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Thermal assessment of extensive green roofs as passive tool for energy savings in buildings

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ABSTRACT

Sustainability trends for buildings require new construction systems to foster energy efficiency and environmentally friendly buildings. Green roofs are interesting construction systems because they provide both aesthetic and environmental benefits. This paper continues a long-term research in order to evaluate and improve the thermal behaviour and sustainability of extensive green roofs. Simultaneously this research provides experimental data for specific Mediterranean continental climate conditions. The experiment consists in evaluating the energy consumption and thermal behaviour of three identical house-like cubicles located in Puigverd de Lleida (Spain), where the only difference is the roof construction system. The roof consists of a conventional flat roof with insulation in the reference case, while in the other two cubicles the insulation layer has been replaced by a 9 cm depth extensive green roof (comparing recycled rubber crumbs and pozzolana as drainage layer materials). The electrical energy consumption of a heat pump system was measured for each cubicle during 2012 and part of 2013. Both extensive green roof cubicles show less energy consumption (16.7% and 2.2%, respectively) than the reference one during warm periods, whereas both extensive green roof systems present a higher energy consumption (6.1% and 11.1%, respectively) compared to the reference cubicle during heating periods.

1. Introduction

During the last two decades, the building sector has experienced an important evolution in terms of quantity of constructed buildings, but less evolution in its energy performance regarding to usage and operational phases. Consequently, 40% of total primary energy consumption in European Union (EU) is due to households and the building sector. For this reason and with the aim to reduce the CO_2 emissions, the EU has issued legislations and regulations on energy efficiency of buildings [1] and built environment sustainability [2,3]. Therefore, in the building sector reduction of both energy demand and environmental impact have become important factors to achieve more sustainable buildings and meet the objectives of "20–20–20" in energy efficiency. In addition, the European Energy Directives promote new building processes and construction systems to improve energy efficiency and sustainability in buildings.

New construction systems have become important for the scientific community in the last decade. Within them, green roofs are seen as interesting construction systems because they provide both aesthetic and environmental benefits [4], being one of them energy savings.

Numerous studies in different fields about green roofs have been conducted during the last twenty years. Some authors divide these systems into two categories, "extensive" and "intensive" [5–8], while other authors introduce an intermediate category called "semi-intensive" green roofs, which are a combination of the extensive and intensive [9]. Generally, extensive green roofs have shallower substrates (<200 mm) that do not represent an excessive overweight for conventional roof structures (70–170 kg/m^2) [8]. Some advantages are: no additional structural reinforcements, less investment in growing media and plants, and less maintenance. On the other hand, intensive green roofs systems, also called living roofs or roof gardens, implement more heavy vegetation, like trees and shrubs, which require deeper substrates (>200 mm). In addition, roof gardens represent an overweight (290–970 kg/m^2) and additional maintenance in plant care [8]. These systems are focused on landscape and aesthetic values to increase living and recreation spaces in densely populated urban areas [7].

After literature review, the main environmental benefits of

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these systems compared to the traditional flat roofs have been found and listed below: water retention capacity [10–12], reduction of surface runoff in large cities [13,14], water runoff quality [14,15], improvement of urban environment, mitigating the Urban Heat Island effect (UHI) [16–18], reduction of CO_2 concentration in the urban environment [19,20], sound absorption [21,22], enhance of internal membranes durability [23,24], aesthetics reactions [25], and enhancement of the biodiversity and reduction of habitat losses [26].

In addition to all the above mentioned advantages, it is known that green roofs are efficient systems to reduce the indoor–outdoor temperature variations and, consequently, to decrease the annual energy consumption [24,27]. However, there are different parameters which influence the final energy performance of a green roof that can be experimentally studied more in detail, such as building insulation characteristics, the climate zone, plant types (Leaf Area Index, stomatal resistance, height, fractional coverage and albedo) [28–30], growing media (thickness, composition, density, moisture content) [28,30,31], and drainage layer properties [28,32,33].

Regarding the importance of the building insulation level, a single family house with conventional and green roofs in a temperate French climate was simulated by Jaffal et al. using TRNSYS software. The authors stated that green roofs only exhibit significant energy savings under both heating and cooling periods for uninsulated (48% energy savings) or moderately insulated (5 cm, 10% energy savings) buildings [24]. Similar results were obtained by Niachou et al. [34] in a simulation study conducted in a hotel located in Loutraki region (temperate and warm climate). Energy savings up to 48% for non-insulated, 7% for moderate insulated and less than 2% for high-insulated cases were estimated. Under similar climate conditions, Santamouris et al. [35] also used TRNSYS to calculate, under several scenarios (insulated and noon-insulated green roofs), the cooling and heating loads compared to conventional flat roof over the whole building. Cooling load reductions between 15 and 49% for the non-insulated case and between 6 and 33% for the insulated case were found. However, the heating load variation due to the green roof installation was not significant to be remarkable.

The importance of the level of building insulation on the energetic performance of green roofs has been previously studied, but most of those energy saving results derive from mathematical models and parametric studies. Thus, new experimental studies of long term about extensive green roofs without insulation are useful to obtain real data.

On the other hand, the seasonal performance of green roofs in different climate zones has been studied. Several authors as Perez et al. [36] and Coma et al. [37] show the energy savings potential of green roofs during summer in Mediterranean climate despite having low vegetation coverage (20%). In addition several authors shows the performance in both summer and winter seasons, such as Getter et al. [33] conducted an experimental study in Midwestern U.S. climate (Michigan State University), characterized by hot humid summers and cold snowy winters. The results showed that green roof reduced heat flux through the building envelope by an average of 13% in winter and 167% during summer. A similar experimental study under mild climate with moderate rainfall in winter and low rainfall in summer Portland (Oregon) was conducted by Spolek [38]. The results showed significant heat transfer reductions of around 13% in winter while in summer conditions was around 72%.

Nonetheless several authors have concluded that the performance of these systems in different climate zones have no effect on the building or may have negative effect during winter periods. As an example, for humid subtropical regions with high temperatures and intense rain events, Simons et al. [39] evaluated six different green roof platforms and concluded that all the studied systems showed significantly lower internal temperatures on warm days, while in cold days no differences were observed when compared to traditional and cool roofs. In addition to, Jim and Tsang [40] under similar climate conditions conclude that green roofs cause notable heat losses from the substrate to the ambient air during heating period thus increasing the energy consumption to warm the indoor air. Also some simulation studies as Jaffal et al. [24] provided results by several cities (Athens, La Rochelle and Stockholm), where the performance of green roof during heating period may vary due to the climate zone. The results showed that the main indoor air temperature in hot summer was reduced by 2.6, 2.0, and 1.4 °C for Athens, La Rochelle, and Stockholm, respectively. However, the green roof does not impact on the heating demand in the temperate climate of La Rochelle and an increment of 8% in the Mediterranean climate of Athens was observed.

From these studies it could be stated that the potential of energy savings of green roofs under summer season in several climates are globally known. However, winter experimental tests have been less studied and sometimes the results are controversial. In addition, the literature review strongly recommends the study on the performance of green roofs in winter time for different climates zones [32].

Therefore this paper aims a long term experimental study about the potential of extensive green roofs as passive systems for energy savings under dry Mediterranean continental climate, providing new data for summer and winter periods. For this purpose, in the present paper, several experiments in order to assess the differences in energy consumption between two extensive green roofs compared to a conventional flat roof for both cooling and heating periods have been carried out.

2. Materials and methodology

2.1. Experimental setup

The experiments were done in Puigverd de Lleida, Spain. The experimental set-up consists of three house-like cubicles (Fig. 1) with identical internal volumes (2.4 × 2.4 × 2.4 m). Their foundations are concrete reinforced slabs of 3 × 3 m. The compositions of the walls show the following layers from inside to outside (Fig. 2): gypsum, alveolar brick (30 × 19 × 29 cm), and cement mortar as internal coating. Due to the insulation properties of the alveolar brick, additional insulation layer is not required in this wall system [41,42]. The roof is the only construction system that differs among the studied cubicles.

The roofs evaluated in this study are shaped by the following construction systems:

a) Reference. A traditional insulated flat roof, with precast concrete beams and ceramic floor arch 25 cm with 3 cm of polyurethane insulation layer above, concrete relieved pending formation of 2%, double asphalt membrane, and a single layer of gravel of 7 cm thickness (Fig. 2).
b) Pozzolana. A traditional non insulated flat roof, with precast concrete beams and ceramic floor arch 25 cm, concrete relieved pending formation of 2%, double asphalt membrane, 4 cm of pozzolana as drainage layer, substrate layer of 5 cm thickness, and the vegetation layer (Fig. 3).
c) Rubber crumbs. Identical composition and thickness layers than Pozzolana roof but using 4 cm of rubber crumbs as drainage layer material instead of pozzolana (Fig. 3).

One of these studied extensive green roof systems is new and innovative, designed with the purpose to improve the