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Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates

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Abstract

This paper discusses the thermal effect of covering the building envelope with vegetation on the microclimate in the built environment, for various climates and urban canyon geometries. A two-dimensional, prognostic, micro scale model has been used, developed for the purposes of this study. The climatic characteristics of nine cities, three urban canyon geometries, two canyon orientations and two wind directions are examined. The thermal effect of green roofs and green walls on the built environment is examined in both inside the canyon and at roof level. The effects of this temperature decrease on outdoors thermal comfort and energy savings are examined. Conclusions are drawn on whether plants on the building envelope can be used to tackle the heat island effect, depending on all these parameters taken into consideration.

Keywords: Green roofs; Green walls; Urban canyon; Plants; Built environment

1. Introduction

Since the beginning of human existence man has clearly intended to alter his microclimate, to a more "human-friendly" one, protecting himself from extreme climatic conditions. Even from the first evidence of Neolithic houses and settlements, it is obvious that they were not sited in a purely natural environment, but in a part of nature transformed according to a human plan [1]. With the evolution of human societies, settlements were transformed, evolved into villages, towns or cities, developed or faded away, according to the geographical, economic, social and cultural transformations taking place throughout time. With the Industrial Revolution, urban spaces expanded dramatically, much faster and with much more significant changes than in their previous evolutionary periods. The large areas modern cities occupy, their structure, materials and the general lack of vegetation cannot but have altered the climatic characteristics of urban spaces.

These changes have a direct effect on the local climate of urban spaces, especially the central parts of the city, causing a significant rise of the urban temperature and other alterations, known as the *heat island effect*. This may cause serious local climatic unpleasant conditions and even imperil human health, especially for cities in climates with a distinctively hot season [2,3]. The moderation of extreme heat in the local environment of such climates could mean not only their sustainability, but also the potential of occupying them without the morbidity and mortality risks caused by excessive heat [4,5].

On prima facie evidence, the general lack of vegetation in existing cities is one of the factors affecting the formation of raised urban temperatures. In most urban spaces, appreciable amounts of vegetation exist mostly concentrated in parks or recreational spaces. Although parks manage to lower temperatures within their vicinity [6–9], they are incapable of thermally affecting the concentrated built spaces where people live, work and spend most of their urban lives. By placing vegetation within the built space of the urban fabric, raised urban temperatures can decrease within the human habitats themselves and not only in the detached spaces of parks. Urban surfaces which

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Nomenclature

Latin Letters

C	net sensible heat loss on leaf tissue (W/m^2)
c_1:	isobaric specific heat of component 1 (moisture) of the mixture (J/kg K)
c_2:	isobaric specific heat of component 2 (air) of the mixture (J/kg K)
c_c	building material specific heat capacity (J/kg K)
c_{pa}	isobaric specific heat capacity of air (J/kg K)
$c_{p\ell}$	specific heat capacity of the leaf tissue (J/kg K)
D	binary diffusion coefficient (m^2/s)
I_1	any source of mass of moisture ($kg/m^3 s$)
K_{Hx}	eddy diffusion coefficient of energy in x-axis (m^2/s)
K_{Hz}	eddy diffusion coefficient of energy in z-axis (m^2/s)
K_{Ex}	eddy diffusion coefficient of water vapour in x-axis (m^2/s)
K_{Ez}	eddy diffusion coefficient of water vapour in z-axis (m^2/s)
q	relative concentration of water vapour, expressed as specific humidity (kg/kg)
q_E	heat gains/losses from the building's fabric (W/m^2)
t	time (s)
T	air temperature (K)
T_{in}	indoors air temperature (K)
T_ℓ	leaf surface temperature (K)
T_{out}	outdoors air temperature (K)
U	average building's fabric U-value ($W/m^2 K$)
u	air velocity in x axis (m/s)
w	air velocity in z axis (m/s)

Greek Letters

α_a	coefficient of thermal diffusivity of air (m^2/s)
a_c	building material thermal diffusion coefficient (m^2/s)
a_m	diffusion coefficient of moisture in the building material (m^2/s)
ε	evaporation number of the building material
λ	latent heat of vaporisation (J/kg)
λE	net latent heat loss on leaf tissue (W/m^2)
ρ_a	density of moist air (kg/m^3)
ρ_ℓ	density of the leaf tissue (kg/m^3)
Φ_n	net heat gain on leaf tissue from radiation (W/m^2)

are not used, such as the building envelope (walls and roofs), could easily be covered with vegetation and alter the microclimate of the built environment, as well as the local climate of the city. The magnitude of temperature decreases due to this transformation depends on the climatic characteristics, the amount of vegetation and urban geometry.

This paper presents the results of a quantitative research on how the heat island effect can be tackled by covering the envelope of urban buildings with vegetation. The aim of this research has been to assess the potential of mitigating raised urban temperatures through vegetation, for different urban geometries and climates.

2. Methodology

A two-dimensional, prognostic (dynamic) micro-scale model has been developed and programmed in C++, describing heat and mass transfer in a typical urban canyon (Fig. 1). The differential equations describing heat and mass transfer in the air, building materials (considered as capillary—porous bodies), soil and vegetation have been solved with finite differences approximations, where surface elements are replaced by nodes [10]. The effect of vapour gradients on temperature gradients has been described analytically in the air nodes near the surfaces as the effect of diffusion on heat transfer [11,12]:

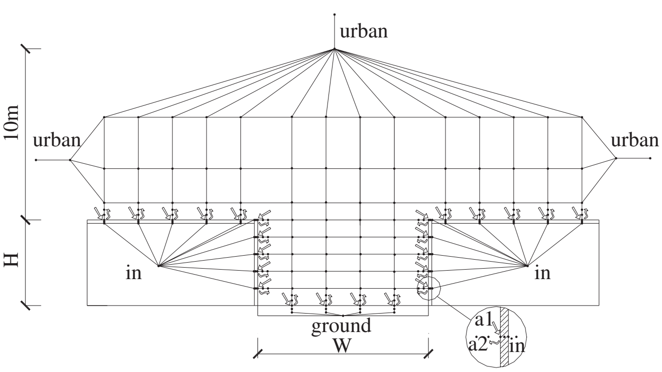

Fig. 1. Two-dimensional canyon model.

$$\frac{dT}{dt} = \nabla[\alpha_a \nabla T] + \frac{\lambda}{c_{pa}\rho_a} I_1 - \left(\frac{c_1 - c_2}{c_{pa}}\right)(D\nabla q \nabla T), \quad (1)$$

$$\frac{dq}{dt} = \nabla[D\nabla q] + \frac{1}{\rho_a} I_1, \quad (2)$$

where T is the air temperature (in K), t is time (in s), α_a the coefficient of thermal diffusivity of air (in m^2/s), D the binary diffusion coefficient (in m^2/s), c_{pa} the isobaric specific heat capacity of air (in J/kg K), ρ_a is the density of moist air (in kg/m^3), λ the latent heat of vaporisation (in J/kg), I_1 is any source of mass of moisture (in $kg/m^3 s$), q is the relative concentration of water vapour, expressed as