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Optimization of the performance of double-façades with integrated photovoltaic panels and motorized blinds

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Abstract

Double-façades with integrated photovoltaic panels may be employed to generate electricity, thermal energy and for daylighting. A theoretical study of double-façades with integrated photovoltaics (PV) and motorized blinds is presented, which investigates the effect of various design parameters in order to maximize the conversion of solar radiation to useful energy. Two configurations of the façade with a lower section with integrated PV and an upper Vision (viewing) section with motorized blinds, are examined. A one-dimensional finite-difference thermal model is developed, with an algorithm that iteratively determines which convective heat transfer coefficient correlation to use for each surface inside the cavity using expressions that consider system characteristics and temperature distribution. When PV modules are installed in the middle of the cavity, air flows on both sides, increasing PV section overall (thermal-electric) efficiency by about 25%, but lowers electricity generation by 21%. Integrating 0.015 m long, 0.002 m wide fins to the PV back plate leads to a similar increase in efficiency without compromising electricity generation. Placing the blind in the middle of the cavity increases the Vision section efficiency by 5%. Using this approach to optimize performance can lead to combined thermal-electric efficiencies of over 60%.

Keywords: Building-integrated photovoltaics; Motorized blinds; Ventilated façade

1. Introduction

Double-façades with integrated photovoltaic (PV) panels may be used to generate electricity, thermal energy, and for daylighting. Many researchers (e.g. Faggembauu et al., 2003a,b) have examined various configurations of double façades and have developed thermo-fluid models to investigate performance. However, a limited amount of work has been done to develop systematic optimization procedures to improve their overall performance and cost effectiveness.

The performance of a double-façade depends on geometric, thermo-physical, optical and aerodynamic properties of the various components, making it difficult to outline general design guidelines (Hensen et al., 2002). Since design parameters have differing impacts, the

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Nomenclature

A	overall area of the double façade
BIPV/T	building-integrated photovoltaic-thermal double façade
A_p	fin profile area
A_PV	overall area of the PV section
C	specific heat of air (J/kg K)
D, D_h	hydraulic diameter
E_pv	electricity generated by PV
E_trans	solar radiation transmitted through BIPV/T façade
E_fan	electricity consumed by fan
f	friction coefficient
G	incident solar irradiation (W/m^2)
Gr	Grashoff number
h_i	heat transfer coefficient in i
h_c	convective heat transfer coefficient
H	overall height of the double façade
H_pv	height of the PV section in the double façade
In_i	radiation directed outside from i
Ip_i	radiation directed to room from i
k_i	thermal conductivity of i (W/K)
L	gap width
L_c	corrected fin length
L_fin	fin length
L2b	inner cavity width in configuration 2
L2f	outer cavity width in configuration 2
M	mass flow rate of air (kg/s)
Nu	Nusselt number
Pr	Prandtl number
Q_air	heat absorbed in the air
Q_room	heat transferred to room by façade
q_fin	heat transferred from fins
q_max	maximum theoretical q_fin
Ra	Rayleigh number
Re	Reynolds number
$S_\mathrm{pv\cdot heat}$	irradiation absorbed as heat in PV
tod	time of day (h)
t	fin thickness
T_i	temperature of surface i
$\overline{T}_\mathrm{ma}$	mean air temperature
U_i	thermal conductance of i
V_0	external air velocity
X	vertical boundary layer thickness
X_T	thermal boundary layer thickness
w	width of double façade
Greek	
ρ_air	air density (kg/m^3)
ε_i	emissivity of surface i
τ_i	transmissivity of surface i
ρ_i	reflectivity of surface i
σ	Stefan–Boltzman constant ($5.67 \cdot 10^{-8}$ W/m^2 K^4)
η_pv	PV module efficiency

overall performance may be improved by determining interactions between key parameters.

One critical parameter is the channel width due to its intrinsic relationships with heat transfer coefficients, friction losses and flow velocity. Using a simple steady-state control volume model, Balocco (2002) found that the maximum flow rate that could be achieved by stack effect occurred at a cavity width of 20–30 cm for a ventilated façade. As fan-driven flow is assumed in this investigation, optimal width will be different. The impact of width and other critical parameters will be examined further.

The system considered in this paper is far more complex since in optimizing the façade one must consider electricity generated, useful heat recovered and daylighting. If cooling load is reduced (e.g. by cooling the blind) this factor needs to be also considered.

2. Model description

2.1. System configuration

The façade considered in this investigation consists of a PV and a Vision section as depicted in Fig. 1. An alternate setup, referred to as Configuration 2, is shown in Fig. 2. Configuration 2 has the PV and roller blind in the middle of the cavity, allowing air to flow on both sides. Double-façades with integrated PV configured as above are also referred to as BIPV/T façades. Configuration 2 will result in more heat being extracted from the PV since air is flowing on both sides. However, adding fins to the PV is obviously another approach to cool it effectively.

2.2. Mathematical formulation

As the façade is divided into two sections, the mathematical formulation of the problem considers the two sections separately. The two are linked such that the output air temperature calculated for the PV section is used as an input value to the Vision section. A nodal model is used to determine an expression for the temperature of each component by doing an energy balance at each solid node. For the simple case of the PV section depicted in Fig. 1, the corresponding energy balance equations (1)–(3) are obtained.