Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 121 (2015) 56–67

SOLAR ENERGY

www.elsevier.com/locate/solener

Modeling double skin green façades with traditional thermal simulation software

Silvana Flores Larsen [a,*], Celina Filippín [b], Graciela Lesino [a]

[a] Instituto de Investigaciones en Energía No Convencional (INENCO), Universidad Nacional de Salta, CONICET, Avenida Bolivia 5150, 4400 Salta, Argentina

[b] CONICET, CC302, Santa Rosa, 6300 La Pampa, Argentina

Received 30 December 2014; received in revised form 23 July 2015; accepted 22 August 2015
Available online 27 September 2015

Abstract

The use of plants attached to the building walls is a bioclimatic strategy that has grown in popularity due to the savings in building energy consumption. The plant is a living component of the façade that responds to the environment in a very complicated way, by regulating their transpiration levels. The simulation of this response is generally not included in the available software for transient thermal simulation of buildings, thus making difficult the simulation of green walls by architects and building designers. The aim of this paper is to present a simplified method to simulate a green wall using a traditional wall/glazing element, with fictitious properties, whose thermal model is included in transient simulation softwares. Thus, green walls can be simulated with softwares that do not provide specific modules for plant calculation. The model is more accurate under humid conditions and for low wind speeds. An application example is presented, consisting of a building prototype with a green façade that was simulated through EnergyPlus software. Inside and outside glass temperatures, plant foliage temperature, and window heat gain and losses were calculated. The results were discussed and recommendations for simulating green façades were done.

Keywords: Green wall; Evapotranspiration; Double façades; Plants

1. Introduction

Using plants on building walls is an effective passive design strategy that has benefits at the urban, building, and human scales. At the urban scale, this strategy mitigates the heat island effect and reduces the CO_2 emissions (Alexandri and Jones, 2008; Thottathil et al., 2010; Metselaar, 2012). When compared with green roofs, green walls have larger potential surface area for greening because in tall buildings the area of the walls is always greater than the area of the roof. Thus, green walls can play an important role in urban rehabilitation and they can contribute to the insertion of vegetation in the urban context without occupying any space at street level (Manso and Castro-Gomes, 2015). At the building scale, green walls can reduce the energy demands of buildings and provide benefits related to the acoustic comfort (GhaffarianHoseini et al., 2013; Manso and Castro-Gomes, 2015). The reduction of the energy demand is due to the additional insulation layer provided by the vegetation together with the shading of building façades and the evaporative cooling effects on the surrounding air (Pérez et al., 2011; Renterghem et al., 2013). For example, reductions of around 12–32% in the cooling loads were reported for a building in Singapore with 50% and 100% of glazing coverage, respectively (Wong et al., 2009), while reductions of 28% were found by Di and Wang (1999) in a west vegetated wall in summer.

* Corresponding author. Tel.: +54 387 4255578.
E-mail address: seflores@unsa.edu.ar (S. Flores Larsen).

http://dx.doi.org/10.1016/j.solener.2015.08.033
0038-092X/

Nomenclature

A_f	effective area, m^2
$c_{p,f}$	specific heat at constant pressure, J/(kg K)
d	characteristic length of the leaf, m
e_{air}	the actual vapor pressure, kPa
e_f	average leaf thickness, m
e_0	saturation vapor pressure at the mean air temperature, kPa
F_{ground}	view factor between the green façade and the ground, unitless
F_{sky}	view factor between the green façade and the sky, unitless
g	gravitational acceleration, m/s^2
G	heat absorbed by the soil, usually negligible when compared to the other contributions ($G \cong 0$), W/m^2
Gr	Grashoff number ($Gr_L = \beta g L^3 \Delta T / u_\infty{}^2$), unitless
h_c	reference crop or plant height, m
$h_{f,in}$	heat transfer coefficient between the foliage and the air cavity, $W/(m^2\,K)$
$h_{f,out}$	heat transfer coefficient between the foliage and the outdoor environment, $W/(m^2\,K)$
h_w	heat transfer coefficient between the outer wall/window surface and the air cavity, $W/(m^2\,K)$
I_s	solar radiation incident on the green façade, including the shortwave radiation reflected by the ground and surrounding surfaces, W/m^2
$I_{IR,f}$	radiative heat exchange between the foliage and the surrounding environment (sky, ground, and glass/wall surface), W/m^2
k	von Karman constant (equal to 0.41), unitless
LAI_{active}	active (sunlit) leaf area index, m^2 of leaf area/m^2 of soil surface, unitless
L_f	latent heat, W/m^2
Pr	Prandtl number, unitless
$qrad$	infrared net flux between the green façade and the surrounding, W/m^2
r_a	aerodynamic resistance to moisture transfer, s/m
r_l	stomatal resistance, resistance of a single leaf to the diffusion of water vapor from the leaf stomata into the atmosphere, s/m
$r_{l,min}$	minimum stomatal resistance, s/m
r_s	'bulk' surface resistance, resistance of vapor flow through the transpiring crop and evaporating soil surface, s/m
Re	Reynolds number ($Re_d = u_\infty \rho d/\mu$), unitless
T_{ground}	ground temperature (K)
T_{sky}	sky temperature (K)
$T_{w,out}$	outer surface temperature of the glass or wall (K)
u	wind speed, m/s
W	water evaporated, $g/(s\,m^2)$
x	ratio of latent heat expelled from the plant to total absorbed radiation by the plant, unitless

Greek symbols

α_f	solar absorptivity of the vegetation, unitless
β	volumetric thermal expansion coefficient, 1/K
γ	psychrometric constant ($\gamma = 665 \times 10^{-3}\,P$, with P the air pressure in kPa), kPa/°C
ΔT	in Gr number, the absolute value of the temperature difference between the surface and the fluid in the free stream, K
ε_f	infrared emissivity of the vegetation, unitless
ε_w	glass (or wall) infrared emissivity of the vegetation, unitless
λ	specific heat of water evaporation ($\lambda = 249$ KJ/kg)
Λ	slope of the saturation vapor pressure–temperature curve at the mean air temperature $\overline{T}$ in °C (kPa/°C)
ρ_f	density of the plant, kg/m^3
σ	Stephan–Boltzmann constant, $5.67 \times 10^{-8}\,W/(m^2\,K^4)$
τ_f	solar transmissivity of the vegetation, unitless

Reductions of the temperature of the external surface of building walls between 1.1 °C and 11.6 °C were found, depending on the vegetation type (Wong et al., 2010). Other studies reported reductions of 5.5 °C (Pérez et al., 2011) and 1.9–8.3 °C (Eumorfopoulou and Kontoleon, 2009). At the human scale, using plants in the built environment is recognized, beyond its aesthetic value, as a source of psychological and therapeutic benefits (Fjeld et al., 1998).

Pérez et al. (2011) proposed a detailed classification of green vertical systems. The authors make a first classification of green vertical systems into *green façades* and *living walls*. In *green façades*, climbing plants or hanging port shrubs are developed using special support structures, mainly in a directed way, to cover the desired area. The plants are mainly rooted at the base of these structures, in the ground, in intermediate planters or even on rooftops. On the other hand, *living walls* are made of panels and/or geotextile felts, sometimes pre-cultivated, which are fixed to a vertical support or on the wall structure. These panels can be made of various types of material, and support a great variety of plant species. Due to the diversity and density of plant life, *living walls* normally require more intensive maintenance and protection than green façades (Kontoleon and Eumorfopoulou, 2010). This paper focuses