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Towards the optimization of convective losses in photovoltaic–thermal panels

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Abstract

Photovoltaic–thermal panels offer a practical means of generating both electricity and hot water but, at the same time, inefficiencies arise from combining these two types of collectors. This study aims to improve on convective losses in pane spacing in a covered panel by substituting the inside Air with different gases and also optimizing the distance between panes. Although a striking improvement of up to 50.4% in the convective heat loss coefficient was observed for Xenon gas with optimized spacing, the overall heat loss coefficient only improved by 8.1%, due to the significant radiative losses in comparison to convective losses in that compartment. The Xenon/Argon photovoltaic–thermal panels outperform air panels in most operating conditions, up to 3.5%. However, considering economic/environmental issues, Argon appears as the most suitable filling gas.

The EES code is available for future replications of the study as an 'Electronic Annex'.

Keywords: PVT panel; Convective losses; Xenon; Argon

1. Introduction

Photovoltaic (PV) panels can normally transform between 5% and 20% of incident solar irradiance into electricity, while the rest of the absorbed irradiance turns into residual heat. And furthermore, the efficiency of photovoltaic cells decreases with an increase in temperature. In the midst of the 1973 oil crisis, several authors began to investigate potential uses for that residual heat with a double objective in mind: improve solar cells performance and transfer the heat to a fluid (Wolf, 1976; Hendrie, 1979). This was the beginning of photovoltaic–thermal panels (PVT), which were considered very promising for domestic-use, given that this sector demands electricity and hot water, both for heating and sanitary use (Axaopoulos and Fylladitakis, 2013). Nowadays, the residential sector plays an important role in the energy consumption of a country; in the European Union it accounts for 25% of electricity and 29% of final energy consumption (SECH, 2011).

The performance of a PVT panel is based on the principle that a PV cell not only produces electricity but also acts as a thermal absorber. This thermal energy is transferred to

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Nomenclature

Symbols

α	solar absorption coefficient (–)
A_c	collector area (m^2)
B	collector width (m)
β	tilt angle (°)
β_g	volumetric expansion coefficient (K^{-1})
c	panel height (m)
C_{bond}	bond conductance (W/m/K)
C_p	water specific heat (J/kg/K)
D_e	outer tube diameter (m)
D_i	inner tube diameter (m)
e	thickness (m)
E	exergy (W/m^2)
ϵ_g	emissivity of glass cover (–)
ϵ_{pv}	emissivity of PV cell (–)
η_0	thermal efficiency at zero reduced temperature (–)
$\eta_{e,NOCT}$	electric efficiency for PV panel for normal operating cell temperature (–)
η_{el}	PVT panel electric energy efficiency (–)
η_{th}	PVT panel thermal energy efficiency (–)
F	standard fin efficiency (–)
F'	collector efficiency factor (–)
F''	flow factor (–)
F_R	heat removal factor (–)
γ	efficiency modifier coefficient (Radiation) (–)
g	gravity (m/s^2)
G	solar irradiance on collector plane (W/m^2)
G_{abs}	absorbed solar irradiance on the panel (W/m^2)
h_{cond}	conduction heat transfer coefficient ($W/m^2/K$)
h_{conv}	convection heat transfer coefficient ($W/m^2/K$)
h_{rad}	radiation heat transfer coefficient ($W/m^2/K$)
h_{fi}	convection heat transfer coefficient between metal tube and fluid ($W/m^2/K$)
k	thermal conductivity (W/m/K)
L	panel length (m)
$loss_T$	efficiency modifier coefficient (Temperature) (K^{-1})
$\dot{m}$	mass flow (kg/s)
μ	dynamic viscosity (kg/m/s)
Nu	Nusselt number (–)
v	kinematic viscosity (m^2/s)
q	heat flow (W/m^2)
Q	heat flow (W)
Pr	Prandtl number (–)
Ray	Rayleigh number (–)
T	temperature (K)
T_a	ambient temperature (K)
T_{fm}	mean fluid temperature (K)
T_{in}	inlet fluid temperature (K)
T_{out}	outlet fluid temperature (K)
T_{pm}	mean absorber temperature (K)
T_{STC}	standard test conditions temperature (K)
T_0	reference temperature (K)
τ_n	solar transmission of glass cover (–)
u	Atomic Mass Unit
U	overall heat loss coefficient ($W/m^2/K$)
U_L	collector overall heat loss coefficient ($W/m^2/K$)
W	distance between two neighbored tubes (m)
ξ_{el}	PVT panel electric exergy efficiency (–)
ξ_{th}	PVT panel thermal exergy efficiency (–)

Subscripts

abs	absorber
b	back
bond	bond between thermal absorber and tubes
cell	PV cell
eva	EVA (encapsulant)
ins	insulation
lat	lateral
pv	photovoltaic
w	water
*g*1	outer glass cover (outer side)
*g*1*i*	outer glass cover (inner side)
*g*2	pv glass cover
*g*1*g*2	from the pv glass cover to the outer glass cover
u	useful
t	top

a heat transfer fluid (HTF), obtaining useful thermal energy and refrigerating the PV cells at the same time. Another advantage of PVT panels is that the necessary surface to generate both types of energy (electricity and heat) is condensed, since panels are integrated in a single device. Nevertheless, PV cells are not as efficient at absorbing solar radiation as the coated copper sheet used in regular thermal panels.

PVT panels are classified according to several criteria. One classification takes into account the relative position of the HTF with respect to PV cells and its containment form. Several types exist: *sheet and tube*, *channel*, *free-flow* and *dual-channel* (Zondag et al., 2003). Another classification considers the existence or absence of an air gap formed by a transparent cover over the PV cells, dividing the PVT panels in *covered* or *uncovered*. Regarding the HTF, either water or air can be utilized, although water is normally more prevalent in applications since it offers the highest efficiency and is generally more suitable for the final use (Ibrahim et al., 2011; Herrando et al., 2014). Concerning the photovoltaic part, studies suggest that amorphous silicon cells, with a lower temperature coefficient, are ideal for