Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 129 (2016) 310–331

SOLAR ENERGY

www.elsevier.com/locate/solener

Development of a dynamic model for natural ventilated photovoltaic components and of a data driven approach to validate and identify the model parameters

J. Cipriano [a,*], G. Houzeaux [b], G. Mor [a], U. Eicker [c], J. Carbonell [d], S. Danov [d]

[a] *Centre Internacional de Mètodes Numèrics a l'Enginyeria (CIMNE), Building Energy and Environment Group, CIMNE-UdL classroom c/Pere de Cabrera s/n, Office 1.16, 25001 Lleida, Spain*

[b] *Barcelona Supercomputing Center (BSC-CNS), 08034 Barcelona, Spain*

[c] *Research Centre Sustainable Energy Technologies, University of Applied Sciences Stuttgart, Schellingstr.24, 70174 Stuttgart, Germany*

[d] *Centre Internacional de Mètodes Numèrics a l'Enginyeria (CIMNE), Building Energy and Environment Group, c/Rambla St Nebridi 22, 08222 Terrassa, Spain*

Received 28 January 2015; received in revised form 2 December 2015; accepted 6 January 2016
Available online 5 March 2016

Communicated by: Associate Editor Mario A. Medina

Abstract

In the development of dynamic models for the energy performance evaluation of building integrated natural ventilated PV components there are still many open questions regarding the uncertainty of the estimated parameters of the models. Traditionally, the dynamic models for these complex components are derived from the heat transfer balance equations, and the unknown heat transfer coefficients (convection and radiation), the solar properties of the materials or the pressure coefficients for the air mass flow rate balance, are assigned based on literature or on manufacturer prescriptions. However, there is a lack of systematic methods able to validate the simulation outputs with the measured data, taking into consideration the uncertainty of the parameters and their effect over the results. This research is focused on the development of a dynamic simulation model for a PV ventilated component, and on the application of a data-driven iterative approach to identify the unknown parameters, to evaluate their influence in the simulation outputs and finally, to determine the deviations of the simulations outputs against the measured data. During the identification process, 43 unknown parameters are detected and 13 of them are categorized as strong parameters. The implemented data driven approach is able to achieve high goodness of fit with the measured data and it is recommended to analyses which aim at evaluating the influence of some component parameters or the thermal and electrical energy produced by these natural ventilated PV components.

Keywords: Building integrated photovoltaics; Dynamic simulation modeling; Data driven optimization; Sensitivity analysis; Latin Hypercube Monte Carlo

1. Introduction

For the last years, many authors have been working in the field of double skin ventilated photovoltaic (PV) components with and without building integrated photovoltaics (BIPV). Since the 1990's Hans Bloem,

* Corresponding author at: Centre Internacional de Mètodes Numèrics a l'Enginyeria (CIMNE), Building Energy and Environment Group, CIMNE-UdL Classroom, c/Pere de Cabrera s/n, CREA building, Office 1.16, 25001 Lleida, Spain. Tel.: +34 973003574; fax: +34 973003575.
E-mail address: cipriano@cimne.upc.edu (J. Cipriano).

http://dx.doi.org/10.1016/j.solener.2016.01.039
0038-092X/© 2016 Published by Elsevier Ltd.

Nomenclature

A	area (m^2)
b	depth of the air gap (m)
C_d	discharge coefficient (–)
c_p	specific heat capacity of the air (J/kg °C)
d	length of the finite elements (m)
D_h	hydraulic diameter (m)
g	gravitational acceleration (m/s^2)
G	incident solar radiation (W/m^2)
B	buoyancy term, (–), $B = 2SGr_{Dh}/Pr$
$\overline{h}$	average convective heat transfer coefficient (W/m^2 °C), $\overline{h} = \overline{Nu} \cdot k/D_h$
h_r	linearized radiative heat transfer coefficient (W/m^2 °C)
h_i	thickness of each solid layer (m)
H	height of the ventilated PV component (m)
H^+	dimensionless height, (–), $H^+ = H/2bRe$
k	thermal conductivity (W/m °C)
k_h	inlet and outlet hydraulic losses (–)
$\dot{m}$	air mass flow rate (kg/s)
$\overline{Nu}$	average Nusselt number (–)
P	Packing factor (–), $P = A_{PV}/A_T$
Pr	Prandtl number (–)
q''	specific heat flux (W/m^2)
q''_e	specific electrical production of the PV laminate (W/m^2)
Q	volumetric heat source (W/m^3)
Ra''_b	modified Rayleigh number for uniform heat flux boundary conditions, (–), $Ra'' = \rho^2 g \beta c_p q''_w b^5/\mu k^2 H$
Re	Reynolds number (–)
S	coefficient of stratification (–)
S_g	solar radiation absorbed by the solid layers (W/m^2)
T	average temperature of the air gap at a fixed height (°C)
y	vertical distance (m)
W	width of the ventilated PV component (m)

Greek letters

α	solar absorptivity (–)
ε	total hemispherical emissivity (–)
σ	Stefan Boltzman constant, $\sigma = 5.67 \cdot 10^{-8}$ (–)
τ	solar transmittance (–)
ρ	density (kg/m^3)
ν	kinematic viscosity (m^2/s)
μ	dynamic viscosity (kg/m s)
η	unitary vector at normal direction (–)
η_{PV}	photovoltaic cells efficiency at standard conditions (–)
θ	incident angle (°)

Subscripts

a	ambient
app	apparent
b	beam
c	front node of the PV laminate
$cond$	conduction
d	diffuse
e	back node of the PV laminate
e_i	thickness of the solid layers
f	air or fluid
g	rear facing material
$g1$	front node of the rear facing material
$g2$	back node of the rear facing material
gPV	clear glass of the PV module
h	horizontal
i	inlet
m	weather station
n	normal
o	outlet
PV	photovoltaic cells
$PV1$	node of the PV cells layer
r	radiation
s	sky
t	turbulent
tr	semi transparent surface
T	total surface
wc	cold wall
wh	hot wall

Superscripts

b	back
f	front

Bloem et al. (2004), Bloem and van Dijk (2000), Bloem et al. (1997) and Bloem (2008) have been carrying out an intensive characterization of PV ventilated components, with and without ventilated air gaps. Some European funded projects have been actively supporting this work, PASSLINK, PV-HYBRIDPAS and IMPACT (Strachan and Vandaele, 2008). Between 1999 and 2000, Mei et al. (2003) undertook the theoretical analysis and monitoring of the Mataro's public library building, which had the first PV ventilated façade in Europe. More recently, the treatment of the induced flow and the heat transfer at the air gap and the surfaces of a natural ventilated double skin façade has been progressively refined by Brinkworth (2000a), Brinkworth et al. (2000), Brinkworth (2000b) and Brinkworth and Sandberg (2006). Concerning to the mathematical model to define the energy performance of such PV components, simplified methods have been proposed by Ursula Eicker (2003) and Mei et al. (2003). More sophisticated models for double skin façades have been also developed by Faggembauu et al. (2003) and Saelens