Design and Experimental Study for Using PV/T Collectors in the Faculty of Mechanical Engineering University of Aleppo

Marderos Ara SAYEGH*, Nabhan KHAYATA, Tamar NAHHAS

Department of Power Engineering, faculty of Mechanical Engineering University of Aleppo, Aleppo- Syria

Abstract

In recent years building integration of solar thermal with PV modules has become more and more popular in different countries, where national support programs have accelerated the dissemination of grid connected PV systems. The installation of a (BIPV) systems have certain advantages compared to a traditional PV or thermal system mounted in a separate structure on the roofs. The main purpose of this project to evaluate the feasibility of using combined PV/T collectors in typical Syrian building installations, and to test this system as a optional solution for a public, governmental or service sector buildings, there are two main advantages for such systems, large area of the roofs are suitable for mounting such systems, and specially for periodic uses or where short term thermal and electrical energy outputs are needed. PV/T collectors being considered in this paper are collectors which can provide both electrical and thermal energy. An experimental model of PV/T air collector was designed and constructed on the roof of Faculty of Mechanical Engineering in University of Aleppo, then it was inspected. This model consisted of a conventional air solar thermal collector with PV cells . One of the main conclusions of this study is that the thermal linking between PV cells and absorber plate is very important for the thermal efficiency. The electrical efficiency is depend on the flow rate of the air which passes through the collector, because the PV cells are on the inlet, then the cool air will pick the heat generated from the PV cells, so it will become relatively warm after passing under the PV cells, and thus PV cells will have a higher electrical output.

This results of the measurement show that the project will provide yearly saving for the building about: thermal energy 6133 S.P/year (2496 kW/year) and electrical energy saving 1579 S.P/year (520 kW/year).

* Corresponding author. Tel.:+963944870345; fax: +963212679101
   E-mail address: arasateg@scs-net.org

Nomenclature

L: width of absorber surface (m)
T: temperature (^{o}C)
$\dot{m}$: mass flow rate(kg/s)
v: velocity (m/s)
μ: viscosity (N.s/m^2)
C_P: specific heat (J/kg.K)
S: incident solar flux absorbed of the absorber surface (W/m^2)
U_L: overall loss coefficient (W/m^2. K)
h: heat-transfer coefficient (W/m^2. K)
F': collector efficiency factor
F_R: collector heat-removal factor
f: friction factor
Ap: area of the absorber plate (m^2)
Q_u: rate of useful heat gain (W)
A_{pv}: area of the PV cells (m^2)
E_{pv}: The required energy from the collectors (Wh/day)
E_m: capacity that can be provided by PV panels (kWh)
η_b: safety factor
E_b: capacity of the battery (kWh)
E_{load}: Daily load power (kWh/day)
DOA: the number of the cloudy days
I: Intensity of the current (A)
V: voltage (V)
η_e: electrical efficiency
η_{th}: Thermal efficiency
ΔT: Air inlet and outlet temperature difference (^{o}C)

Subscripts

f: fluid
a: ambient
m: mean
b: bottom surface
p: absorber plate
fi: inlet
r: radiative
e: effective
mpp: maximum power point

Shortcuts:

FPSAC : Flat Plate Solar Air Collector
PV/TSC: Photo Voltaic Thermal Solar Collector
PV: Photo Voltaic
BIPV: building integrated Photovoltaic

1. Introduction

The large increase in the energy consumption of buildings sector is one of the major present problems in the world. This increase is due to various reasons, including new architectural design of buildings, and using of energy-consuming equipment and advanced technologies..etc. All of that led to increase the interest in solar energy. One of the most important applications of solar energy is solar air collectors, which has an important place among solar thermal systems because it is widely used in many commercial applications such as the supply of hot air to school buildings and agricultural and industrial drying, etc [1]. PV cells have been used recently, because of increasing energy cost. One of the most recent collectors is Combined PV/T collectors, which depends on incorporating air solar collectors with PV cells. In Combined PV/T collectors, air adsorbs heat of PV cells which improve the efficiency of the cells, and the warm air can be used for heating.

In this research, combined PV/TSC was studied for heating an eastern room in the Faculty of Mechanical Engineering in University of Aleppo and providing electrical need of that room. This experimental prototype is implemented and tested.

2. Experimental setup

FPSAC consists of two parallel plates, one of these plates is the absorber plate and the other is the glass cover, and air current passes under the absorber plate. Absorber plate is made 1 mm copper plate painted with black paint. Glass cover prevents the solar radiation from escaping out of the collector, and it reflects a portion of this radiation again to the absorber plate. Insulating materials were used for the bottom and side surfaces to reduce the thermal losses by conduction. The container of the collector is made of iron. Absorber surface attains temperatures higher than ambient temperature, so air passing under the absorber plate can be heated [3].

2.1 Performance Analysis of a FPSAC

Figure (1) illustrates the studied FPSAC. We assume that the mean temperature of the air changes from T_f to $(T_f + d\,T_f)$ as it flows through the distance dx, the air mass flow rate is m, the mean temperature of the absorber plate and the bottom plate are T_{pm} and T_{bm} respectively and their variations may be neglected, also side and bottom losses can be neglected. The following equations are obtained [3]:
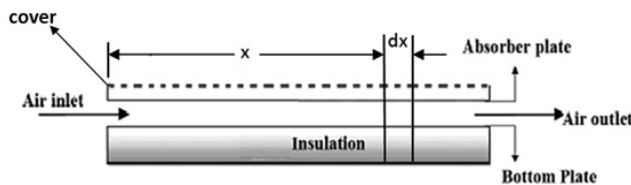

Fig. 1. FPSAC

The heat-balance equation for absorber plate is:

$$S = U_L \left(T_{pm} - T_a \right) + h_{fp} \left(T_{pm} - T_f \right) + h_r \left(T_{pm} - T_{bm} \right) \tag{1}$$

The heat-balance equation for bottom surface is:

$$h_r (T_{pm} - T_{bm}) = h_{fb} \left(T_{bm} - T_f \right) \tag{2}$$

The heat-balance equation for air stream is:

$$\frac{mcp}{L} dT_f/dx = h_{fp}(T_{pm} - T_f) + h_{fb}(T_{bm} - T_f) \qquad (3)$$

average temperature equation is given as follows [2]:

$$T_{bm} = (h_r T_{pm} + h_{fb} T_f)/(h_r + h_{fb}) \qquad (4)$$

and [4]:

$$h_e = h_{fp} + h_r h_{fb}/(h_r + h_{fb}) \qquad (5)$$
$$F' = (1 + U_l/h_e)^{-1} \qquad (6)$$
$$F_R = \frac{m \cdot cp}{Ap U_L}\left(1 - \exp\left(-\frac{U_L F' Ap}{m \cdot cp}\right)\right) \qquad (7)$$
$$Q_u = F_R Ap(S - U_L(T_{fi} - T_a)) \qquad (8)$$

The following equations give the Noselt and Reynolds numbers [7]:

$$Nu = 0.0158 Re^{0.8} \qquad (9)$$
$$Re = \rho v de/\mu \qquad (10)$$

Equivalent diameter [2]:

$$de = \frac{4 * cross - \sec tional.area.of.duct}{Wetted.perimeter} \qquad (11)$$

pressure drop can be calculated from the following equation [2]:
$$f = 0.079 Re^{-0.25} \qquad (12)$$

thermal efficiency can be calculated from:
$$\eta th = Qu/SAp \qquad (13)$$

3. PV Cells

PV cells transform solar energy into electrical energy directly without intermediate processes. PV cell absorbs most of the incident solar radiation and converted a portions of this radiation –approximately 15% or less- to electrical energy which could be used immediately or could be stored [5]. PV collector included in the considered system was consisted of the following parts:
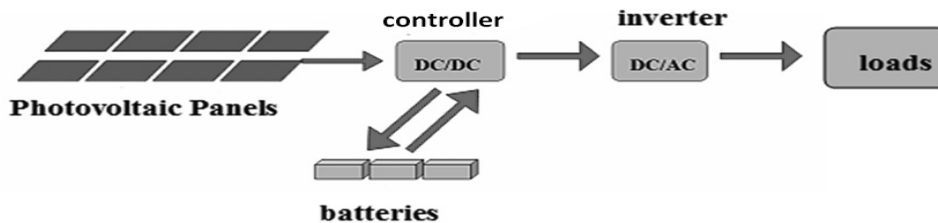

Fig. 2. A simplified scheme of the studied PV circuit

- PV panels.
- batteries: regulate voltage and store electrical energy generated by the collectors during the day and to supply it at night and during periods of low radiation.
- controller: balances charging of the batteries as well as protects them of overcharging and deep discharge.
- inverter: converts DC to AC.

3.1 Analysis of the Electrical Performance of the PV System

for supplying the electrical need, calculating the number of batteries, and selecting the controller and the appropriate inverter, the required number of collectors must be calculated:

$$Module\ number = E_{pv}/E_m \qquad (14)$$
$$E_b = E_{load} * DOA/ \eta_b \qquad (15)$$

The number of batteries can calculated by the formula :

$$Batteries\ number = E_b/(C_b * V_b) \qquad (16)$$

Acidic batteries which were used have capacity of C_b=100 (Ah) and voltage V_b=12 (V).
The capacity of inverter equal to sum of the loads that is connected to the PV system. Controller was selected depending on the maximum charge and discharge currents in the PV system.
Electrical efficiency can be calculated from [6]:

$$\eta_e = V_{mpp}I_{mpp}/ S.A_{pv} \qquad (17)$$

4. Combined PV/TSC

The Combined **PV/TSC** has two purposes: energy production from PV cells and providing heat to the air passing through the bottom surface of the cells [9]. The waste heat rejected to the air stream is useful for two reasons; 1) it cools the PV cells allowing higher power conversion efficiencies and 2) it provides a source of heat for many possible low-grade temperature applications including heating of room air as shown in Fig. (3) [8].
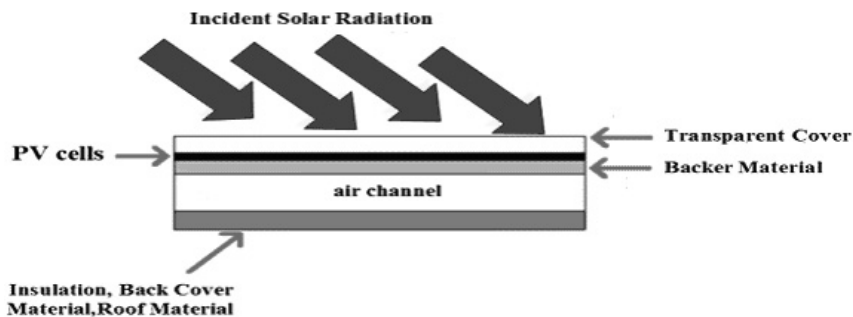

Fig. 3. cross-section of combined PV/TSC

5. Experimental Study of the Considered System

a room in the building of Faculty of Mechanical Engineering at University of Aleppo was Studied in order to provide the winter heating and electrical need for this room by taking advantage of solar energy as shown in Fig. 4.
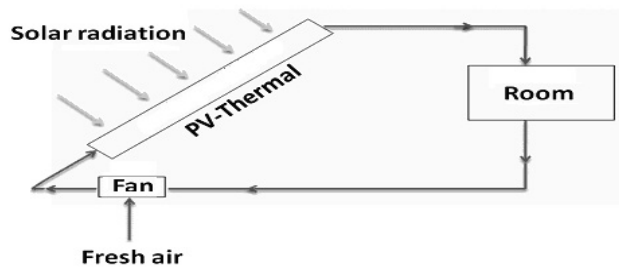
Fig. 4. a simplified schematic of the tested system

5.1 The Internal Conditions of The Studied Room

The Room to be heated has an area of 10.4(m^2) and a height of 3 (m), it is situated in the eastern direction of the building. The ambient design temperature in winter is -2(^{0}C) and the indoor design temperature is 20(^{0}C). The heating load of the room is 1600 (W) and the electrical load 250(W), which includes four energy-saving lamps, portable computer, a fan and an electrical panel.

5.2 The Thermal Part

The thermal part Consists of a FPSAC with dimensions 1.2 ×5 (m), a supply duct, a return duct, a fan of 62(W) capacity, mixing box and 9 temperature sensors placed in certain points as referred to in Fig. 5. The form (6.a) shows the cross-section of FPSAC and Fig.(6. b) cross-section of Combined PV/TSC.
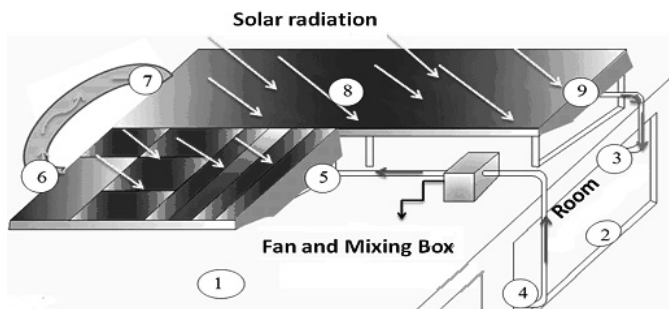

Fig. 5. General schematic of studied system

1-ambient, 2- room, 3- entry of the air to the room, 4- exit of the air from the room, 5- entry of the air to the PV collector, 6- exit of the air from the PV collector, 7- entry of the air to the thermal collector, 8- in the middle of the thermal collector, 9- exit of the air from the thermal collector, 10- opening control of the *mixing box.*
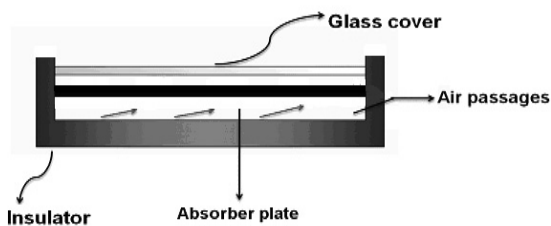

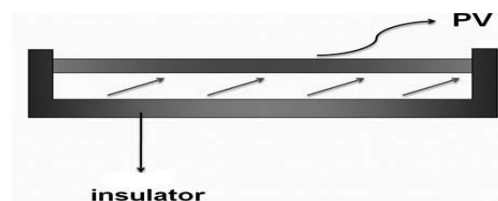Fig. 6.a. cross-section in FPSAC   Fig. 6.b. cross-section in Combined PV/TSC

5.3 The Electrical Part

The electrical Part consists of 8 PV panels with capacity of 55 (W) for each panel, a controller with a capacity of 400 (W) and 24 (V) voltage, 4 batteries with 12 (V) voltage and a capacity of 100 (Ah), an inverter of 800 (W) and circuit breaker located in the electrical panel.

5.4 The used Equipments

The following measurement instruments were used: A solar radiation sensor with measurement range of 0 - 1500 (W/m^2), BT100 type temperature sensors, an anemometer with measurement range of 0 - 10 (m/s) and measurement equipments for voltage and electric current.

5.5 The overview of the project

(a)   (b)

(c)

(a) Collectors on the roof
(b) General view of the PV/STC system
(c) Installed equipment in the room

6. Results and Discussion

- The average solar insolation over the measurements period was 630 (W/m^2) (during the period from the beginning of October to the end of January).
- The overall efficiency of the PV collector panels increases with increasing of mass flow rate of air through the duct, as a result of reduction of the PV panels temperature as in Fig.7.
- the overall efficiency of the thermal system increases with increasing of mass flow rate of air through the duct as a result of reduction of losses from the system as in Fig.8.

- As in Fig.9 depicts the useful heat gain of the FPSAC and the PV/TSC. Where the useful heat gain of FPSAC was between (900-2650)W and for the PV/TSC was between (450-1400)W during the measurements periods.
- Air inlet and outlet temperature difference is illustrated in   Fig.10. The greatest temperature difference of the FPSAC is 30(^{0}C), and 15(^{0}C) for the PV/TSC during the measurements periods.
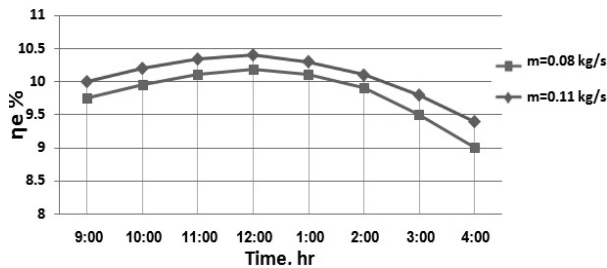
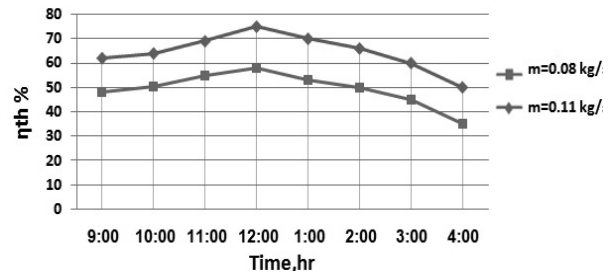Fig. 7. Electrical efficiency in various mass flow rate

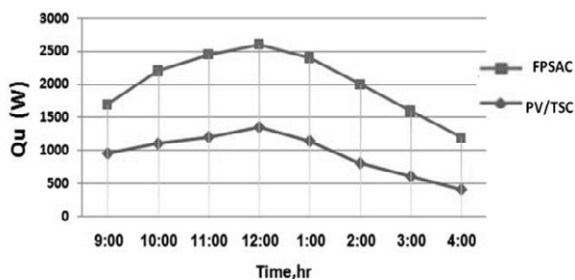Fig. 8. Thermal efficiency in various mass flow rate

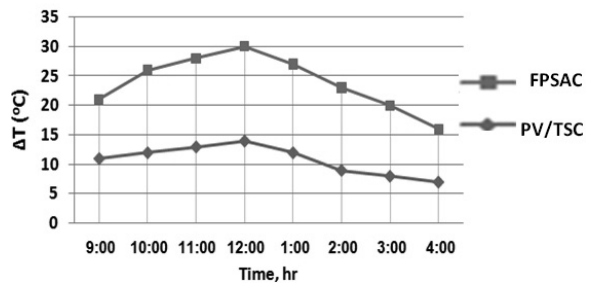Fig. 9. Useful heat gain from FPSAC and PV/TSC collectors

Fig. 10. Air inlet and outlet temperature difference

7. Conclusions

The results of measurement show that our project will provide about 2496 kW/year (6133 S.P/year) of thermal energy saving and about 520 kW/year (1579 S.P/year) electrical energy saving. To define the thermal behaviour of the PV/TSC collectors we will continue the measurements to cover the solar radiation and air temperature conditions all over the year.

References

 [1] Ucar.A. Inalli.M. Thermal and exergy analysis of solar air collectors with passive augmentation techniques. Intrnational communications in heat and mass transfer 2006;33:1281-1290.

[2] J. Richared Williams. Design and Installation of solar heating and hot water systems. 1995 by Ann Arbor Science Publishers.

[3] S.P.Sukhatme. Solar energy principles of thermal collection and storage. 1997 by Tata mcgraw-hill.

[4] Ursula Eicker. Solar Technologies for Buildings.B.G. Teubner GmbH 2003.

[5] Bruno Gaiddon, Henk Kaan and Donna Munro. Photovoltaics in the urban environment. Earthscan in the UK and US in 2009.

[6] Coventry Joe S.Performance of a photovoltaic/ thermal solar collector.Solar Energy 2005;78:211-222.

[7] Romdhane Ben Slama.The air solar collectors: comparative study, introduction of baffles to favor the heat transfer.Solar Energy 2007;81:139-149.

[8] Sodha M.S.,Tiwari Arvind. Parametric study of various configurations of hybrid PV/thermal air collector: Experimental validation of theoretical modle. Solar Energy Materials and Solar Cells 2007;91:17-28.

[9] Chow.T.T A review on photovoltaic/thermal hybrid solar technology.Applied Energy 2010;87:365-379.