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Design and analysis of a BIPV/T system with two applications controlled by an air handling unit

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ABSTRACT

A building integrated photovoltaic thermal (BIPV/T) system was designed and analyzed. The BIPV/T system is composed of multiple PV/T air collectors integrated into the building facade and connected to an air handling unit (AHU) to control the air flow. The system operates with two applications, an application for cold weather and an other for hot weather. In cold weather, the BIPV/T system recovers heat from the PV modules to preheat the outdoor fresh air. While in hot weather, the cool air exhausted from the conditioned spaces of the building is used to decrease the PV cells temperature, instead of ambient air as in conventional PV/T air collectors. An experimental tests were conducted to see the effect of using the cool exhaust air as coolant for the PV cells instead of ambient air. In order to predict thermal and electrical performance of each PV/T air collector under real climatic conditions, a theoretical model of a single pass PV/T air collector was developed and validated against experimental observations from previous literature. The theoretical and experimental comparison between the case of using exhaust air as coolant and the case of using ambient air as coolant showed an important decrease in PV cells temperature. The maximum decrease value in PV cells temperature obtained from the simulation is 9.46 °C in a selected day from August, while the electrical simulation showed that the average increase value in electrical efficiency in a selected day from August is 0.350. The simulation of the BIPV/T system in cold weather indicated that the average rate of saved useful thermal energy when using preheated outdoor fresh air in a selected day from February is 24.20%. Furthermore, the PV/T air collector performances were compared for the optimal tilt angle and the complete vertical position. The results revealed that installing the PV/T air collector at optimal tilt angle showed much better performances than a one installed at a complete vertical position, especially the electrical performance in Summer.

1. Introduction

The overconsumption of fossil fuels is one of the most important issue that the current world is facing, especially with the decrease in their availability. Moreover, burning fossil fuels liberates carbon dioxide and other greenhouse gases, which are dangerous and harmful to the environment. Currently, solar energy represents the most interesting alternative solution to the conventional energy sources. The solar energy applications can be divided into two categories: photovoltaic (PV) and solar thermal collectors. The two applications can be combined into one system, which can be called as photovoltaic/thermal (PV/T) collector. The PV/T collector is a hybrid system producing simultaneously electrical and thermal energies. It uses a fluid as coolant, this fluid is in most of cases either water or air. The fluid recovers the heat from the PV panels, thus decreasing the PV cells temperature, then the recovered heat can be exploited. In terms of thermal efficiency the solar thermal collector is way more interesting than the PV/T collector. Nonetheless the advantage of this system is that the decrease in PV cells temperature increases their electricital efficiency [1]. And working in high temperature can irreversibly degradate the PV cells conditions [2]. An other advantage is that the combination of photovoltaic and thermal systems reduce the total space required for their installation.

Furthermore, the PV/T collector can be integrated into the building, this system is referred to as the building integrated photovoltaic thermal (BIPV/T) system. Beside electrical energy production, the BIPV/T system can also produce a thermal energy that can be used for several applications in the building, like space heating, water heating, drying systems, etc.

A significant amount of theoretical and experimental studies of PV/T and BIPV/T systems have been conducted by many authors. Sarhaddi

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Nomenclature

$\dot{m}$	mass flow rate (kg/s)
A	area (m^2)
a	ideality factor
C	specific heat capacity (J/kg K)
d	air gap depth (m)
D_h	hydraulic diameter (m)
e	thickness (m)
f	Darcy friction factor
H	heating loads (kW)
hc	convective heat transfer coefficient (W/m^2 K)
hr	radiative heat transfer coefficient (W/m^2 K)
hw	convection exchange coefficient between glass cover and the ambient
I	circuit current (A)
K	Boltzmann constant (J K^{-1})
k	thermal conductivity (W/m K)
K_I	temperature coefficient of short circuit current (A K^{-1})
K_V	temperature coefficient of open circuit voltage (V K^{-1})
L	PV/T air collector length (m)
N	number of data
Nu	Nusselt number
OA	outdoor air rate
Pr	Prandtl number
Q	air flow rate (m^3/s)
q	elementary charge (C)
Qu	useful thermal energy (W)
R	electrical resistance
RA	return air rate
	Reynolds number
T	temperature (K or °C)
t	time
U	conductive heat transfer coefficient (W/m^2 K)
Uv	overall heat transfer coefficient (W/m^2 K)
V	circuit voltage (V)
v	volume (m^3)
W	PV/T air collector width (m)
w	wind speed (m/s)
Xe	experimental data
Xs	simulated data

Greek symbols

α	absorptivity
β_c	packing factor
$\dot{m}$	flow rate (m^3/s)
η	efficiency
γ	temperature coefficient of electrical power (W K^{-1})
ρ	density (kg m^{-3})
σ	Stefan–Boltzmann constant (W/m^2 K^4)
τ	transmissivity
ε	emittance

Subscripts

0	reverse saturation
a	ambient
aac	ambient air case
c	solar cell
cn	conditioned space
dp	dew point
e	electrical
eac	exhaust air case
f	fluid
g	glass
hc	exit point of the heating coil
ib	bottom surface of insulation
in	inlet
it	top surface of insulation
L	light
m	mixed air
mp	maximum power point
od	outdoor
out	outlet
ref	reference conditions
s	series
sh	shunt
t	Tedlar
tb	bottom surface of Tedlar
th	thermal
tt	top surface of Tedlar

et al. [3] modeled and calculated the thermal and electrical performance of a typical PV/T air collector. The developed model was compared to previously published experimental results. The simulation showed a good agreement with the experimental measurements. It was also observed that the thermal efficiency, electrical efficiency and overall efficiency are about 17.18%, 10.01% and 45% respectively for a sample climatic operating and design parameters. Slimani et al. [4] presented a comparative study between four solar device configurations: PV module (PV-I), conventional PV/T air collector (PV/T-II), glazed PV/T air collector (PV/T-III) and glazed double-pass PV/T air collector (PV/T-IV). They developed a numerical model, which was validated through experimental results indicated in previous literature. The results show that the average overall efficiency reached 29.63%, 51.02% 69.47% and 74% for (PV-I), (PV/T-II), (PV/T-III) and (PV/T-IV) respectively. The results were obtained by introducing a sample of experimental weather data collected in Algiers site for a sunny summer day. Jarimi et al. [5] developed a 2D steady-state model using MATLAB, and conducted indoor experiments for a bi-fluid type PV/T collector. The test included three modes: air mode, water mode and simultaneous mode of water and air. The simulation results were validated against the experimental ones. The results of the theoretical model showed a good agreement with the experimental results. The PV/T collector designed in this study can be used in a variety of applications. Simonetti et al. [6] developed and validated a model for the simulation of a PV/T collector under transient regime. The PV/T collector was divided into small elemental volumes. The energy equations were solved using a bi-dimensional finite difference method. In order to validate the model, an experimental study was realized on two hybrid PV/T solar tiles connected in series. The tests were conducted in real environmental weather conditions. The observed experimental data showed an agreement with the numerical values of the instantaneous power production, the water outlet temperature and the calculated electrical and thermal energies, giving the conclusion that the developed model is quite reliable. Yang et al. [7] developed improved designs of an open loop air-based BIPV/T collector with multiple inlets. The BIPV/T collector were simulated using a numerical control volume model which was validated through the results from series of experiments in a full scale solar simulator in Concordia University, Canada. Simulation results indicated that the BIPV/T collector with two inlets showed an increased thermal efficiency by about 5% compared to BIPV/T collector with single inlet, while electrical efficiency increased marginally. Furthermore, they added a vertical glazed solar air collector, this improved the thermal efficiency by about 8%, and the improvement was about 10% with wire mesh packing in the collector. Afterward, the developed