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Investigation of thermal and electrical performances of a combined semi-transparent PV-vacuum glazing

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HIGHLIGHTS

- Thermal and electrical performances were measured using indoor test cell for crystalline silicon based PV-vacuum glazing.
- Maximum PV cell temperature was achieved 97 °C under 1 sun exposure (1000 W/m^2)
- Overall heat transfer coefficient was 0.8 W/m^2 K for this glazing.
- Solar factor was calculated for this PV-vacuum glazing.

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ABSTRACT

Combined semi-transparent PV-vacuum glazing provides low overall heat transfer coefficient, reduces solar heat gain, generates clean electricity and admits comfortable daylight. In this work, thermal and electrical performances of a multicrystalline silicon based PV-vacuum glazing were characterised using indoor test cell. For this particular combined system, PV covered 32% of the glazing area. Two different combinations of PV-vacuum glazing systems were manufactured where for the first case vacuum glazing faced test cell external environment (VPS) and for the second case vacuum glazing faced test cell internal environment (SPV). SPV type was found to have superior performance as PV cell achieved lower temperature than VPS type after 125 min exposure under 1000 W/m^2 constant intensity from a simulator. For this type PV-vacuum glazing, overall heat transfer coefficient (*U*-value) was 0.8 W/m^2 K and the solar factor was 0.42. *U*-value of this PV-vacuum glazing was 66% lower and the solar factor was 46% lower than PV double-glazing. Close power drop from PV due to elevated temperature was observed for both PV-double and PV-vacuum glazing.

1. Introduction

Consumption of world energy increased by 40% from 1990 to 2007. Until 2035, another 8–10% increment is expected due to rapid growth of urbanization [1]. Transport, industry and buildings are the major energy consuming sectors. Building sector alone accounts 40% of global energy. To mitigate this high building energy demand, zero energy or low energy buildings are potential [2]. To achieve efficient buildings, energy efficient windows are essential which can control incoming excessive solar heat gain (reduce building cooling load), limit heat loss (reduce building's heating load), and maintain comfortable daylight (possess discomfort glare). However, windows are the most essential building envelope by allowing visual connection between indoor space and external environment.

Building-integrated photovoltaic (BIPV) glazings are innovative and emerging glazing technology which has capability to replace conventional low performance building facade materials. In urban cities and places where rooftop and ground areas are limited, semi-transparent BIPV glazing or glazed façades are alternative advanced technology [3]. In a photovoltaic (PV) glazing, PV device is sandwiched between two glass panes [4]. This glass –PV –glass structure is advantageous over traditional PV device as they allow daylight into the indoor space while they are installed as a BIPV. Thus, a semi-transparent BIPV glazing controls entering solar heat gain and discomfort glare, introduces comfortable daylight, and generates electricity. PV device for BIPV glazing includes first generation silicon, second generation amorphous silicon (a-Si) [5], cadmium telluride (CdTe) [6], CIGS, third generation DSSC [7] and perovskite [8]. Second and third generation PV devices have advantages over silicon as tuning the thickness modulation of transparency is possible. However, DSSC [9], and perovskite [10,11] both have stability issue which hindrance them to be applied as practical glazing under outdoor environmental

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Nomenclature

A_{cell}	area of PV cell (m^2)
$A_{encapsulant}$	area of encapsulation (m^2)
$A_{glazing}$	aperture area of glazing (m^2)
C_{air}	heat capacity of air (kJ/kg K)
E_g	band gap
FF	fillfactor
I	incident radiation from simulator (W/m^2)
I_{sc}	short circuit current (A)
g	solar heat gain coefficient
g_{opaque}	solar heat gain coefficient due to opaque PV cell of glazing
$g_{transparent}$	solar heat gain coefficient due to non PV covered part of glazing
k	Boltzmann constant
K_{pl}	thermal conductivity of polystyrene (W/mK)
L_{pl}	thickness of polystyrene (m)
M_{tc}	mass of air inside test cell (kg)
P_{pv}	power output from photovoltaic (W)
P_m	maximum power output from photovoltaic (W)
q	elementary charge
Q_{in}	incident radiation on the glazing (W)
$Q_{test\ cell}$	total heat inside the test cell (W)
Q_g	total heat transfer through the glazing (W)
Q_{loss}	total heat loss through the glazing (W)
R_{total}	total thermal resistance of the system (m^2 K/W)
R_{out}	thermal resistance from external surface of glazing (m^2 K/W)
$T_{in,tc}$	temperature inside test cell (K)
$T_{out,tc}$	temperature outside test cell (K)
V_{oc}	open circuit voltage (V)
v_{air}	internal volume of test cell (m^3)
ρ_{air}	density of air (kg/m^3)

condition. Second generation a-Si is the most investigated PV device for PV glazing application as their see through structure allow natural daylight [12]. Second generation a-Si, CdTe and CIGS have currently reached the best laboratory efficiency of 11.9%, 21.7% and 21.4% respectively [13]. Crystalline silicon is still preferable over all those aforementioned PV as it offers high efficiency and high stability under outdoor environment.

Semi-transparent type PV glazing introduces daylight illuminance into the indoor space, which is not possible to obtain from an opaque silicon based PV glazing. Thus spaced type PV structure using crystalline silicon based glazing is attractive. These regular distributions of small area PV cells block the incident incoming solar radiation and the gap between cells allow daylight and near infrared radiation (NIR) [14]. Depends on the PV coverage different transparency level is achievable [15]. To obtain best PV cell coverage, local climatic conditions, buildings orientation and consumptions details are essential [16].

PV glazing has potential to reduce cooling load but increase seasonal heating loads [17] as it blocks incoming solar heat gain. For cold climate building, comfortable daylighting, high solar gains and low heat loss are required. Thus, for large glazed façades, vacuum glazing type is the best choice to provide allowable daylight and allow solar heat gain for reduction of the space heating demand during day time [2]. Vacuum glazing is composed of two low – emissivity (e) coated glass panes, arrays of small pillars between the two glasses to sustain the outside atmospheric pressure and leak free edge sealing [18,19]. Vacuum glazing offers low heat transfer as vacuum between two glasses reduce conductive and convective heat transfer and presence of low emission coating reduces the radiative heat transfer [20]. First vacuum glazing was fabricated using high temperature melting point solder glass edge sealing which degrades low emission coating [21]. Low temperature indium alloy edge sealing was employed later on to enable the low-e coating [22]. Cerasolzer type CS186 was also investigated for replacement of costly indium edge sealant [23]. Metal-based opaque small pillars array was replaced by transparent pillars to make this glazing more aesthetic [24].

Vacuum glazing offers similar transmittance to a double glazing with 53% low heat loss compared to double glazing [18]. This higher transmittance often creates discomfort glare. Addition of solar heat gain-glare control PV material can control this excessive glare and possess suitable daylight. Addition of spaced type PV and vacuum glazing will form low heat loss clean power generating glazing as shown in Fig. 1. Spaced type semi-transparent PV-vacuum glazing is truly multifunctional by controlling solar heat gain, heat loss, glare and introduces allowable daylight. Interesting fact of this glazing is that no distortion of transmitted light through the non-PV covered part of the glazing. This indicates that daylight available outside will be very similar to inside after passing through this glazing as light passes through only three silica made glass pane and low emission coating.

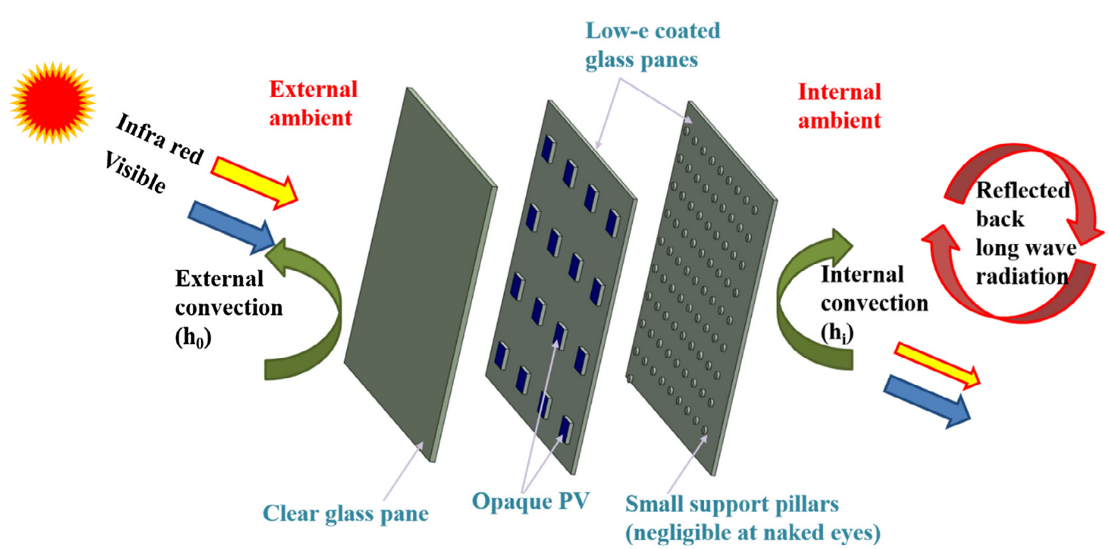

Fig. 1. Exploded view of semi-transparent PV-vacuum glazing.