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Experimental measurements and numerical modelling of a green roof

Renato M. Lazzarin, Francesco Castellotti *, Filippo Busato

Department of Management and Engineering, University of Padova, Stradella S. Nicola 3, 36100 Vicenza, Italy

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Abstract

Green roof utilisation has been known since ancient times both in hot and cold climates. Nowadays, it has been reconsidered at issue of energy saving and pollution reduction. In this paper, some measurement sessions on a green roof installed by the Vicenza Hospital are described. A data logging system with temperature, humidity, rainfall, radiation, etc. sensors surveyed both the parameters related to the green roof and to the rooms underneath. The aim is to evaluate the passive cooling, stressing the evapotranspiration role in summer time. Furthermore, the enhanced insulating properties have been tested during winter time. A predictive numerical model has been developed in a building simulation software (TRNSYS) to calculate thermal and energy performances of a building with a green roof, varying the meteorological dataset for a specific geographic zone.

Keywords: Green roof; Energy saving; Evapotranspiration

1. Introduction

In the last decades, the space left to the greenery in the urban landscape has decreased, allowing the uncontrolled growing of roads and buildings. The most worrying effects are the worsening of the air quality and the increasing of the average urban temperature. The last is due to the particular urban morphology that increases the thermal storage and lowers the thermal exchanges with the surrounding areas: more thermal energy is ‘‘entrapped’’ in the city and the urban air gets hotter than in the surrounding country. The phenomenon is called Urban Heat Island effect (UHI): it can increase air temperatures to even more than 10 °C [1–3].

It is possible to reduce this effect by increasing the vegetation cover of urban areas and buildings roofs. Moreover, the vegetation used to cover roofs can limit the heat flux through the roof itself reducing the thermal load of the rooms underneath [4–6]. Few experimental works and accurate analytical models are available in literature to explain the evapotranspiration phenomenon as evidenced by many authors [7,8].

In the present paper, after a brief description of the characteristics of a green roof, the specific aim of the research is described. The potentiality of a green roof in the reduction of the cooling and heating load of a building is evaluated by means of experimental data. The evaporative cooling effect is investigated with a finite difference method: its contribution is computed as residual term in the energetic balance of the system. The whole system is also simulated developing a computing model that takes into account all the variables (both regarding the weather and the building).

2. Technical characteristics of a green roof

The various layers of a green roof perform the different functions of a natural soil: giving the nutritional elements, storing water, letting transpiration and drainage in the meantime (Fig. 1).

Generally speaking, on the pre-existing roof covered with a waterproofing sheet, an anti-root barrier prevents the damage of the structure. A retention sheet collects the

* Corresponding author. Tel.: +39 0444 998778; fax: +39 0444 998888.
E-mail address: caste@gest.unipd.it (F. Castellotti).

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Nomenclature

A	adduction flux (W/m^2)
C	thermal accumulation (W/m^2)
e	air partial vapour pressure (Pa)
e^*	air saturation vapour pressure (Pa)
ET	evapotranspiration flux (W/m^2)
G	conduction flux (W/m^2)
K_c	crop coefficient
k_s	short-wave extinction coefficient
LAI	leaf area index
r	water specific heat of vaporisation (J/(kg K))
R	incident global solar radiation (W/m^2)
R_n	solar radiation entering the system (W/m^2)
RH	relative humidity
s	layer thickness (m)
t	temperature (°C)
u	wind speed measured at 2 m above the soil (m/s)

Greek symbols

α	adduction coefficient (W/(m^2 K))
γ	psychrometric constant (Pa/K)
Δ	slope of saturation vapour pressure versus temperature function (Pa/K)
$\Delta\tau$	time interval (s)
ψ	soil water content (kg/m^2)
λ	thermal conductivity (W/(m K))
ρ	specific gravity (kg/m^3)
θ	water flux (kg/(m^2 s))

Subscripts

0	reference value
I, II, III	soil layer
a	air
c	concrete roof
d	drainage
ev	evaporation
i	inside
o	outside
r	rainfall
s	soil
sat	saturation
w	waterproofing sheet

particles eventually fallen down from the upper layers. The drainage layer has the function of recreating the natural condition for the vegetation growing: it accumulates the water by means of little tanks in the upper side, but it permits the drainage of the excess water through some holes. The drainage layer can be made of different materials (recycled polyethylene or caoutchouc, for example) depending on the requested function: it can offer also an added thermal insulation. Over the drainage element, a filter sheet stops the

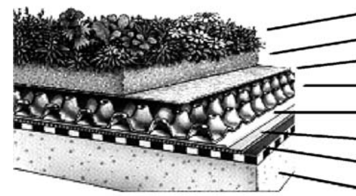

Fig. 1. The different layers of a standard green roof.

finest soil particles, letting the water pass. The soil used in a green roof has a low volumetric mass (800–900 kg/m^3) and it is enriched with minerals and humus. The thickness can vary from 10 to 50 cm: it is the main characteristic that allows to distinguish the so-called extensive green roof from the intensive one. The extensive solution is suitable for lightweight and low height buildings: the utilised plants are species of sedum, shrubs and bushes that need low maintenance and can be self-generative. The intensive landscape, suitable for underground garages and heavy buildings, is a common roof garden, with bushes, ornamental plants and also trees, and needs regular garden maintenance.

3. The model of the physical system

The experimental sessions described in this paper, regard the summers of 2002 and 2003 and the winter of 2004. The measurements were carried out on a green roof installed by the S. Bortolo Hospital in Vicenza, in the north-east of Italy. The green roof has an extension of about 1000 m^2 and it consists of a 20 cm soil layer over an 11 cm drainage layer made of expanded polyethylene. The greenery is a kind of sedum, grown from premixed seed in the soil.

The green roof system has been investigated in dynamic state in a mono-dimensional analysis at the finite differences [9]. The physical system is divided into different segments and nodes. The soil is described with three nodes (subscribes I, II and III), while one node describes the drainage layer (d), the waterproofing sheet (w) and the structural concrete roof (c). The others elements are neglected for the limited mass. The upper border is the ambient air and the lower one is the underneath room.

The whole system is described in Fig. 2, where the oriented thermal fluxes are indicated with continuous lines. ET_i is the thermal flux due to the evapotranspiration process of the generic node i: for the nodes II, III and d, it enters the nodes I, II and III, respectively, with opposite sign: that means that the evaporation heat of the node i is the condensation heat of the upper one. $G_{i,j}$ is the conduction flux between two adjacent nodes and C_i is the thermal accumulation of each node. A_o and A_i indicate the external and internal adduction fluxes, sum of convection and radiative fluxes.