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Performance of ventilated double-sided PV façade compared with conventional clear glass façade

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ABSTRACT

The outdoor performance of a naturally ventilated double-sided PV facade was evaluated through field monitoring from a small scale test rig. The comparison of its thermal performance with that of a conventional clear glass façade with shield was made through the field measurement. The measured data show that the maximum indoor air temperature for conventional facade is close to 34 °C, while 29 °C only for PV façades under same summer weather conditions. This indicates that heat gain to building in summer could be substantially reduced and additional electrical power could also be generated from such façade as a byproduct. In addition, the temperature influence on thin-film solar cells was tested. The effect of temperature on the conversion efficiency of thin-film amorphous silicon solar cell is found small. It is observed that a reduction of 15.6 °C in module temperature of the thin-film solar cell only leads to a decrease of 0.29% in conversion efficiency. However, the ventilation cooling of PV reduce the possibility of potential overheating problems when PV is integrated into building as an external façade, especially in extreme hot weather conditions. In addition, the internal heat gain could be considerably reduced compared with conventional clear glass façade with shield in summer. A better thermal comfort of indoor occupants thus could be anticipated in the present proposed façade system.

1. Introduction

Undesirably high temperatures experienced by solar cells, due to the absorbed heat from solar radiation, will decrease their conversion efficiency. In addition, overheating in a closed glazing cavity without adequate air circulation may cause thermal discomfort to indoor occupants especially in severe summer conditions. Thermal regulation of the temperature rise is, therefore, important to enable maximum solar to electricity conversion efficiency. For achieving this goal, one can fit a naturally ventilated open channel in the back of the PV panel. This measure not only provides an effective means of heat release, but also helps to reduce the heat gain of the building external envelope. The air in the channel behind the PV modules can be either actively circulated by mechanical facilities (blowers, pumps, compressors) driven by electric power, or passively ventilated by natural ventilation driven by buoyancy force. For example, mechanical ventilated PV facades (PVF) were proposed and a simplified approach to thermal performance calculation has been applied to a ventilated façade of a public library in Spain [1].

Fluid flow and heat transfer in the PVF cavities are considerably important in the evaluation of energy performance and thermal behavior of the building integrated photovoltaic (BIPV) system. There has been a fair amount of investigation dealing with theoretical and numerical modeling of airflow and heat transfer in the air channel behind PV modules. Sandberg and Moshfegh [2] investigated the fluid flow behind PV modules in a ventilated PVF by using a CFD tool and other numerical analysis. Fossa [3] investigated the physical mechanisms which influenced the thermal behavior of a double-skin PV façade, and showed that variation in the air gap width could decrease the glass surface temperature and thus enhance PV conversion efficiency. Charron and Athienitis [4] presented a theoretical study of double-facades with integrated PV and motorized blinds, analyzed various design parameters which affected the conversion of solar radiation, and investigated a two-dimensional model of a double-facade with integrated PV panels. Heat transfer in a BIPV thermal system was studied by Liao et al. by using a two-dimensional CFD model [5]. The effect of air gap on the PV performance in terms of cell temperature or different roof pitches and PV panel lengths was investigated through CFD tools by the same author [6]. In addition, CFD analysis was conducted to evaluate the thermal performance of glass double envelope and PV shading devices as well [7]. CFD was also applied to the prediction of air flow and temperature distribution in atrium integrated with

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Nomenclature

AR	aspect ratio (H/L) (–)
C	specific heat capacity (J/kg K)
g	gravitational acceleration (m/s^2)
H	height of the open cavity (Fig. 2) (m)
k	thermal conductivity (W/m K)
L	width of the cavity (m)
P	pressure (N/m)
P_∞	pressure in the free stream (N/m)
T	temperature (°C)
T_∞	temperature in the undisturbed fluid far from the surface (°C)
u	horizontal velocity component in the x direction (m/s)
v	vertical velocity component in the y direction (m/s)
x	coordinate as defined in Fig. 2 (–)
y	coordinate as defined in Fig. 2 (–)
Greek symbols	
β	volumetric expansion coefficient (1/K)
ρ	density (kg/m^3)
ν	kinematic viscosity (m^2/s)
ψ	stream function (m^2/s)
ω	vorticity (1/s)
Subscripts	
air	indoor or outdoor air (–)
c	refers to cold wall (–)
CF	Conventional Facade
con	conventional façade with curtain for shading (CF) (–)
h	refers to hot wall (–)
in	inside (–)
max	maximum (–)
m	mean (–)
out	outside (–)
PVF	PV façade (PVF) (–)
∞	free stream condition (–)

PV modules [8]. CFD modeling results revealed the effectiveness of air cooling channels underneath the roof PV arrays. Performance of an amorphous silicon photovoltaic window in Hefei, east China was explored experimentally and numerically by He et al. [9]. Their results show that indoor heat gain of PV double glazing window is reduced to 46.5% based on measured data.

BIPV system has long been credited as one of the most important applications for PV in developed countries and has been well-developed all over the world among the other types of PV applications. PV modules, especially semi-transparent a-Si solar cells, can be incorporated in a glass-glass construction for providing shading solutions with lower maintenance cost compared with a conventional double skin façade without integration of PV. Research studies were conducted to investigate semi-transparent PV panels that provide both electricity and day lighting [10]. Day light through semi-transparent PV modules can facilitate natural lighting for buildings. Fung et al. [11] developed a one-dimensional transient heat transfer model, the semi-transparent PV module (SPVHG) model, for evaluating the heat gain of semi-transparent PV module for building-integrated applications. Innovative solar windows for "cooling-demand climate" have been developed and investigated intensively by Chow et al. [12]. Their results show that water flow window can reduce air conditioning load and enhance thermal and visual comfort. Possible applications of see-through solar cells in ventilated glazing in Hong Kong were evaluated [13]. According to the results, about 28% of the air conditioning power consumption can be reduced, compared with conventional single absorptive glazing system.

Fig. 1. Outdoor test facility for PV façade (left) and the conventional façade with internal curtain (right).

However, so far, to the authors' knowledge, there has been little research conducted on the airflow in ventilated photovoltaic facade integrated with see-through thin-film solar cells and evaluation of its temperature dependence. It is believed that a better understanding and assessment of the airflow and heat transfer within the ventilated air cavity would enable architects to improve the thermal design of building external envelopes during building design stage. In this study, an outdoor test facility has been firstly developed in order to facilitate evaluation on the thermal performance of a naturally ventilated double-sided PV façade through comparing with conventional clear glass façade in hot weather conditions in Hong Kong.

2. Experimental set-up and model description

An experimental testing facility at Hong Kong Polytechnic University was set up. The test facility was located at E114°10′, N22°18′ and at an altitude above sea level of 32.0 m. The experimental facility is composed of two identical test cells, each with the dimensions of 1.22 m × 0.82 m × 0.99 m, as shown in Fig. 1. The configuration of the experimental set-up of PVF (vertical view) and CF with shield is depicted in Fig. 2. Previous research studies show air flow patterns in the cavity behind the PV play an important role in determining the total performance of the PVF [14,15]. This study, therefore, focuses mainly on the investigation of the airflow characteristics of the air cavity. The geometry of the 2D tall cavity is shown in the schematic diagram of Fig. 3(left). The height of the cavity (H) is 1.02 m, and its width (L) 0.16 m, aspect ratio (AR) of AR = H/L = 6. The outside air is drawn from the bottom inlet of the cavity due to buoyancy force. The airflow inside the glazing cavity is considered as steady. The flow is considered as either laminar or turbulent. The air layer within the rectangular cavity is heated and cooled by isothermal hot T_h and cold T_c vertical walls. Two horizontal walls are adiabatic with zero heat flux boundary at horizontal surfaces. Constant fluid properties were assumed and the Boussinesq approximation was used to estimate the effect of the density variation. The physical properties were treated as constants except the density in the simulation and evaluated for air at the inlet temperature of $T_0 = 26\,^\circ\mathrm{C}$. The density ρ equals to 1.184 kg/m^3,