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Analysis of the green roof thermal properties and investigation of its energy performance

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Abstract

The advantages of the planned roofs are undoubtedly numerous from both the ecological and the 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 the 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 the summer and to the increase of their heat during the winter. Due to the decrease of the thermal losses, the green roofs save the energy consumption.

This paper refers to the analysis of the thermal properties and energy performance study of the green roof. The investigation were implemented in two phases: during the first phase, extended surface and air temperature measurements were taken at the indoor and outdoor environment of the buildings where the green roof had installed and during the second phase of the study, the thermal properties of the green roof, as well as, the energy saving were examined, through a mathematical approach. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Green roof; Energy; Thermal fluctuation

1. Introduction

Sufficient green surfaces in dense urban centres are indispensable to prevent uncomfortable (or even dangerous) and energy wasting (climatisation of buildings) heat island effects. Unfortunately, more and more planted surfaces are disappearing because of ground speculation in city centres. By consequent, turn flat roof surfaces green becomes a efficient and stabilising choice [1].

Although the passive cooling benefits of earth sheltering are reported to be substantial [2], actual quantification of the associated energy savings is less well defined. Much of the current field monitoring of earth shelters is referenced to cold climate designs and performance [3]. In addition theoretical formulations dealing with the benefits of earth cover have often tended to emphasise the winter situation, sometimes at the expense of potentially significant summer benefits [4]. However, a developing awareness of earth sheltering as a design option for overheated climatic regions is becoming apparent [5].

Good thermal protection may greatly reduce the high thermal loads from which the construction suffers during the summer period. Planted roofs 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 [6,7].

Plants have an effect on the climate. Foliage protects the buildings from the solar radiation, controls the temperature and the humidity of the indoor environment and protects the building from winds. In closed spaces with planted roofs, the air temperature beneath the plants is lower than that of the air above.

The difference between the planted roof and the bare roof of a building is both qualitative and quantitative. The process of heat transfer into the planted roof is totally different. The solar radiation, the external temperature and the relative humidity are reduced as they pass through the foliage, which covers the roof. The plants for their biological functions, such as photosynthesis, respiration, transpiration and evaporation absorb a significant proportion of the solar radiation [8]. The remaining solar radiation changed in thermal load, influences the internal climate as it passes through the garden element and through the building element of the roof.

The green roof energy performance and its thermal properties is a subject to which a lot of scientists lead their research the last years. Important work on this subject has been performed by experimental and computational

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methods. It can be mentioned the work of Cappelli et al. [9], where 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. The research of Palomo [10], Dominguez and Lozano [11], and Good [12] is also referred to the implementation of green roofs on the buildings.

This study presents an analysis of the thermal properties of the green roof, as well as, the results of its energy performance.

The main objectives of this study are the following:

- The presentation of the existing situation and the inference of the results concerning the microclimate of the indoor and outdoor environment of buildings where green roof has been located.
- The evaluation of the green roof's thermal properties through both experimental and mathematical approach.
- The estimation of the green roof impact on the total energy saving consumption of buildings.

The analysis was completed in two phases. Initially, experimental measurements were conducted in summer of 2000 in a hotel situated in Loutraki region, near the extended Athens basin. The experimental measurements were conducted in indoor and outdoor spaces, where the green roof has been placed. Then, a study of the green roof's thermal properties, as well as, of its thermal performance using a computational code and a numerical simulation model was performed.

2. Implementation of the experimental measurements

2.1. Instrumentation and temperature measurements

During the first phase of the study extended surface temperature measurements are implemented in the interior and outdoor environment of buildings with the green roof, as well as, in adjacent buildings without the green roof. The basic experimental equipment used for the implementation of the measurements consists of the following:

- A camera of infrared thermograph for the thermograph illustration of the surface temperatures.
- An infrared thermometer for the measurement of the interior and exterior surface temperatures.
- A thermometer–psychrometer for the measurement of the indoor and outdoor air temperature and of the relative humidity.
- Recording indoor air temperature sensors for the study of the thermal comfort conditions.

The selected data (measured by the temperature sensors) refer to the summer period 30 June to 17 August 2000 taken with a 30 min rate, while the rest of the measurements were taken on a specific day at the end of June at noon.

2.2. Results and discussion of the experimental measurements

In Figs. 1–3, some indicative results of the infrared thermographes are presented, for insulated and non-insulated buildings with green roof. Every page consists of four schemes:

- On the upper left part of the page, there is the space thermograph, in other words a figure showing the ''photographic'' temperature distribution in the specific place. Every colour represents a different temperature range as it is shown on the right part of the figure.
- On the upper right part of the page, the respective ''visual'' photo of the specific place exists. Thus, it is possible to have the exact position of the visualised space, as well as, its temperature distribution.
- On the lowest left part again of the page, a diagram is given a presenting the temperature distribution along a horizontal section, illustrated by a straight line in the upper thermograph.
- Finally, on the lowest right part of the page, there is a table presenting the surface temperature of selected points of the infrared thermograph.

It can be concluded that the temperature of the external surfaces presents a significant variation depending on their material. Furthermore, these temperature variations extend even to the surfaces covered by the green roof, depending on the kind of grace and vegetation used in every place of the green roof. The respective measurements were taken on a summer day at the end of June, when the ambient air temperature was 28°C and the relative humidity 57%. Thus, for each type of building, the following results are presented.

2.2.1. Roofs of insulated buildings

According to the infrared thermographs, the temperature range of the green roof, on the external surfaces of insulated buildings, varies from 26 to 40°C, depending on the kind of vegetation covering every place. Besides, there is a similar variation of the temperatures of adjacent surfaces, which are not covered by the green roof, depending on the construction material.

The lowest temperatures of the green roof are ranging between 26 and 29°C and are measured in places dominated by thick dark green vegetation. The highest temperatures are between 36 and 38°C and are measured in places covered by sparse red vegetation, while on the bare ground (soil) of the green roof the temperature approached the value of 40°C. The surface temperatures of the outdoor spaces of insulated buildings without the green roof, range from 27°C for white unshaded walls to 40°C for the unshaded ground, as the infrared thermometer measured them.

Therefore, there are not significant temperature variations between the external surfaces of insulated buildings with and without the implementation of the green roof.

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