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Investigating and analysing the energy and environmental performance of an experimental green roof system installed in a nursery school building in Athens, Greece

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Abstract

This paper deals with the experimental investigation and analysis of the energy and environmental performance of a green roof system installed in a nursery school building in Athens. The investigation was implemented in two phases. During the first phase, an experimental investigation of the green roof system efficiency was presented and analysed, while in the second one the energy savings was examined through a mathematical approach by calculating both the cooling and heating load for the summer and winter period for the whole building as well as for its top floor. The energy performance evaluation showed a significant reduction of the building's cooling load during summer. This reduction varied for the whole building in the range of 6–49% and for its last floor in the range of 12–87%. Moreover, the influence of the green roof system in the building's heating load was found insignificant, and this can be regarded a great advantage of the system as any interference in the building shell for the reduction of cooling load leads usually to the increase of its heating load.

Keywords: Greenroof system; Energy performance of buildings; Passive cooling of buildings

1. Introduction

Plants have a strong effect on climate. Trees and green spaces can help to cool our cities and save energy. Trees can provide solar protection to individual houses during summer while evapotranspiration from trees can reduce urban temperatures. Trees also help mitigate the greenhouse effect, filter pollutants, mask noise, prevent soil erosion, and calm their human observers. Moreover, evapotranspiration from soil vegetation systems can remarkably reduce urban temperatures. Shading from trees is an effective way to significantly reduce energy for cooling purposes [1]. Results of computer simulations aimed at studying the combined effect of shading and evapotranspiration of vegetation on energy use of several typical one-storey buildings in US cities showed that by adding one tree per house, the cooling energy savings varied from 12% to 24% [2,3]. Moreover, three trees per house can reduce the cooling load between 17% and 57% [2]. The direct effects of shading account for only 10–35% of the total cooling energy savings. The remaining savings result from temperatures lowered by evapotranspiration [2].

Air temperatures in densely populated and built areas are higher than those measured in the surrounding rural country. The phenomenon is known as 'heat island' and it is a reflection of the microclimatic changes brought about by man-made alterations of the urban surface [4].

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Increased industrialisation and urbanisation in recent years have affected dramatically the number of urban buildings with major effects on the energy consumption of this sector [5]. Urban areas without a high climatic quality, which are areas characterised by high temperatures during summer, dense population, heavy traffic, increased industrialisation, increased building density, reduced green spaces, etc., use more energy for air conditioning in summer and even more electricity for lighting [5]. Moreover, discomfort and inconvenience to the urban population due to high temperatures, wind tunnel effects in streets and unusual wind turbulence due to urban canyon geometry is a very common phenomenon [5,6].

The city of Athens is characterised by a strong heat island effect, mainly due to the accelerated industrialisation and urbanisation during last years. The effect appears during both summer and winter, with mean daily intensity ranging between 6 and 12 °C for the major central area [7–9]. Green roofs present a great number of advantages from both the ecological and social point of view. They act positively upon the climate of the city and its region, as well as upon the interior climate of the buildings beneath them. They give protection from solar radiation, which is the main factor in passive cooling. By reducing thermal fluctuation on the outer surface of the roof and by increasing their thermal capacity, they contribute to the cooling of the spaces below the roof during summer [10]. Green roofs provide significant environmental and human health benefits including ameliorating the urban heat island effect, lowering energy expenditures, purifying the air, and reducing storm-water runoff [11]. Good thermal protection may greatly reduce the high thermal loads from which the construction suffers during summer. Plants on the bare roofs of buildings can also offer this protection. This is an acceptable ecological solution, which contributes not only to the reduction of the thermal loads of the building's shell, but also to the improvement of densely built urban centres with little natural environment [12,13].

The green roof energy performance is a subject which gained ground during recent years. Significant work on this subject has been performed by experimental and computational methods [14–18]. In [14] the thermal behaviour and effectiveness of vegetation covers with different average absorptance for solar radiation and diffusive properties which shield roof-covering structures of different masses are analysed through a finite-difference simulation model. In [15–18], the implementation of green roofs on buildings is presented and analysed.

The present paper has the following as main objectives:

- To present an experimental investigation of an installed green roof system. This experimental investigation mainly consists of measuring major physical parameters such as the outdoor and indoor air temperature and relative humidity for a certain time period.
- To calculate using a transient simulation program the thermal behaviour of the examined building equipped with the green roof system, thus resulting in an investigation of the system's energy efficiency.

Measured parameters were the outdoor air temperature, the outdoor relative humidity, and the indoor air temperature in each thermal zone of the building, while the simulated parameters were the energy consumption (heating and cooling load), and the indoor air temperature in each thermal zone.

2. Experimental investigation of the installed green roof system

The green roof system was installed in a nursery school building located near the centre of Athens. It is a two-floor building with a small basement. An atrium is found at the building's centre. For calculations, the building was divided in eight air-conditioned thermal zones, presented in Table 1. The overall air conditioned area of the building was equal to 854.9 m^2. From this area, the ground floor was equal to 512.5 m^2 while the first floor was 342.4 m^2. The building's aspect ratio, which is the ratio of the building's height over its width, was equal to 0.47. The external walls of the building were mainly made of brick while polystyrene was used as insulation material. The floors were made of marble, concrete and polystyrene as insulation material. The building's roof was made of polystyrene and of the green roof system. Windows were made of simple double glazing materials and the windows' area was 71 m^2 for the ground floor and 53 m^2 for the first floor. The infiltration rate was considered to be equal to 0.2–0.5 air changes per hour while the ventilation rate for the experimented time period was 1–1.5 air changes per hour [19]. The green roof system was installed on the roof of the building and it is made of materials described in Table 2. The system requires a daily quantity of irrigation equal to 1.2 kg/m^2. For a better estimation of system parameters used in simulations the following assumptions, regarding the green roof installation, were taken into account:

(a) The stonewool is an hydroponic material which acts as a water store inside the system. The thermal conductivity

Table 1
Thermal zones of the nursery school building

Thermal Zone	Floor	Area (m^2)	Use
Z1	Ground floor	81.0	Dining room
Z2	Ground floor	367.0	Bedrooms
Z3	Ground floor	64.5	Corridor
Z4	First floor	61.0	Babies room
Z5	First floor	80.1	Staff room and WC
Z6	First floor	119.5	Babies rooms and WC
Z7	First floor	10.8	Administration
Z8	First floor	71.0	Corridor