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Green roof yearly performance: A case study in a highly insulated building under temperate climate

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ABSTRACT

The research deals with the experimental assessment of the yearly thermal performance of a green roof compared to other passive cooling technologies under temperate climate. All roofs are installed on highly insulated slabs (U-value < 0.25 W/m^2 K), in order to understand whether in summer the passive cooling effects are inhibited by the low thermal transmittance recently introduced in many southern Europe countries to meet the demands of the energy saving regulations for the winter heating season. Even though many studies have focused on the performance of green roofs, there is little knowledge regarding their potential in highly insulated roofs. Most of the studies derived from analytical simulations, but the thermal behaviour of a green roof is a complex phenomenon and involves combined heat and mass transfer exchanges difficult to assess with analytical models, while more experimental data are necessary. Optical properties of the roofs covering materials were experimentally measured, and the thermal transmittance of the roofs was experimentally evaluated. Field measurements show how in winter the green roof is able to guarantee further insulation even in saturation conditions. In summer, the green roof mitigates incoming heat fluxes and ceiling temperatures. Its performance is however partially hindered by high insulation.

1. Introduction

In the past 10 years, with an ever-increasing interest in energy saving techniques and environmental sustainability, numerous researches have been carried out on the potential benefits of using green roofs on buildings.

These roofs can be used not only as systems for construction purposes for reducing energy consumption for heating in winter as well as for cooling in summer [1,2], but they can also be used for reducing the urban heat island (UHI) effect of big metropolitan areas [3,4].

The culture substrate of green roofs could act as a natural insulating material with low thermal conductivity and high thermal mass, while the vegetation in it is useful for reducing solar heat gains due to its high albedo and to the evapo-transpiration phenomena that take place on it [5–8].

Numerous studies have been carried out on the energy performance of green roofs under warm and temperate climates, but most of them analysed the performance of green roofs on buildings that have a high level of thermal transmittance.

Wong [9] analysed the performance of a green roof mounted on a building in Singapore. The U values for the bare roof and the planted roof were 0.58 and 0.45 W/m^2 K, respectively. Authors recorded temperature of the substrate at different levels and with different types of vegetation. One of the main benefits of having a green roof was a reduction in substrate temperature, especially with thick vegetation on it leading to a subsequent reduction in solar heat gains penetrating the building. The author also recorded the ability of the roof to draw out the accumulated heat during the day, at nightime providing indoor comfort inside the building.

Santamouris et al. [10] presented an experimental investigation of the green roof system efficiency in a Greek school and performed simulations to calculate both the cooling and heating load for the summer and winter period. The energy performance evaluation showed a significant reduction of the building's cooling load during summer (for the whole building in the range of 6–49%), while the influence of the green roof system in the building's heating load was found insignificant.

Parizotto and Lamberts [11] analysed the thermal performance of a green roof in both summer and winter by comparing it with other low insulated roofs with ceramic and metal cladding. The green roof was installed on top of an experimental single-family house in the city of Florianopolis (Brazil) which has temperate climate. Results in summer showed that the green roof performed

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better than other kinds of roofs. The green roof led to reduce external surface temperatures, better indoor comfort, reduced thermal flux by up to 97% compared to a metal clad roof, and increased outgoing heat flux by up to 49%. Moreover, the green roof gave excellent performance in winter also. Even though the vegetation in the roof reduces solar heat gains, insulation of culture substrate contributes to reducing the outgoing thermal flux by up to 52% compared to a metal clad roof.

Even though all the above-mentioned studies agree on the overall efficiency of the green roof in terms of both energy saving and environmental comfort, the benefits found are linked to specific cases. In particular, our knowledge about the influence that the installation of a green roof on a highly insulated slab could have on its thermal performance is still limited.

Plus, there is no standard regulation that planners can refer to, a regulation that is able to precisely define stationary and periodic thermal transmittance of green roofs. Some information can be found in literature, also in connection with soil saturation conditions, and there are some studies still going on [12,13].

In this unclear and undefined regulatory context, green roofs mounted together with high insulation levels that respect the national building standards, risk of becoming less efficient. Some studies confirm that the use of high insulation in roofs could limit the potential of some cooling systems on the covering [14]. Other studies demonstrate that green roofs, although being efficacious especially in terms of solar heat gains in summer, can find their potential limited if they are associated to strongly insulated roofs.

Niachou et al. [15] used the results of an experiment that was carried out on a green roof mounted on a building in Athens, to validate an analytical model implemented with TRNSYS. Subsequently, they tried to simulate the energy saving performance of the green roof in terms of different levels of insulation. Results show excellent benefits of the green roof in the case of existing buildings retrofit, that is, in the absence of insulation (U value up to 1.99 W/m^2 K) or with moderate insulation (U value up to 0.8 W/m^2 K), with a reduction in annual energy consumption by up to 48% and 7%, respectively. Contribution of the green roof to an insulated building (U value up to 0.26 W/m^2 K) turns out to be almost next to nothing (2%).

Simulations carried out by Theodosiou [16] on the basis of the analytical model by Palomo del Barrio [5] confirm that increasing the insulating layer in the roof reduces the capacity of the green layer to draw out the stored heat during the day, at nightime because it reduces heat flux that passes through the system.

Zinzi and Agnoli [17] analysed the performance of cool and green roofs on the already existing non-insulated (U = 1.4 W/m^2 K) and moderately insulated (U = 0.6 W/m^2 K) building roofs with the help of Energy Plus software. They were able to obtain savings in consumption compared to traditional roof coverings: by up to 13.9% in the case of non-insulated ones and up to 7.8% in the case of moderately insulated ones.

These results confirm that green roofs are less effective with increased insulation, even if the case of the thermal transmittance of roofs imposed by Italian law (up to U = 0.38 W/m^2 K in the warmest areas, up to 0.29 W/m^2 K in the coldest ones), is not analysed. This probably lead us to hypothesise the major use of these systems for restructuring existing roof coverings.

Jaffal et al. [18] analysed the impact of a green roof on the energy performance of a single-family house, by integrating it into a building thermal programme. The summer indoor air temperature and the energy demand were evaluated for different insulation depths. Results showed that green roofs only exhibit significant effects for uninsulated or moderately insulated buildings, which makes the use of green roofs more thermally advantageous for retrofitting than for new building construction.

Fig. 1. External view of the experimental building near Ancona (Italy): north roof slope.

Most of the results of the above-mentioned studies derived from analytical simulations, while more experimental data are necessary.

The experiment described in this paper would give a contribution, by analysing the thermal performance of a green roof in the summer and winter period, also comparing it with other types of roof coverings, when installed on roof slabs that are strongly insulated in accordance with the present Italian regulation on energy saving in the construction industry. Field measurements were also carried out to assess the optical properties of the different roofs covering materials and evaluate the thermal transmittance in winter season.

2. Materials and methods

The research was carried out by comparing the thermal performance of an extensive green roof with that of 6 other types of roofs in terms of covering and slab (Fig. 1). All of them were installed on a real-scale experimental building in the vicinity of Ancona (Italy, 2064 DD).

The building was 8.20 × 10.50 m, totalling 82.30 m^2 with a unique volume of around 250 m^3, which created a realistic attic. The S/V ratio was 0.89. The side walls were built with multi-layered insulating panels made of polyurethane resin (U = 0.20 W/m^2 K). Inside the envelope, a 30 cm air cavity was created with the help of 22 mm OSB panels in order to reduce the impact of solar radiation on the walls. The floor was insulated with polystyrene panels in order to make the building almost adiabatic (U = 0.33 W/m^2 K).

The roof was divided into 6 modules of roofs of the same width (1.50 each) and same length of 6 m on the south slope and 3 m on the north slope, in order to obtain a similar size as that of traditional roofs.

The roofs, in pairs, were different from each other in terms of the kind of slab (made of wood or concrete), type of roof covering (copper or clay tiles) and the type of under covering ventilation (ventilation absent, 3 or 6 cm air cavity). Fig. 2 shows the stratigraphies which are the focus of the present study (roofs on wooden slab).

The common element among all the roof coverings is the insulation, which was made of two crossed layers of EPS panels with a total thickness of 12 cm (U = 0.25 W/m^2 K). In order to avoid heat transmission in between the modules, the paths of connection were also insulated with EPS panels that were positioned vertically.

In spring 2010 the covering module MNV_LR, facing south, was divided into two parts so as to accommodate on one part (1.5 m × 1.5 m) a green roof (Fig. 3).