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Effect of water flow on performance of building integrated semi-transparent photovoltaic thermal system: A comparative study

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ABSTRACT

In this paper, a periodic thermal model has been developed for a building integrated semi-transparent photovoltaic (PV) thermal (BiSPVT) system with intermittent water flow (from 0945 h to 1415 h) over the PV array. The model is based upon the energy balance equations formulated at the various nodes of the system. Further, to validate the theoretical model, an experiment has been conducted on a BiSPVT system installed at SODHA BERS Complex, Varanasi, India on 24th September 2017 (clear day). It has been found through the periodic model that with a water flow rate of 1.81 kg/sec over the PV array, there is a decrease in the PV cell temperature by 20.00 °C. The correlation coefficient and root mean square deviation have been used to find the degree of resemblance between the theoretical and the experimental results. Furthermore, a performance comparison of the BiSPVT system (with water flow) and a rooftop semi-transparent photovoltaic (RtSPV) system (without water flow) installed at the same complex has been carried out for the same day. The orientation, the specifications of the PV modules and the additional circuitry involved with both the systems are identical except for minor difference in the tilt angle. The net measured electrical output of the BiSPVT system with water flow was found to be 10.14 kWh which is 1.44 kWh higher than that obtained from the RtSPV system. In addition to the higher electrical energy, the thermal energy generated by BiSPVT system was 379.82 kWh.

1. Introduction

In India, the present load demand of buildings is 30% of the total electrical power generation and due to the increasing urbanisation the percentage is increasing annually by 8%. In the present scenario, the backbone of power generation in India is fossil fuels (Babu and Vyjayanthi, 2017). The dependency on conventional energy resources is jeopardizing not only because of its limited stock but also due to its tremendous impact on environment and climate change. Moreover, in villages of developing countries like India many houses are still off-grid and even those connected with the grid suffer from frequent load shedding due to inadequate power generation (Jhunjhunwala et al., 2016). Standalone PV system (Ma et al., 2017) and roof top PV system (Emziane and Ali, 2015) have emerged as an attractive solutions for the above addressed problems. Roof top PV system has the potential of eliminating the transmission and distribution losses associated with the standalone PV system installed far away from the building (Shugar, 1990).

Further, passive designs are widely accepted as an economical and an effective tool to reduce the energy demand of buildings (Badescu et al., 2011; Sadineni et al., 2011). The passive solar designs are incorporated in small residential houses to large commercial buildings (Kruzner et al., 2013; Samuel et al., 2013) and the passive techniques namely Trombe wall, wind tower, cross ventilation, orientation and earth shelter etc. (Tiwari et al., 2016) are applicable to a wide range of climatic conditions (Ralegaonkar and Gupta, 2010). Further, the addition of roof top PV system can fulfil the required energy demand of these passive buildings and has a great potential to move towards net zero energy buildings.

It is well known that there are two types of PV module namely opaque PV (OPV) module and semi-transparent PV (SPV) module. Based on analytical modelling and validation of OPV and SPV modules of same packing area, it has been found that SPV module gives better electrical efficiency in comparison to OPV module (Dubey et al., 2009; Tiwari and Dubey, 2010; Tiwari and Mishra, 2012). The back surface of OPV module and SPV module has an opaque tedlar and a transparent glass respectively. The solar irradiance falling on the non-packing area in OPV module is absorbed by the opaque tedlar whereas solar irradiance falling on the non-packing area in SPV module is transmitted through the transparent glass. Therefore, the temperature rise of PV

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Nomenclature

U_{tca}	overall heat transfer coefficient for cell to ambient from top of the PV array ($W\,m^{-2}K^{-1}$)
U_{tcw}	heat transfer coefficient for cell to water from top of the PV array ($W\,m^{-2}K^{-1}$)
U_{bca}	heat transfer coefficient for cell to ambient from bottom of the PV array ($W\,m^{-2}K^{-1}$)
h_1	overall heat transfer coefficient from water to ambient ($W\,m^{-2}K^{-1}$)
h_{rw}	radiative heat transfer coefficient from water to ambient ($W\,m^{-2}K^{-1}$)
h_{ew}	evaporative heat transfer coefficient from water to ambient ($W\,m^{-2}K^{-1}$)
h_{cw}	convective heat transfer coefficient from water to ambient ($W\,m^{-2}K^{-1}$)
U_{bcr1}	overall heat transfer coefficient from bottom of cell to thermal room ($W\,m^{-2}K^{-1}$)
h_{cfr1}	convective heat transfer coefficient for floor to thermal room ($W\,m^{-2}K^{-1}$)
h_{cfr2}	convective heat transfer coefficient for floor to room 2 ($W\,m^{-2}K^{-1}$)
U_{sba}	overall heat transfer coefficient from side through brick to ambient ($W\,m^{-2}K^{-1}$)
U_{sga}	overall heat transfer coefficient from side through glass to ambient ($W\,m^{-2}K^{-1}$)
$\dot{m}_w$	mass flow rate of water ($Kg\,sec^{-1}$)
P_r	Prandtl number
ν	ratio of dynamic viscosity to density of water ($m^2\,sec^{-1}$)
RCC	reinforced cement concrete
$R.H._{r10}$	relative humidity of outside thermal room

Greek symbols

α_c	absorptivity of solar cell
τ_g	transmissivity of glass
η_c	efficiency of solar cell
β_e	ratio of glass area to total area of east wall
β_m	packing factor of a PV module
β_r	ratio of non-module to total PV array area
γ	air humidity

Suffix

c	solar cell
f	floor of thermal room
g	glass
e	east
we	west
n	north
s	south
A_e	area of wall facing east (m^2)
K_{gc}	thermal conductivity of glass used in PV module ($W\,m^{-1}K^{-1}$)
K	thermal conductivity of RCC ($W\,m^{-1}K^{-1}$)
L	thickness of RCC (m)
L_{gc}	thickness of glass used in PV module (m)
C	specific heat of RCC ($J\,kg^{-1}K^{-1}$)
C_{a1}	specific heat of air in thermal room ($J\,kg^{-1}K^{-1}$)
M_{a1}	mass of air in thermal room (kg)
N_1	number of air change of thermal room
V_1	volume of thermal room (m^3)
b_r	breadth of PV array excluding ladder breadth (m)
L_r	length of PV array (m)
R_{el}	Reynold number
v_w	speed of water flowing on PV array ($m\,sec^{-1}$)
$I_{inc,r}$	solar irradiance on inclined PV array of Rtspv system ($W\,m^{-2}$)
FF	fill factor
A_{ms}	total area of 32 PV modules (m^{-2})
ρ	density of RCC ($Kg\,m^{-3}$)
β_0	temperature coefficient (K^{-1})
ω_0	angular speed ($rad\,sec^{-1}$)
ω	angular speed ($rad\,h^{-1}$)
ε	emittance of surface
σ	Stefan- Boltzmann constant ($W\,m^{-2}K^{-4}$)
gc	glass used in solar cell module
gw	glass used in glazed side wall
bw	plastered brick used in wall
1	thermal room
2	room-2
0	zero Harmonics
w	water

cells is more in OPV modules which results in lower electrical performance as compared to SPV modules. Further SPV modules have many advantages in building design such as thermal heating and daylighting in addition to higher electrical power generation. An extensive review on OPV and SPV modules used as a façade in buildings has been carried out by Quesada et al. (2012). They have concluded that the use of PV module as a façade in buildings has achieved a great interest due to its simple technology. However, an optimization of this concept has not been carried out for different climatic conditions. As a facade in buildings, SPV modules may be a better option as stated earlier. The various applications of SPV modules in buildings are given in Fig. 1. The performance of integration of semi-transparent PV module in a

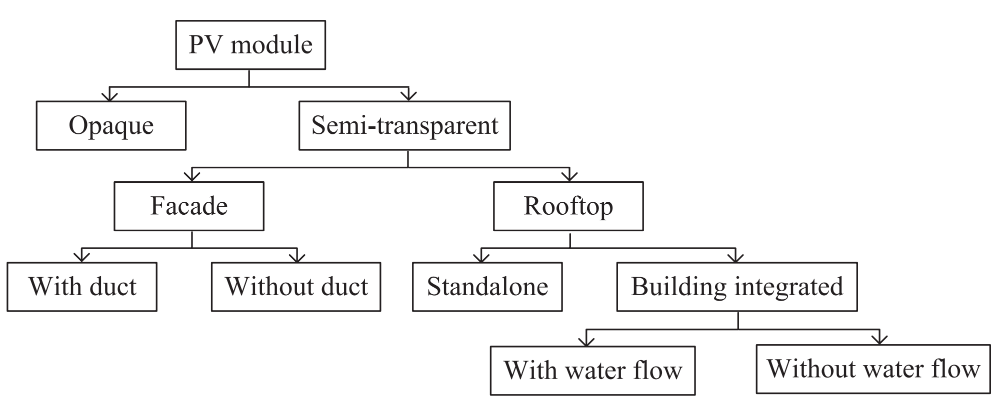

Fig. 1. Classification for usage of semi-transparent PV module in buildings.