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Energy economic analysis of photovoltaic–thermal-thermoelectric (PVT-TE) air collectors

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ABSTRACT

Photovoltaic–thermal (PVT) collectors can generate electrical and thermal energy simultaneously. The combination of these two technologies can reduce the required space, time installation and use of materials. PVT air collector present increased total efficiency by increasing solar radiation amount. This review presents the concepts and descriptions, as well as previous works conducted on thermoelectric (TE). A theoretical study of PVT-TE air collectors is also performed. Mathematical models are proposed and solved using iterative process based on the matrix inversion method. An improvement in energy yields can be obtained using TE solar collector technology because TE devices increase the energy conversion efficiency of the system. The annual cost (AC) and annual energy gain (AEG) of PVT-TE air collectors are determined. The cost–benefit ratio or AC per AEG (AC/AEG) is presented for different combinations of mass flow rate and number of TE to increase the feasibility of users in selecting the optimal design features that correspond to minimum AC/AEG.

1. Introduction

Energy is a key requirement for undergoing and performing works in everyday life. Energy demand and consumption have increased in the 20th century, and most of energy sources are fossil fuels. In the 21st century, we expect global energy consumption to increase annually. Fossil fuel sources are limited and cannot last for long periods. The release of green gas resulting from excessive fossil fuel combustion causes greenhouse gases and global climate change. However, this energy source cannot be classified as a sustainable energy source. The present world considers energy use from renewable resources to be a key factor in improving and adding benefits to the society. Renewable energy is a form of sustainable energy. Particularly, solar energy is a renewable and environment-friendly energy.

Photovoltaic (PV) cells from solar energy are widely adopted renewable energy sources and commercially available systems that can be used in various applications. However, PV cells generally become insignificantly efficient because the cells reject approximately 80% of incident solar energy either reflected back or converted into thermal energy [1]. Thus, PV–thermal (PVT) systems have been introduced to utilise the electrical and thermal energy from the sun. Electrical energy can be generated using a PV solar collector and placed under the sun. Nevertheless, the amount of electricity produced by PV solar collectors is decreased by the increased heat on PV cells in solar collectors. Heat energy can also be obtained easily as long as sunshine is available, but the heat energy received from the sun cannot be controlled. As a result, the drying process of agriculture has failed to reach a satisfactory efficiency level.

PVT collectors have been developed in various systems over the past few years. However, new studies are still being conducted to improve system efficiency in terms of electrical and thermal aspects. Modules and building-integrated PVs have become increasingly popular in many areas, particularly in industrialised countries where government support has accelerated the installation of PV systems to the grid connection. The connection to PVT collectors will increase PV efficiency. Various studies have been conducted on PVT systems based on water and air as heat carriers [2–8]. A PVT collector typically comprises an absorber plate, PV cells, and a heat removal system. The PV cells are usually attached to the absorber plate [9–13]. Numerous experimental and theoretical studies of PVT collectors are available in literature. Raghuraman [14] introduced several methods for predicting the efficiency achieved by air and water in the flat plate of PVT collectors. Prakash [15] conducted an in-depth study of the effects of air flow rate, air duct depth, length and area fraction of the absorber plate surrounded by solar cells. From these parameters, various analyses, including energy (thermal), exergy, economic and environmental

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Nomenclature

A	area (m^2)
α	Seebeck coefficient ($V\,K^{-1}$)
C	specific heat of air (J/kg °C)
d	channel height (m)
h	heat transfer coefficient (W/m^2 °C)
H	height of photovoltaic (m)
I	current (A)
k	thermal conductivity (W/m °C)
L	length of photovoltaic (m)
$\dot{m}$	mass flow rate (kg/s)
N	number of thermoelectric
R	electrical resistance (Ω)
R_e	Reynolds number
S	solar radiation (W/m^2)
P_r	Prandtl number
W	width of photovoltaic
T	temperature (°C)

Greek symbols

ε	emissivity
σ	Stefan–Boltzmann constant
τ	transmission coefficient
α	absorption coefficient
μ	dynamic viscosity
η	efficiency

Subscripts

1 and 2	first and second streams
a	ambient
b	back plate
c	photovoltaic panel cell
f	fluid
i	inlet
o	outlet
r	radiative
s	sky
w	wind

Table 1
Performance analyses of solar PVT-TE air collectors.

Year	System description of solar PVT-TE air collectors	Performance analyses						Remarks	Ref.
		1	2	3	4	5	6		
2013	Various PVT types	√	√		√			η_t= 32% Ex_{PVT} = 55.9% η_{EX} = 53%	[16]
2016	PVT transpired plate	√	√					η_{PVT} = 55% at 400 W m^{-2} η_t= 69.91% at 25% PV coverage η_{EX} = 8.66% at 100% PV coverage	[17]
2015	Glazed PVT air collector	√	√	√	√	√		Energy basis: EPBT(year) = 1.8, cost/kW h = 3.6, tCO_2/annum = 76.5 Exergy basis: EPBT(year) = 7.8, cost/kW h = 15.7, tCO_2/annum = 17.7	[19]
2013	PVT array	√	√		√	√		η_t = 11.3% η_{EX} = 16.3% $/annum($t$) = 1447.2 $/annum($Ex$) = 658.89	[20]
2016	Greenhouse PVT dryer	√	√	√	√	√	√	$En(kWh)$ = 1686.22 $Ex_{PVT}(kWh)$ = 208.05 EPBT (energy) = 1.23 y (exergy) = 10 y tCO_2 = 81.75	[21]
2008	Double-pass TE solar air collector	√						η_t = 80.3% η_{PVT} = 72.2%	[23]
2008	Greenhouse PVT	√	√					$Ex_{th}(kWh)$ = 12.8 η_{EX} = 4%	[24]
2013	Glazed PVT air collector	√	√	√	√	√		Energy basis: EPBT(year) = 1.8, cost/kW h = 3.6, tCO_2/annum = 36.97 Exergy basis: EPBT(year) = 7.8, cost/kW h = 15.7, tCO_2/annum = 5.88	[25]
2010	PVT air collector	√	√					η_t = 17.18% η_{PVT} = 45% η_{EX} = 10.75%	[26]
2010	PVT air collector	√						η_t = 17.18% η_{PVT} = 45%	[27]
2016	Various configurations of PVT air collector	√						η_t = 41.09% η_{PVT} = 67.04%	[28]
2014	Various configurations of PVT air collector	√						η_t = 75% η_{PVT} = 86%	[29]
2012	Glazed PVT air collector	√	√					$Et(kWh) = 27.6 \times 10^{-3}$ $Ex_{PVT}(kWh) = 7.56 \times 10^{-3}$	[30]
2013	PVT air collector	√		√				η_t = 17.7% Cost (kW h/kWp) = 1390.3	[31]
2012	Glazed PVT air collector	√	√				√	$Et(kWh)$ = 1252.0 $E_x(kWh)$ = 289.5 Cost (kW h) = 234.7	[32]
2012	PVT air collector	√						η_t = 22.8% η_{PVT} = 53.6%	[33]
2015	Various configurations of PVT air collector	√	√					η_t = NA η_{PVT} = NA η_{EX} = NA	[34]

Note: 1: Energy analysis, 2: Exergy analysis, 3: Economic analysis, 4: Environmental analysis, 5: Enviroeconomic analysis and 6: Exergoeconomic analysis.