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Green roofs energy performance in Mediterranean climate

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ABSTRACT

This paper quantifies green roofs energy savings which is a challenging topic, namely in Mediterranean climate with distinct heating and cooling seasons. The thermal behavior of a green roof case study in Lisbon, Portugal, was assessed through an experimental campaign during heating and cooling periods of the year of 2013. These experimental results were then used to calibrate a building energy simulation in EnergyPlus. After validation, the numerical model was used to compare the energy performance of intensive, semi-intensive and extensive green roofs. The three green roof types lead to similar heating energy needs but extensive green roof solution shows higher cooling energy needs than semi-intensive and intensive ones, of 2.8 and 5.9 times more, respectively. Furthermore, the performance of each type of green roof and different insulation properties was compared to traditional roof solutions. With no thermal insulation, extensive green roofs require 20% less energy use than black roofs and show a similar annual behavior than white roofs. Semi-intensive and intensive green roofs energy use is 60–70% and 45–60% lower than black and white roofs, respectively. Well insulated roofs do not take full advantage of evapotranspiration cooling effects, which is particularly noticeable when comparing with high reflective white roofs.

1. Introduction

The increasing global warming phenomenon together with the rising development of highly populated and impermeable urban areas have amplified severe environmental issues, such as the occurrence of flash floods, soil erosion and management of storm waters, urban heat-island effect, air quality or noise pollution, see e.g. [1–3] for a general review. In this context, there has also been an increased awareness of global environment impacts on energy use [4,5]. To address these concerns, two complementary approaches are typically referred: (i) sustainability of energy sources; (ii) energy efficiency. The present work focuses on the last approach, more specifically on the energy efficiency of buildings. It is estimated that buildings consume about 40% of the total energy use in urban centers, namely in Europe e.g. [6]. Moreover, the energy use is bound to increase as the building sector is expanding.

The energy efficiency of buildings depends directly on the thermal envelope of each building, namely on the thermal behavior of roofs [6]. A green roof is a roof covered with vegetation and a growing medium. Between the structural support and the growing medium, the constructive system may be composed by a waterproofing membrane, a root barrier, and drainage and insulation layers [4]. Usually, green roofs are classified in three types, e.g. [7]: extensive, intensive and semi-intensive. An extensive roof is characterized by a thin growing medium (6–25 cm), small plants, light and minimal maintenance. Intensive green roofs are heavier and thicker (15–70 cm), require more maintenance and support a wider variety of plants. Semi-intensive roofs show intermediate characteristics.

Several green roof studies indicate the importance of green roofs on the temperature regulation of buildings: green roofs may provide a direct decrease of heating and cooling energy use [4,5] and also an indirect contribution to this reduction through water runoff and heat-island effects [8,9]. Greening rooftops is also an interesting option to tackle other environmental challenges, especially in consolidated cities with an important amount of impermeable surfaces and lack of free spaces for introducing new greening areas, see e.g. [10] for a general review.

Although studies indicate a positive contribution of green roofs on the thermal behavior of buildings and urban areas, there is relatively little quantitative information and a growing debate regarding building Heating, Ventilation and Air Conditioning (HVAC) actual energy savings of this solution. Green roofs thermal behavior is associated to an increased thermal resistance but it is also function of the seasonally and diurnally varying shading and evapotranspiration effects of the growing medium

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and vegetation. Therefore, thermal performance of green roofs may vary for different climatic conditions, building characteristics and type of green roof, specifically substrate and vegetation characteristics. Many studies have pointed out the need of regional studies to demonstrate the thermal benefits of green roofs [10–14]. In particular, the impact of this constructive solution on buildings energy in Mediterranean areas is still challenging and ongoing [12].

This paper contributes to the evaluation of building energy performance of green roofs in Portuguese climatic conditions. Consistent with the findings in the Mediterranean region, Portugal is classified as Csa, Csb (C – warm temperate; s – summer dry; a/b – hot/warm summer) according to Köppen climate classification, with a distinct summer and winter seasons [15,16]. Paper is organized with a Methodology section, followed by Results and discussion and finally Conclusions.

2. Methodology

The thermal effectiveness of a green roof case study in Lisbon, Portugal, was assessed through both experimental and numerical approaches. After validation, the numerical model was adopted to evaluate the energy performance of intensive, semi-intensive and extensive green roofs in Mediterranean climate. Finally, energy savings obtained with each type of green roof and different insulation properties were compared with energy use of traditional roof solutions, namely white and black roofs.

Fig. 1 illustrates the methodology used in this work.

2.1. Case study

Field experiments were carried out on the green rooftop of the main building of the Calouste Gulbenkian Foundation (Fig. 2a) located in the center of Lisbon (38°7′ N, 9°1′ W), Portugal, in a park covering a total area of around 7.5 ha. The technical sound room presented in Fig. 2b was selected for monitoring.

The total area of the room is of 17.2 m^2 and ceiling height is 2.2 m. The room has a suspended ceiling with a maximum air gap of 1.30 m (slab area). The compartment is located in the main building and surrounded by conference rooms and a corridor, all acclimatized by the same air-conditioning system. Thus, walls and floor can be considered as adiabatic surfaces. Therefore, thermal fluxes occur only through the green roof. The green roof comprises a 0.20 m concrete slab, beams of 0.90 m and is covered with a 0.10 m drainage layer of gravel and a filter layer. No thermal insulation was used. The rooftop shows a 0.25 m thick soil layer protected with grass or local concrete flags, as illustrated in Fig. 2c. No concrete flags are located over the technical sound room. Height of plants (h = 0.10 m) and Leaf Area Index (LAI = 2) were confirmed on site. The value of LAI is accordance with study [13].

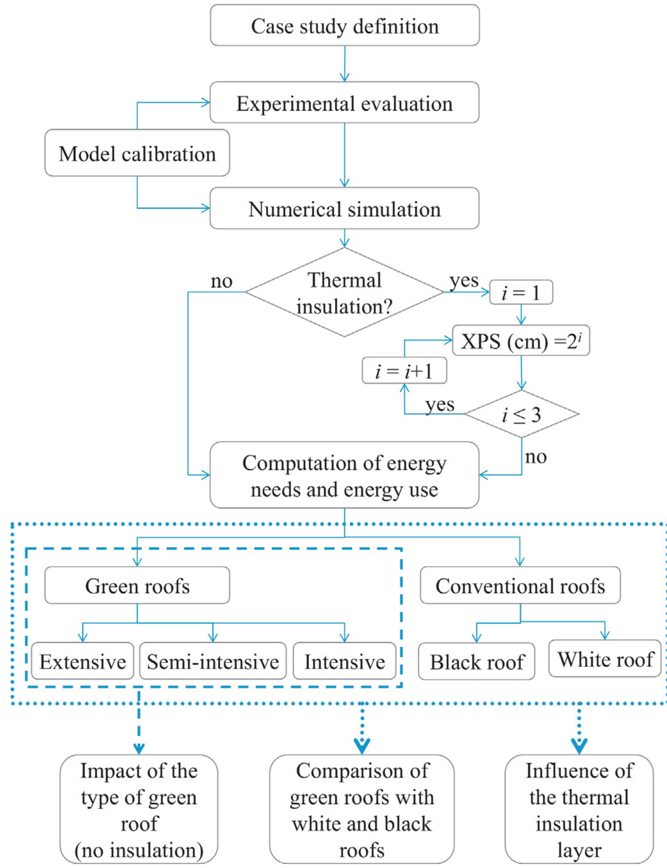

Fig. 1. Methodology flowchart.

2.2. Experimental evaluation

The thermal performance of the green roof was experimentally evaluated for both heating and cooling periods. The campaigns were conducted in the year of 2013 from 21st January to 30th January (winter – heating season) and from 5th to 11th July (summer – cooling season).

The physical parameters measured included: (i) outdoor and indoor temperatures and humidity; (ii) outdoor and indoor surface temperatures; (iii) heat fluxes; (iv) global solar radiation. Field measurements are schematically illustrated in Fig. 3. Equipment details

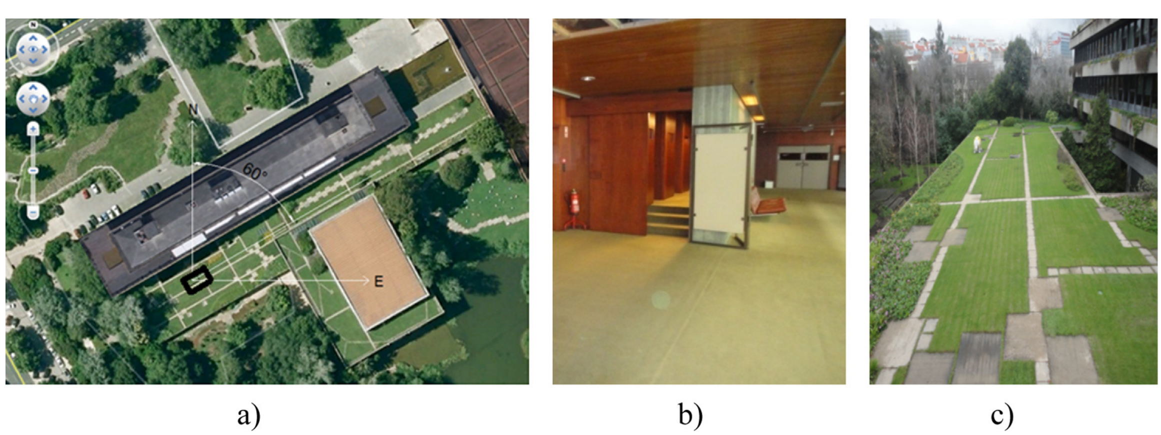

Fig. 2. Technical sound room: (a) localization in Calouste Gulbenkian Foundation; (b) entrance area and (c) green roof.