle.

Fig. 6. New experimental cubicles. July 2010.

- Electrical consumption of the air conditioner or the electric heater.
- Solar radiation.
- External ambient temperature and humidity.

All temperatures were measured using Pt-100 DIN B probes, calibrated with a maximum error of ±0.3 °C. The air humidity sensors were ELEKTRONIK EE21FT6AA21 with an accuracy of ±2%. The heat flux sensors used were HUKSFLUX HFP01 with an accuracy of ±5%.

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

- Free floating temperature, where no heating/cooling system is used. The temperature conditions in the cubicles are compared.
- Controlled temperature, where an air conditioner system is used in summer and an electrical oil radiator is used in winter to set the internal ambient temperature of the cubicle. The energy consumption of the cubicles is compared using different set points. 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 and 20–24 °C for winter).

The construction of these new cubicles took place in 2010. The roof construction was done layer by layer (Fig. 7), measuring the temperature inside the cubicle and the energy consumption at each stage. Thus, first, data were taken when only the drainage layer was extended, and then when the substrate layer was extended above the drainage layer. At the later stage, experiment with plants will be carried out.

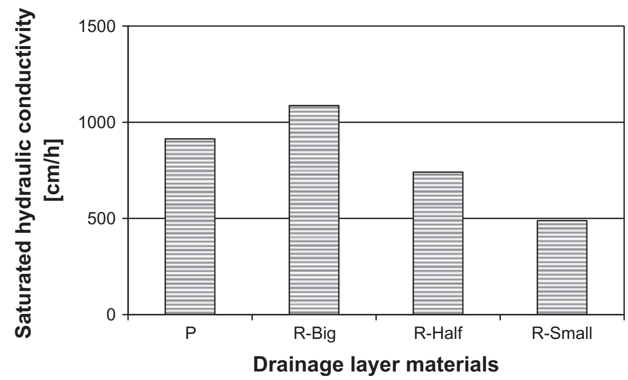

Fig. 8. Saturated hydraulic conductivity of only drainage layer.

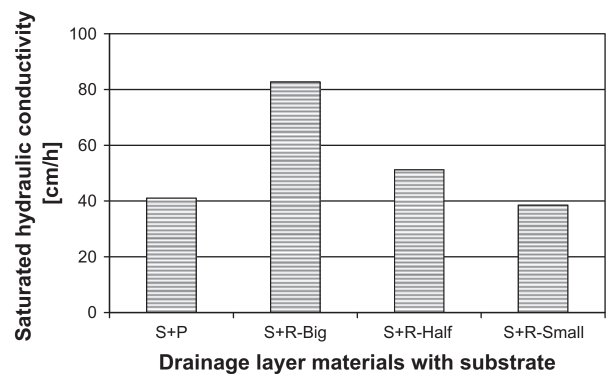

Fig. 9. Saturated hydraulic conductivity of substrate and drainage layers, together.

3. Results and discussion

3.1. Drainage ability of the materials

Figs. 8 and 9 show the lab results for the saturated hydraulic conductivity for the different drainage layer materials. When only the drainage layer is considered (Fig. 8), the values are more than 10 times higher than if the substrate layer is added (Fig. 9).

In Fig. 9, it is noticed that the behavior of half-particulates rubber crumbs (R-Half) and small-particulates rubber crumbs

Fig. 7. Roof construction layer by layer.

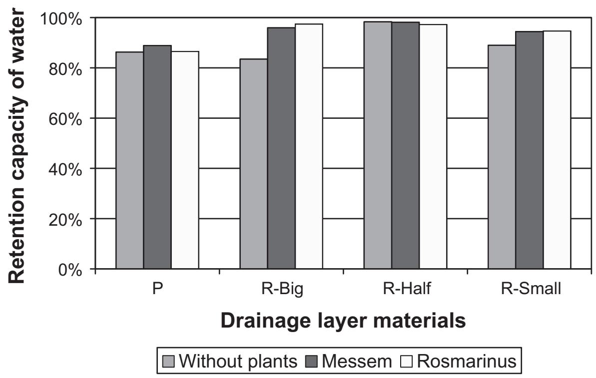

Fig. 10. Retention capacity of green roofs in experimental trays.

(R-Small) is similar to that of the puzolana (P). Therefore they can be used interchangeably from the point of view of the drainage function of the system (substrate and drainage layers).

Fig. 10 shows the water retention capacity of green roofs in experimental trays for the period of the study. Recycled rubber had similar water retention capacity to puzolana in green roof trays (slightly higher in most cases, between 3% and 12% higher, except for R-Big without plants).

In terms of plant development we observed that Rosemary showed some lack of water during the first weeks of the period of study, thus from this moment the irrigation was increased. Messem showed no sign of water stress throughout the studied period (Fig. 11).

3.2. Experimental green roof in cubicles

Fig. 12 shows the indoor temperature in the first provisional extensive green roof for a period of 15 days in August 2009. The higher oscillations of the reference cubicle indoor temperature evidence the insulation effect in the others cubicles. Moreover, in the cubicle with green roof indoor temperatures between 2 and 5 °C lower were recorded. This fact, which was repeated during the months of August and September the same year, showed that the use of vegetated roofs can be a good passive energy savings system.

After the construction of the new cubicles with green roof, the implementation of the green roof was used to monitor the effect of the different layers of the green roof in the interior temperature of the cubicle. Experiments with free-floating and with constant indoor temperature of 18 °C were performed.

Fig. 13 shows the cumulative energy consumption in the three cubicles for 5 days in July, when only drainage layer had been placed. There were no significant differences in energy consumption between the three cubicles. The cubicle with a layer of rubber crumbs consumed 5.4% more than the reference cubicle. The cubicle with a layer of puzolana consumed 1% more than the reference cubicle.

Fig. 14 shows the cumulated energy consumption in the three cubicles for 4 days in August, when a substrate layer had been added above the drainage layer. Again there were no significant

Fig. 11. Plant growth in experimental in trays.

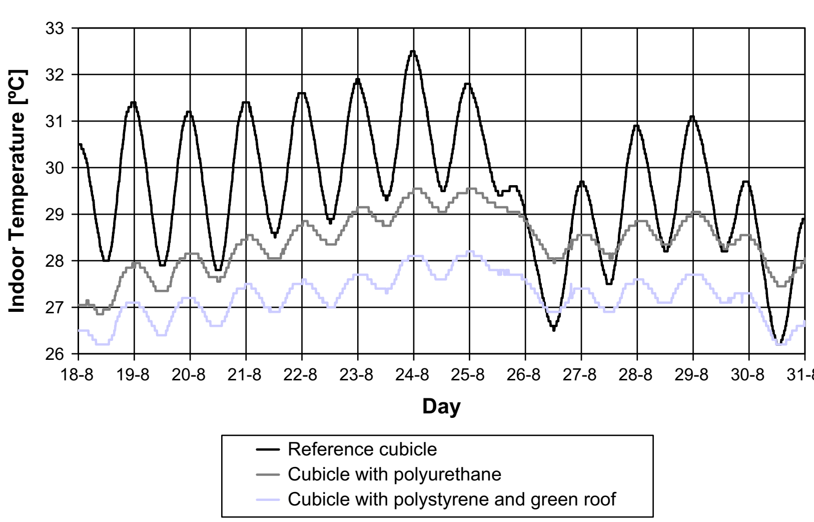

Fig. 12. Cubicle indoor temperature, August 2009.

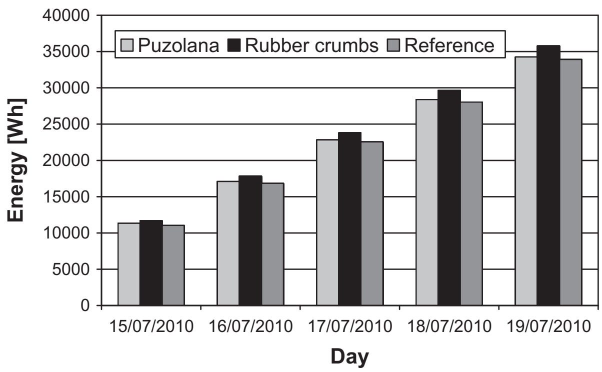

Fig. 13. Cumulative energy consumption. Only drainage layer and set point 18 °C.

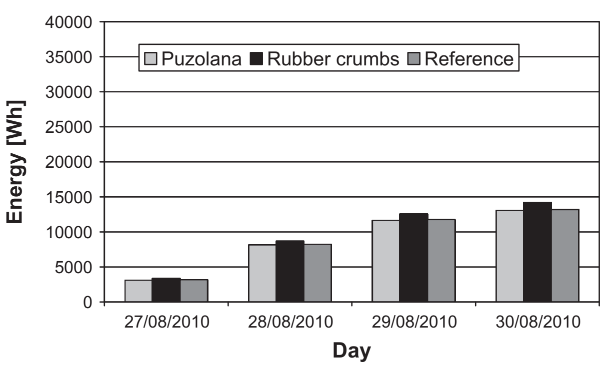

Fig. 14. Cumulative energy consumption. Drainage layer plus substrate layer and set point at 18 °C.

differences in cumulative energy consumption among the three cubicles when the two layers were implemented, drainage and substrate. The cubicle with a layer of rubber crumbs consumed 7.7% more than the reference cubicle, and the cubicle with a layer of puzolana consumed 0.86% less than the reference cubicle.

Fig. 15 shows the indoor temperatures evolution of the three cubicles in free-floating regime for 6 days in August 2010, when there was only the drainage layer. The temperature evolution within the cubicles was very similar and there were no significant differences. The temperature inside the cubicle with puzolana layer was about 0.5 °C higher than the reference cubicle, and 1 °C compared to the cubicle with the layer of rubber crumbs.

Fig. 16 shows the indoor temperatures evolution of the three cubicles in free-floating regime on 6 days in September 2010, when the substrate layer was added above the drainage layer.

Again, there were no significant differences. The temperature inside the cubicle with the rubber crumbs layer during this period was 0.5 °C lower than in the reference cubicle and in the cubicle with puzolana layer.

Comparing Figs. 15 and 16, one can verify that the substrate has an important effect on the indoor temperature of the building. When only drainage layer is placed on the cubicle the internal temperature fluctuates between 25 and 30 °C, and when drainage layer and substrate are present, the internal temperature is between 22 and 27 °C, both cases having similar outdoors temperature. This same effect could be seen in Figs. 13 and 14, when constant indoor temperature experiments are carried out.

4. Future actions

As irrigation is essential during the summer months in this climate, during 2011 a simple irrigation system was implemented. We have also undertaken the planting of plants which are currently in a growth phase; therefore data of the extensive green roof with plants are not yet available for publication.

Future objectives of this study are:

- Study of extensive green roof system as a passive energy saving in Continental Mediterranean climate.
- Study of the use of rubber crumbs against puzolana as drainage layer material.
- Study of the improvement in the acoustic insulation due to this change of material.

5. Conclusions

Of the various actions carried out in this work about an extensive green roof system in Continental Mediterranean climate, it is possible to conclude that:

- In the lab tests it is noted that there are not significant differences in the hydraulic conductivity when puzolana as material for drainage layer is replaced with rubber crumbs, especially when small and half particulate sizes are used.

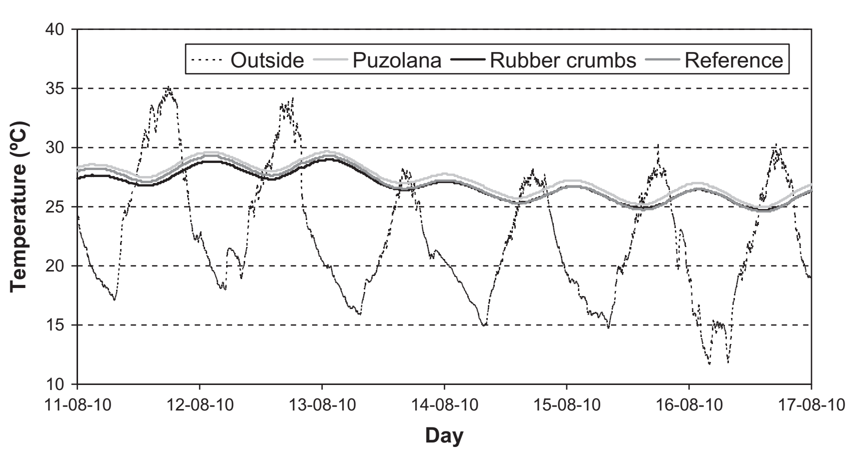

Fig. 15. Temperature inside the cubicles and outdoors temperature. Only drainage layer and free-floating.

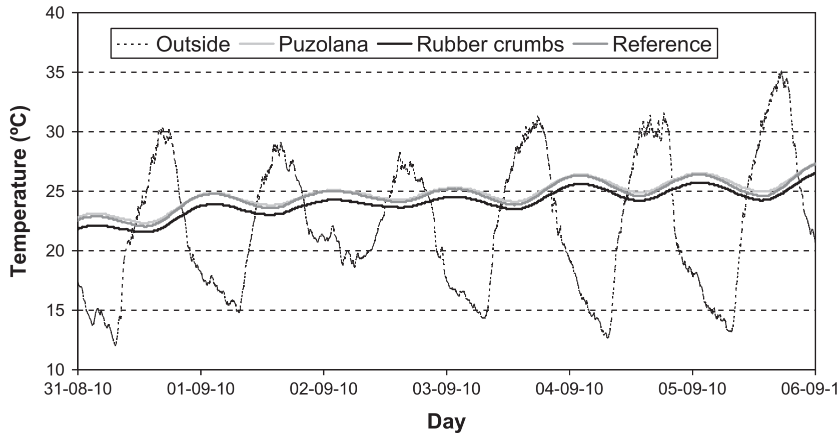

Fig. 16. Temperature inside the cubicles and outdoors temperature. Drainage layer plus substrate layer and free-floating.

- The behavior of the extensive green roof system in trays (water retention capacity, plant development) was independent of the use of rubber crumbs or puzolana as drainage layer.
- Simply installing one provisional extensive green roof (9 cm) in an experimental cubicle meant a reduction of indoor temperatures between 2 and 5 °C during the summer and early autumn.
- By comparing three experimental cubicles made of the same construction system and only varying the composition of the roof it was observed that:
  - No significant differences were measured in energy consumption for a set point of 18 °C during the summer days tested when only the drainage layer was placed. Nor when the substrate layer was added.
  - No significant differences were found in the indoors temperature when the three cubicles were working in free floating regime during the summer days tested and when only the drainage layer was placed. Nor when substrate layer was added.
  - When the substrate layer was added there was a decrease in temperature inside the cubicles of up to 3 °C.

Generally it can be concluded that extensive green roofs can be a good tool to save energy during summer in Continental Mediterranean climate, and that the use of rubber crumbs instead of puzolana as drainage layer material in extensive green roofs is possible, and should not arise any problem for its good operation.

Acknowledgments

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