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Modeling green wall interactions with street canyons for building energy simulation in urban context

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ABSTRACT

A hygrothermal model of green walls and a model of mass flows in street canyons have been proposed and implemented in a building simulation program (TRNSYS). The coupled models allow the study of the hygrothermal interaction of green walls at the interface of the detailed building model and the urban microclimate of the street. Its use highlights the effects on both urban microclimate and buildings energy loads, especially in the summer period. While reducing anthropogenic heat release, green walls set up on west or east façades mitigate the street air temperature and reduce building cooling loads depending on streets' aspect ratio. Some of the canyon model parameters were calibrated through numerical comparison with experimental data on a reduced scale mockup. This mockup has been designed specifically to assess the green walls hygrothermal impact and to evaluate the developed numerical tools. This experimental calibration made simulating the green walls interactions with street canyons of different aspect ratios possible. The experimental and numerical results obtained with green façades underline the advantage of this modeling approach for the design of passive cooling for buildings and mitigation of excessive thermal conditions within street canyons in dense cities in warm climates.

1. Introduction

Improving the energy performance of buildings and their environmental quality is essential for sustainable urban development. The use of innovative materials for building envelops, such as cool materials or green envelops, may directly or indirectly serve to mitigate the negative effects, such as excessive heat, arising from the urban microclimate (Santamouris, 2014). We focus in this study on the cities where the urban heat island creates more problems in summer than it solves in winter (increased pollution, health risks and mortality, discomfort ... etc.). The objective of this study is to highlight a modeling approach to assess the hydrothermal impacts of vegetated roofs and façades. These latter are, above all, architectural and landscape solutions adopted for any purpose by architects and town planners.

Just as trees can improve urban environment (Akbari et al., 1997), green roofs and green walls have direct impacts on the urban environment (Djedjig et al., 2015a; Kolokotroni and Giridharan, 2008; Synnefa et al., 2008). They can improve building performance mainly for space cooling in certain circumstances e.g. warm background climates (Castleton et al., 2010; Djedjig et al., 2015b; Jaffal et al., 2012; Zinzi and Agnoli, 2012). For warm climates specifically, the use of cool paints and vegetated façades can serve to decrease surface temperature during the day by reducing solar radiation absorption, thus to reduce the

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subsequent release of heat into the canyon at night. In turn, the resulting microclimate modifies the building energy load (Bozonnet et al., 2015; Gros et al., 2014). Since the heat and mass transfers between the building and its environment are coupled, the building energy demand should be estimated accounting for the microclimate interaction.

The impacts of these coating techniques are studied for façades as for roofs, especially in dense urban environments. When the urban structure is characterized by narrow street canyons, the radiation trapping can increase surface temperatures, and reduced airflow recirculation leads to higher air temperatures (Bozonnet et al., 2005). Doya et al. (2012) found, through the same reduced-scale bench brought up in this paper, that the use of a cool selective paint on street façades reduces the daytime air temperature within the street by about 1.6 °C. Although cool painted and vegetated façades have somewhat similar impacts on buildings energy performance, their thermal behavior and their environmental impact are quite different. Indeed, both cool paints and vegetated façades reduce heat storage surface temperature. However, cool paints reflect the most of radiation while vegetated façades absorb more radiation but dissipate much of heat by evapotranspiration (Djedjig et al., 2013, 2015a). The reflected radiation may be intercepted by the street or other buildings in the vicinity which would increase their irradiance. So the use of green façades may be more suitable in some urban configurations. In addition, although vegetated walls and roofs may be more expensive in terms of their upfront cost (Saadatian et al., 2013), they provide other environmental benefits beyond the summer cooling (hydrological, acoustic, ecological and sociological benefits). Moreover, they do not directly increase the heating demand of buildings in winter.

In this paper, we present a modeling approach to assess the thermal impacts of green walls on buildings and their surrounding environment. To do so, a green envelope model developed earlier (Djedjig et al., 2012) is used to simulate the hygrothermal behavior of green walls coupled to the street canyon model of Harman et al. (2004). The green wall model has been developed to overcome certain limitations and assumptions of previous modeling approaches that assume quasi-steady state heat transfer and neglect the effect of water transfer on heat transfer. This green envelope model written in Python programming language is used as a TRNSYS submodel (Djedjig et al., 2015b). Furthermore, Harman et al. (2004) model used here to simulate heat fluxes from street canyons has been integrated into TRNSYS. In addition, measurements data gathered on experimental buildings and street canyons scale mockup are used for experimental comparisons. The experimental approach has allowed us to determine the hygrothermal impact of green roofs and green walls on the built environment in street canyons. The experimental results quantify the microclimatic impact of green walls at the street scale. These measurements are used to calibrate a street canyon model in order to evaluate the energy performance of vegetated buildings subjected to microclimatic conditions.

2. Methodology – model and experiments

2.1. Green wall model and experiment

The developed green envelope model (Djedjig et al., 2012) allows for the evaluation of the coupled heat and mass transfer through the green module. The vegetation is characterized by its coverage ratio (σ_f), its leaf area index (F) and the average leaf thickness (d_f). The substrate is a porous medium whose thermophysical properties depend on its water content (Ouldboukhitine et al., 2012). The model equations establish the heat balance on the leaf canopy (height h_f) and on the substrate surface (depth h_g), see Fig. 1. The energy balances include the main heat fluxes (in W m^{-2}) namely the short- and long-wave radiation (R_n), sensible heat fluxes (H) and latent heat fluxes (L). The direction of heat and mass flux is perpendicular to

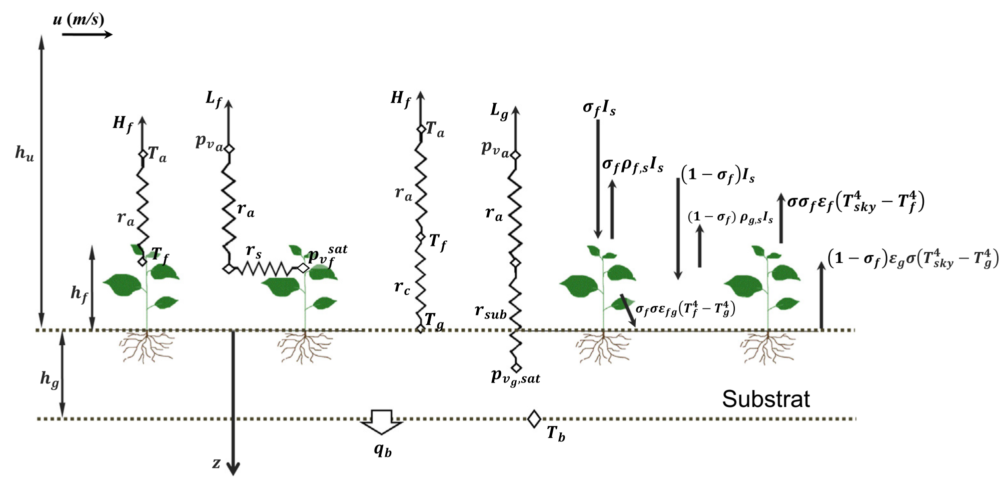

Fig. 1. Main modeled heat fluxes on a vegetated envelope module and corresponding heat and vapor transfer resistances. The total vegetated envelope width is $h_f + h_g$ (foliage and substrate), the backside (building side) temperature is noted T_b and the transmitted heat flux toward the building q_b.