Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Building and Environment 40 (2005) 1505–1511
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

Performance evaluation of green roof and shading for thermal protection of buildings

Rakesh Kumar*, S.C. Kaushik

Centre for Energy Studies, Indian Institute of Technology, New Delhi-110016, India

Received 29 July 2003; received in revised form 5 July 2004; accepted 22 November 2004

Abstract

The present paper describes a mathematical model for evaluating cooling potential of green roof and solar thermal shading in buildings. A control volume approach based on finite difference methods is used to analyze the components of green roof, viz. green canopy, soil and support layer. Further, these individual decoupled models are integrated using Newton's iterative algorithm until the convergence for continuity of interface state variables is achieved. The green roof model is incorporated in the building simulation code using fast Fourier transform (FFT) techniques in Matlab. The model is validated against the experimental data from a similar green roof-top garden in Yamuna Nagar (India), and is then used to predict variations in canopy air temperature, entering heat flux through roof and indoor air temperature. The model is found to be very accurate in predicting green canopy-air temperature and indoor-air temperature variations (error range $\pm 3.3\%$, $\pm 6.1\%$, respectively). These results are further used to study thermal performance of green roof combined with solar shading. Cooling potential of green roof is found adequate (3.02 kWh per day for LAI of 4.5) to maintain an average room air temperature of 25.7 °C. The present model can be easily coupled to different greenhouse and building simulation codes.

Keywords: Foliage; Canopy; Green rooftop; Leaf area index; Shading

1. Introduction

Enormous use of ground for various purposes has lead to disappearance of green planted surfaces. In order to prevent dangerous and uncomfortable urban heat island effects the indispensable need of planted surfaces is quiet inevitable as is confirmed by many researchers viz. [1–5]. Space constraints have further reduced the applicability of green surfaces in various areas surrounding the building envelope. Consequently, planted roofs become the only promising and stabilizing choice in the present scenario.

Good thermal protection can greatly reduce the high thermal loads that badly affect the comfort conditioning of building during summers. Eumorfopoulou and Aravantinos [2] reported that planted roofs contribute not only in reducing the thermal loads on the building's shell but also in reducing urban heat island effects in densely built areas having a little natural environment. Akbari et al. [6] have described the cooling energy potential of shade trees by reduction of the local ambient temperature. For their biological functions such as photosynthesis, respiration, transpiration and evaporation, the foliage materials absorb a significant proportion of the solar radiation. Thermal protection techniques of green roof can provide a great degree of reduction in the local air temperature near canopy, thus reducing the incoming heat flux into the building. A study done by Onmura [4,7] revealed that in closed spaces with the planted roofs, the air temperature beneath the plants is lower than that of the air above, by nearly 4–5°C. Thermal performance of green roof

*Corresponding author. Tel.: +91 11 2659 1253; fax: +91 11 2659 1266.
E-mail addresses: krakesh1999@hotmail.com (R. Kumar), sckaushik@ces.ernet.iitd.in (S.C. Kaushik).

0360-1323/$ - see front matter © 2005 Published by Elsevier Ltd.
doi:10.1016/j.buildenv.2004.11.015

Nomenclature

d	average leaf thickness
D_{VT}	vapor diffusivity
$h_{a\infty}$	heat transfer coefficient to air
h_g	convective coefficient of vapor transport
H_c	height of green canopy
H_s	height of soil layer
H_R	thickness of roof support
i	nodal points
L	canopy layer thickness
p_l	leaf vapor pressure
p_a	air vapor pressure
p_g	vapor pressure at soil surface
r_e	mean canopy resistance to sensible heat transfer
T_c	temperature of canopy
T_a	temperature of air
T_{sky}	sky temperature
T_g	ground temperature
T_{so}	soil Temperature
T_∞	air temperature

Greek letters

$\tau_s =$	shortwave transmittance
$\tau_t =$	transmittance of the leaf tissue
θ_a	air specific humidity
ψ_s	solar radiation
ρ	density
λ_{su}	thermal conductivity of support material

have been studied in great detail recently by several researchers. It is worth mentioning the works on prediction of thermal performance of green roofs by Del Barrio [3] and Good [8]; and on implementation of green roof in the buildings by Dominguez and Lozano [9]; Eumorfopoulou and Aravantinos [2] and Takakura et al. [10]. Capelli et al. [11] predicted thermal behavior and effectiveness of vegetation covers with different average absorptance for solar radiation and diffusive properties, which shields roof-covering structures of different masses. In a study conducted by Niachou et al. [12], investigation of green roof is done in two phases; in the first phase, extensive data measurements for temperature, both indoor and outdoor are considered, and in the second phase, thermal properties of green roof are studied using a mathematical approach. Hoyano [13,14] conducted an experimental study on effect of rooftop lawn planting on thermal environment and also described for climatological uses of plants for solar control and the efforts on the thermal environment.

Many of the studies predict thermal performance of green roof localized to experimental site or employ several numerical techniques to evaluate thermal performance. This restricts the applicability of the green roof to particular buildings and hence thermal space conditioning of different building cannot be predicted, as green roof model is to be coupled to the building simulation code. Effect of parametric variations in thermal components of green roof on cooling potential is also not described. This model improves upon these aspects by incorporating thermal modeling of green roof components, parametric variations in the green roof components and coupling the model to the building simulation code. The process of heat transfer into the planted roof is very different from bare roof, both qualitatively and quantitatively. The analysis of green roof can be classified into three sub-regions, viz. green canopy, soil, and the roof support. Dynamic performance of each of the sub-region can be evaluated and further coupled with each other using the boundary conditions.

The objective of studying green roof is multifold: to determine the effect of variations in foliage characteristics, viz. leaf area index (LAI) and foliage height thickness on thermal performance of green canopy, estimation of thermal load reduction in the building and evaluation with thermal shading on building space conditioning. Results obtained from the simulation of green roof model are validated with experimental data from an existing green roof with similar foliage characteristics and building parameters in Yamuna Nagar, Haryana state of India.

2. Mathematical formulation

The green roof top modeling described is based on Del Barrio [3]. Fig. 1 shows the model of green roof

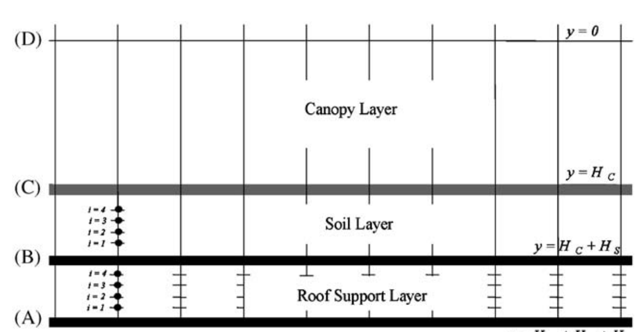

Fig. 1. Schematic of green roof model.