Energy and Buildings 53 (2012) 145–151

Contents lists available at SciVerse ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Indoor experimental analysis of glazed hybrid photovoltaic thermal tiles air collector connected in series

Sanjay Agrawal [a,*], G.N. Tiwari [b], H.D. Pandey [b]

[a] School of Engineering & Technology, IGNOU, Maidan Garhi, New Delhi 110068, India
[b] Centre for Energy Studies, Indian Institute of Technology Delhi, Hauz Khas, New Delhi 110016, India

ARTICLE INFO

Article history:
Received 18 October 2011
Received in revised form 22 May 2012
Accepted 18 June 2012

Keywords:
Photovoltaic thermal tile
Solar simulator
Energy
Exergy

ABSTRACT

In this paper, design and experimental analysis of glaze photovoltaic thermal (PVT) tile air collector has been discussed. Fabricated glazed PVT tile consists of a single solar cell, duct and fan for extraction of heat associated with the bottom of solar cell. Observations taken at glazed hybrid PVT tile 1 and tile 2 have been considered as case-I and case-II, respectively. Experimental validation has also been performed and it has been observed that that there is a good agreement between theoretical and experimental results with correlation coefficient and root mean square percentage deviation of 0.96 and 7.9, respectively. The performance evaluation in terms of electrical efficiency, overall thermal energy and exergy gain of both the cases has been carried out in indoor conditions at various intensities. It has been found that the electrical efficiency is higher in case-I as compared to case-II. On the contrary the thermal output of case-II is higher than case-I on same intensity and mass flow rate. It has been found that the average electrical and thermal efficiency of newly designed and fabricated glaze PVT tile is 12.4% and 35.7%, respectively. This economical solar simulator can be used by manufactures for testing of different type of photovoltaic tiles as well as photovoltaic modules.

1. Introduction

Photovoltaic technology (PV) is commonly known as one of the promising renewable energy technologies. It is a well known fact that the electrical efficiency falls as the temperature of the photovoltaic cells rise. The efficiency of the system falls about 0.0045 when cells temperature is increased by 1 °C [1]. The temperature of the photovoltaic cell can be decreased through extracting the thermal energy associated with the bottom of solar cell by flowing air below the photovoltaic cell and the heated air can be utilized for domestic of application including drying and other industrial process heat application.

The generation of both thermal and electrical energy simultaneously is known hybrid photovoltaic thermal technology (PVT). Solar hybrid PVT system can generate more energy per unit area compared to the system of solar panel and thermal collector separately side by side [2]. The purpose of using hybrid solar PVT system is to increase the electrical efficiency and recover thermal energy losses by flowing water or air as heat carrier. The first PVT hot air collector application has been tested at solar test house in institute of energy conversion, University of Delaware at 1973 [3].

Many researchers have developed the PVT system and they have analyzed theoretically as well as experimentally in indoor and outdoor conditions. Sopian et al. [4] and Prakash [5] have analyzed single pass solar collector with open channel absorber. Comparison of single pass and double pass collector has been done by Hegazy [6] and it has been observed that double pass solar collector shows better performance. Further research has been carried out to improve the heat extraction by combining heat conductor into solar collector such as v-groove, porous media and fin [7,8]. Purpose of adding heat conductor into solar collector was to enhance the heat extraction of collector and thus increase the efficiency of the collector. In this study, rectangle tunnel absorber is added into the photovoltaic thermal collector as heat conductor.

An experimental rig design for natural flow, which was tested in the city of Hefai, 32° N, 117° E, in a south-facing position and with tilt angle of 32 was carried out by He et al. [9] and it has been observed the electrical efficiency obtained was 4.6% based on the ratio of mass of water in thermo syphon system and collector surface area M/A_c of 75 kg/m^2. Erdil et al. [10] fabricated a hybrid system consist of a PV module and a solar thermal collector and tested it for energy collection in Cyprus. They used two PV modules at an area of about 1.2 m^2. In their work, they used glass as glazing and water as cooling agent because of the high transmittance of the two media. They found out that the ratio of gain to losses for thermal energy is 50 times the electrical energy, which was measured between the periods of 12:00 and 16:00 h.

* Corresponding author. Tel.: +91 9999266576; fax: +91 11 29534529.
E-mail address: sanju.aggrawal@gmail.com (S. Agrawal).

0378-7788/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enbuild.2012.06.009

Nomenclature

A_c	Area of solar cell (m^2)
b	Width of the glazed PVT tile (m)
C_f	Specific heat of air (J/kg K)
d	Depth of the duct (m)
D_e	Characteristic dimension or equivalent diameter of duct (m)
$\dot{E}x$	Exergy rate (kW)
f_c	Coefficient of friction
$I(t)$	Incident solar intensity (W/m^2)
I_{sc}	Short circuit current (A)
I_L	Load current (A)
L	Length (m)
m_f	Air mass flow rate in duct (kg/s)
N	Number of glazed PVT tile
Nu	Nusselt number
$\dot{Q}_u$	Useful heat (W)
Re	Reynolds number
T	Temperature (K)
U	Overall heat transfer coefficient (W/m^2K)
U_{tca}	An overall heat transfer coefficient from solar cell to ambient through glass cover (W/m^2K)
U_{tcf}	An overall heat transfer coefficient from solar cell to flowing air through tedlar (W/m^2K)
U_b	An overall back loss heat transfer coefficient from flowing air to ambient (W/m^2K)
V	Velocity of fluid (air) flowing inside of duct (m/s)
v	Velocity of air (m/s)
V_{oc}	Open circuit voltage (V)
V_L	Load voltage (V)

Greek letters

α	Absorptivity
β	Packing factor
τ	Transmittivity
η	Efficiency
ρ	Density (kg/m^3)

Subscripts

a	Ambient
c	Solar cell
eff	Effective
f	Fluid (air)
f_i	Inlet fluid
f_o	Outgoing fluid
in	Insulation

Tonui and Tripanagnostopoulos [11] reported a cheap and simple method to cool the PVT system. They introduced a method to effectively extract heat from the back wall of the air duct using a suspended thin metallic sheet. From thermal efficiency tests, it has been found that the modified system gives a higher performance and increased the electrical and thermal outputs. They further investigated two methods, namely, using a thin metal sheet suspended at the middle and fins attached to the back wall, which could improve the heat extraction from the system. The validation done showed constructive results between predicted and measured data. Sopian et al. [12] developed and tested a double pass PVT solar collector, which is suitable for solar drying purposes. Analysis has been taken based on the energy balance equations at different positions such as the glass cover, inlet flow and outlet channels and back plate. They also made comparisons between the experimental results and theoretical results and they found close agreements between the values that were reported. The relations between energy and exergy, energy and sustainable development, energy policy making, exergy and the environment and exergy in detail are reported by Dincer [13]. Performance analysis of a hybrid photovoltaic-thermal integrated system has also been done by Radziemska [14] who presented the concept of exergy analysis for evaluation of the PVT systems which is very useful tools for the improvement and cost-effectiveness of the system. Energy and exergy analysis of hybrid micro-channel PVT module has been carried by Agrawal and Tiwari [15] and they concluded that micro-channel PVT module gives better results than single channel PVT module.

Till now, most of the researchers have carried out the electrical and thermal performance analysis on PVT system consists of PV module and a duct. The objective of this study is to develop a small hybrid PVT tiles air collector system consisting of single solar cell and a duct is known as glazed hybrid PVT tile air collector. The electrical and thermal performance evaluation of glazed PVT tiles air collector has been carried out on various intensity and constant mass flow rate. Analysis has been carried out glazed PVT tile air collector connected in series.

2. Experimental setup

An experimental testing setup has been designed and fabricated to test the glazed hybrid PVT tile air collector connected in series under quasi steady-state condition. The testing setup mainly consists of glazed hybrid PVT tile air collectors thermally connected in series and a solar simulator.

2.1. Glazed hybrid PVT tile air collector

In the glazed hybrid PVT tile air collector, duct has been placed between tedlar and insulation. The glazed PVT tile consists of a single solar cell (mono crystalline silicon), rated at 2.2 Wp having dimensions 0.12 m length and 0.12 m width has been considered and it has been mounted on a rectangular wooden channel. The channel has dimensions 0.12 m × 0.12 m × 5 mm. The wooden channel has been sealed with putty and adhesive tape to avoid air leakage. There is provision for the inlet and outlet air to flow through the duct of solar cell under forced mode.

For experimentation, outlet of one glazed hybrid PVT tile air collector is connected to the inlet of another similar glazed hybrid PVT tile air collector. The photograph and orthographic view of glazed hybrid PVT tile air collector connected in series have been shown in Fig. 1(a) and (b), respectively. The air has been flown with the help of small DC fan through the duct of tiles to withdraw the heat associated with base of solar cell. A DC fan of 6.0 V and 0.1 A has been used to circulate the air through the duct.

2.2. Solar simulator

A solar simulator with a 3-phase lamp array is employed to imitate the necessary solar irradiation in the testing of glazed hybrid PVT tile air collector connected in series. The schematic elevation and plan of experimental setup has been shown in Fig. 1(c). The solar simulator has 28 tungsten halogen lamps (Philips manufactured; Model: 392472) each having 500 W, 9000 lumens. The halogen lamps are arranged in 7 × 4 matrix for uniform distribution of irradiance on the glazed hybrid PVT tile air collector connected in series. The tungsten-halogen lamps generate a continuous spectrum of light that ranges from the central ultraviolet through the visible and into the infrared wavelength regions (Fig. 1(d)). Compared with the emission spectrum of sunlight and a theoretical 5800 K blackbody radiator, the longer wavelength regions always predominate in tungsten-halogen lamps. However, as filament