Building and Environment 92 (2015) 305–316

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Plant cover and floristic composition effect on thermal behaviour of extensive green roofs

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ARTICLE INFO

Article history:
Received 24 February 2015
Received in revised form
21 April 2015
Accepted 25 April 2015
Available online 1 May 2015

Keywords:
Plant cover
Floristic composition
Thermal behaviour
Extensive green roofs

ABSTRACT

In the last few years an increasing attention has been paid to efficient energy construction systems in the building sector. Although in this contest extensive green roofs are reported to be very effective and sustainable systems, the fact that the main agents of this systems are living organisms have generated doubts, especially in locations where the development of plants and vegetation can be greatly affected by climate. This study aims to investigate the thermal performances of a 2000 m^2 particular proprietary extensive green roof system, located on the city of Lleida (Spain), classified as Dry Mediterranean Continental climate. First, plant cover and floristic composition analysis were carried out to evaluate the dynamic of the plant layer over the surface. Then, according to the result of the botanic analysis, summer and winter study in terms of spatial and temporal factors were conducted focussing on the substrate layer, evapotranspiration effect and comparing the different behaviour of the system in low (10%) and high (80%) plant cover conditions. In this extensive green roof, the results showed temporal and spatial changes in floristic composition, with a stable cover of Sedum sp between 20 and 40 %, and a peak of colonizing species in spring and early summer. The increase in vegetation cover appears to have few effects on the above nearby roof environment because of the low moisture level in the substrate layer so that the cooling effect provided by the evapotranspiration does not take place. In addition, the increased presence of vegetation canopy may induce a limitation in substrate night cooling whereas serves as good shield for solar radiation during the day. Finally, the study also reveals the importance of the spatial factor in extensive green roofs, which can lead to not negligible variations on the thermal performance, as well as the floristic composition.

1. Introduction

In the last few years an increasing attention has been paid to efficient construction systems in the building sector. The concern toward environmental issues, as greenhouse emission reduction, improvement of the urban air quality and the need to limit the energy consumption of buildings has induced researchers from every part of the world to investigate solutions that can offer not only energy savings but other environmental benefits at the same time. In this contest green roofs are reported to be sustainable systems and very effective providing multiple ecosystem services such as the urban heat island effect mitigation [1–3], reducing the storm water run-off which lowers risks of urban floods and improving the urban water balance [4–6], improving water run-off quality [7], removing the air pollution of city air [8] as well as enhancing rooftop membrane durability [9,10]. From an energetic point of view, green roofs are able to lower peak roof surface temperature, suppress temperature fluctuation and, most important, are believed to attain important energy savings in buildings in summer because of the combined effects of evapotranspiration and radiative shading of the plant canopy and in winter air conditioning providing an additional insulation effect [11].

It is important to highlight the fact that there are two clearly different typologies of green roofs, intensive and extensive. Intensive green roofs, commonly called ‘roof gardens’, are developed to be accessible to people and are used as parks or building amenities,

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http://dx.doi.org/10.1016/j.buildenv.2015.04.026
0360-1323/

and are characterized by higher investment and maintenance requirements. Plant selection for intensive green roofs ranges from ornamental lawns, to shrubs, bushes and trees, which affect the weight, build-up heights and costs of the roof garden. In contrast, extensive green roofs are not designed for public use and are mainly developed for not only for aesthetic but for ecological benefits. They are distinguished by minimal maintenance requirements (1–2 times per year) and plants selected tend to be of the low maintenance and self-generative type [12]. A typical extensive green roof is made of several layers, from the bottom to the top: an anti-root and waterproof barrier often combined in a single layer, drainage and water storage layer, fabric filter, and growing media with vegetation [13].

Moreover, referring to the energy performance, green roofs has been studied according to different approaches by different researchers. Some performed simulations in order to obtain the annual or seasonal achievable energy savings. Others reported experimental analysis and results in terms of effect on the outdoor air temperature and the vertical temperatures across the different layers, often comparing with a reference roof.

Getter KL et al. [14] by means of an experimental set-up quantified the thermal properties of an inverted extensive green roof versus traditional gravel ballasted inverted. They found out that the green roof can cause reduction in temperatures of 5 °C in autumn with similar variation in spring. The most significant finding was that the peak temperature differences between gravel roof and green roof in summer showed a maximum of 20 °C. Another study conducted by Teemusk and Mander [9] in Estonia compared the temperature regime of a light weight aggregates based roof garden with a modified bituminous membrane roof in different season. The results of their study revealed that a 100-mm-thick substrate layer of the roof garden can decrease the temperature fluctuations significantly in summer periods. Jim [15] investigated the passive cooling effect of green roofs in humid, tropical Hong Kong with reference to three vegetated plots and a bare control plot. The thermal performance of the three vegetation types demonstrated pronounced variations in air temperatures at different heights, surface temperature, and material temperature at different depths. The findings indicate the key role played by biomass quantity and structural complexity in moulding the passive cooling functions.

Santamouris et al. [16], using the thermal simulation program TRNSYS, found that the building cooling load of a nursery school building in Athens was reduced by between 6% and 49% with the installation of a green roof. Spala et al. [17] with the same simulation software reported a cooling load reduction for the whole building between 15% and 39% while 58% for the last floor. Moreover, the observed decrease of heating load was between 2% and 8% for the whole building and between 5% and 17% for the last floor of the building. Jaffal et al. [18] by coupling a green roof thermal behaviour model with a building code performed simulations for a single-family house with conventional and green roof in three different climates. Finally, the green roof reduces the total energy demand in all three studied climates. Reductions of 32% for the Mediterranean climate of Athens, 6% for the temperate climate of La Rochelle, and 8% for the cold climate of Stockholm were observed.

Usually in simulations the vegetation layer is defined by several characteristics: the most important are plant height, leaf area index (LAI), fractional cover, albedo, and stomatal resistance. However, it is necessary to bear in mind that, unless it is a pre-vegetated green roof system, the vegetation takes time to develop after being installed and that the plants may die and the roof may have no vegetation for a certain period of time [19]. Previous research studies have shown that a green roof covered with plants has a different thermal performance from a green roof without plants. The different thermal performances of green roof and bare substrate roof are due to the plants shading, transpiration, and wind shielding [20]. Another key factor in the performance of vegetated systems is the role of evapotranspiration of plants. It is believed that a wet green roof loses more heat through evapotranspiration than a dry green roof. Castleton et al. [11] and Feng et al. [21] demonstrated that, when growing medium is almost saturated in the water, evapotranspiration of the plants and soil system accounted for 58.4% of the solar gain. The study of Lazzarin et al. [22] revealed that the heat lost through evapotranspiration for a dry green roof is less than half of a wet green roof. They also concluded that the value of evapotranspiration differs for various climates. Likewise, the study revealed that the wet roof provides additional evapotranspiration.

According to these considerations from previous studies it is clear that plant layer becomes a key element in thermal dynamics of vegetated roofs. But in the case of extensive green roofs, that mean minimum maintenance and the use of native plants, under extreme climates, in terms of high temperatures and long drought periods, the final plant cover may differ considerably in reference to milder climates. Thus, in these extreme climates, usually characterized by large climatic variations between seasons, vegetation cover can also vary seasonally modifying the roof thermal performance.

As these long term dynamics can only be studied along the pass of time, data obtained in case studies from green roofs placed in real buildings can provide interesting information referring to the real behaviour of the roof.

This study aims to analyse the plant cover influence on the thermal behaviour of a 2000 m^2 extensive green roof located in an office building at the city of Lleida (Spain) by comparing the results obtained in 2012 with a plant cover of 80% with those obtained in 2010 with a low plant cover of 10% [23].

In addition, the seasonal and spatial changes on the floristic composition and plant cover are analysed as well as the possible influence of those changes over the thermal behaviour of this extensive green roof, both in summer and in winter. Special attention to the thermal behaviour of substrate layer and the influence of the water content on this layer was taken.

2. Materials and methods

2.1. Roof description

The 2000 m^2 extensive green roof object of the study is a part of a refurbishment project located in the Gardeny Science and Technology Park in the city of Lleida (Spain) [24].

The extensive green roof system used, commercial type “ecological roof” [25], consists in the following layers: protection layer (geotextile felt), waterproofing layer, air/water chamber (plastic supports), filter layer (geotextile felt), insulation/drainage layer (slab with two layers, one for the insulation and other made with porous concrete), substrate layer and plant layer. As a particular characteristic of this system, the filter layer, by falling through the slabs joints, not only acts as filter avoiding the pass of substrate particles to the drainage layer but also allows the rise by capillarity of stored water to the substrate layer becoming it available for the plants [26,27]. In this particular project, the extensive green roof has two different types of top finish surfaces, not passable green areas and pedestrian areas finished with gravel (Fig. 1). In gravel areas, the vegetation and the substrate layer were replaced by a single 8 cm gravel layer.

The substrate used is compounded by a mix of mulch, made from decomposition and fermentation of various plant materials, coconut fibres, and fine recycled particles of gravels. The percentage of organic matter is 40% and the other 60% is mineral matter.