International Journal of Science, Environment and Technology, Vol. 3, No 3, 2014, 1173 – 1183

ISSN 2278-3687 (O)

DESIGN, DEVELOPMENT AND EXPERIMENTAL INVESTIGATION OF SOLAR PHOTOVOLTAIC/THERMAL (PV/T) WATER COLLECTOR SYSTEM

Pratish Rawat[1*], Mary Debbarma[2], Saurabh Mehrotra[3] and K. Sudhakar[4]
Energy Centre, Maulana Azad National Institute of Technology Bhopal,
Madhya Pradesh, 462 051, India
Email: pratishrawat@gmail.com (**Corresponding Author*)

Abstract: Solar photovoltaic/thermal (PV/T) water collector system was designed and developed at MANIT Bhopal to test its performance. Solar photovoltaic/thermal (PV/T) system consists of PV modules coupled with heat extracting media such as water or air. Solar photovoltaic/thermal (PV/T) collector produces both thermal energy and electricity simultaneously. The electrical efficiency of a PV system drops as its operating temperature rises. Design of solar PV/T system aims to reduce the operating temperature of PV modules and to keep the electrical efficiency at sufficient level. Photovoltaic systems are classified according to their applications. This paper presents a performance evaluation of flat plate solar PV/T collector and comparing its performance with the solar PV system.
Keywords: solar energy, Hybrid solar PV/T collector, PV/T applications, Thermal efficiency, electrical efficiency.

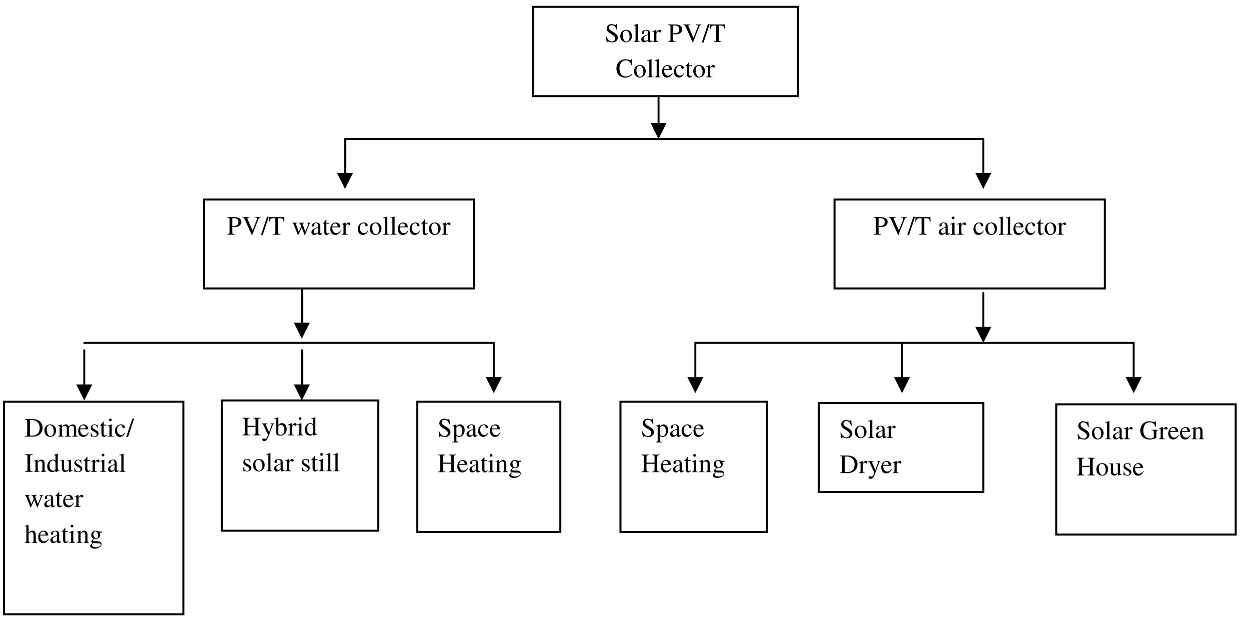
1. Introduction

A solar photovoltaic/thermal (PV/T) hybrid system is a combination of solar photovoltaic (PV) and solar thermal systems simultaneously convert solar energy into electricity and heat from one integrated system. There are different approaches in PV/T system designing. The design parameters are based on collector type, thermal efficiency, electrical efficiency, solar fraction and operating temperature. There can be selections among air or water collectors, monocrystalline, polycrystalline, amorphous silicon or thin-film solar cells, glazed or unglazed panels, natural or forced fluid flow etc. In conventional photovoltaic system, high incident solar radiation on (PV) panel should give high electrical output. However, high incident will increase the temperature of the solar cells and that will decrease the efficiency of the panel. A solar cell converts solar radiation to electrical energy with peak efficiency in the range of 6–15%, depending on type solar-cell at standard temperature and pressure. With increase of 1 0C in temperature there is reduction of the photoelectric conversion efficiency by 0.5%. A PV/T collector consists of a PV module on the back of which an absorber plate is attached. The purpose of the absorber plate is to cool the PV module and thus improve its

*Received May 10, 2014 * Published June 2, 2014 * www.ijset.net*

electrical performance and secondly to collect the thermal energy produced, which would have otherwise been lost as heat to the environment. This collected heat could be used, for low temperature applications. The hybrid design gives additional advantages, such as a reduction of the thermal stresses and hence a longer life of the PV module, high performance and reliability, low maintenance and a stabilization of the solar cell current–voltage characteristics.

2. Classification of PV/T system:



3. Methodology:

The experiments were carried out under the meteorological conditions of Bhopal (latitude of 23.16ºN; longitude of 77.24ºE) in India during 18/04/2014 from 10.00 a.m. in the morning to 5.00 p.m. in the evening.

3.1 Solar PV/T water collector construction

The solar PV/T is constructed using 37 W polycrystalline silicon solar panel. The area of panel is 0.3216 sq. m. behind the panel copper sheet and copper tube is attached. Copper sheet acts as an absorber, which absorbs heat from the panel and transfers it to water flowing in copper tubes. An 18W A.C. pump is used to circulate the water in the system.

Technical specification of PV/T system

1	Solar PV module type	Polycrystalline
2	Maximum power	37 W
3	Voltage at max. power (V_{mp})	17 V

4	Current at max. power (I_{mp})	2.18 A
5	Short circuit current (I_{sc})	2.30 A
6	Open Circuit Voltage (V_{oc})	21 V
7	Module area	0.3216 sq. m.
8	Absorber	Copper sheet 0.5 mm thick and copper tubes 12 mm diameter
9	Fluid	Water

Fig 1: Experimental setup of PV and PV/T system

3.2 Measurements

Total Instantaneous Global Solar irradiance was measured by using portable Solar Power meter (Tenmars TN-207, Taiwan) with an uncertainty of ± 10%. The ambient temperature and humidity was measured with digital thermo hygro meter. An electrical characteristic of PV and PV/T was measured by using Solar Module Analyzer (MECO 9009). The initial and final temperature of water was measured with mercury thermometer. Front side and back side temperature of PV and PV/T panel was measured by using IR Thermometer.

S. No.	Instrument	Accuracy	Range	Model make
1	Solar Module Analyser	+/- 1%	0-10 V 0.01-10A	MECO 9009
2	Solar Power Meter	+/- 5%	0-1999 W/m^2	Tenmars TM-207
3	Humidity/Temperature meter	0.1% R.H. +/- 0.8 ^{0}C	R.H. – 0 – 80% & 0-50 ^{0}C	Lutron HT-3006A
4	IR Thermometer	+/- 2 ^{o}C	-18 to 400 ^{o}C	Raytec MT4
5	Mercury Thermometer	+/- 1 ^{0}C	-10 ^{0}C to 110 ^{o}C	Elite

Fig. 2: Instruments used in the experiment

3.3 Experimental procedure

Experiments were conducted in the month of April 2014 under the meteorological conditions of Bhopal, M.P, India. Water is used as a coolant in the system with a constant mass flow rate of 0.002 kg/sec. Solar intensity, ambient temperatures, relative humidity, open circuit voltage, short circuit current, maximum power, front side and back side temperature of module, fill factor, voltage and current at maximum power, initial and final temperature of water were measured every one hour for both solar PV and solar PV/T systems.

Combination of efficiency terms describes the performance of PVT collector. Thermal efficiency and electrical efficiency are the basic ones. Thermal efficiency and electrical efficiency are respectively the ratio of useful thermal gain and electrical gain of the system to the incident solar irradiation on the collector's aperture within a given period. The sum of thermal and electrical efficiency is known as overall efficiency and is commonly used to assess the overall performance.

Photo Electric conversion efficiency, $$\eta_e = \frac{I_{SC} * V_{oc} * FF}{GA} \quad (1)$$

Thermal Efficiency, $$\eta_{th} = \frac{m c_p (T_f - T_i)}{GA} \quad (2)$$

Where, m is mass flow rate of water, cp specific heat of water (4200 J/KgK), G is the daily global solar radiation on the collector surface, T_i is initial temperature and T_f is the final temperature of the water at the storage tank.

Overall Efficiency, $$\eta_o = \eta_{th} + \eta_e \quad (3)$$

Considered electrical energy as a high grade form of energy gain, the energy saving efficiency η_f is also used [2]: it is defined as:

Energy saving efficiency, $\eta_f = \eta_e / \eta_{power} + \eta_{th}$ (4)

Where η_{power} is the electric power generation efficiency of the conventional power plants; its value can be taken as 38%.

4. Results and Discussion

In the present study, a commercial 37W polycrystalline PV module is used to build an integrated PV/T water collector system. The concept of energy saving efficiency has been used to evaluate the energy gain of the PV/T collector. The present test results show that the energy saving efficiency of a hybrid PV/T system exceeds 0.68, which is larger than the efficiency of conventional solar water heating system. The overall performance of PV/T system including electrical and thermal conversion is affected by various factors like Mass flow rate, inlet & outlet water temperature, intensity of solar radiation, ambient temperature, wind speed, orientation of system.

4.1. Temperature profile of module

More than 80% of energy incident on module is dispersed as heat. This heat raises the temperature of module. Weather data (Solar radiation), air temperature, relative humidity measured on the test day as shown in figure 3. The maximum increase in water temperature was 23 ^{0}C from 23 ^{0}C to 46 ^{0}C, which provided an additional source of energy that can be utilized. PV module back side temperature varied from 40.2 ^{0}C to 72.2 ^{0}C during the test day. It is linearly proportional to the irradiation. Under the same testing condition the back side temperature of PV/T module is very much lower than the PV module, resulting in the higher thermal energy gain. Whereas in the case of PV module it can be observed that the thermal energy is lost to the surroundings. A polynomial regression equation of module back side temperature and irradiation has been obtained based on the experimental data.

A polynomial regression equation for PV module is given by:

$y= -1.65x^2 + 15.92x+32.78$

$R^2 = 0.944$

A polynomial regression equation for PV module is given by:

$y = -0.886x^2 + 9.706x + 24.27$

$R^2 = 0.775$

4.2. Thermal Performance

Initial temperature of water (T_i) and mass flow rate (m) greatly affects the thermal performance of PV/T system but not so much electrical performance. In this study keeping the initial temperature of water below ambient temperature with low mass flow rate increase the heat transfer rate between panel and absorber plate.

The ambient temperature data shows that at 10:00 hours the ambient temperature is at 34 ^{0}C and 35.2 ^{0}C at 17:00 hours with the peak at 38.4 ^{0}C at 13:00 hours.

4.3. Electrical performance

The electrical efficiency of solar module decreases by 0.5% with rise of 1 ^{0}C in temperature. The maximum electrical conversion efficiency is obtained at 25 ^{0}C and 1000 W/m^2. The variation of electrical efficiency of solar PV and solar PV/T is approximately same throughout the day. Figure 3 shows the variation of electrical efficiency of PV and PV/T system. The electrical efficiency of PV/T varies between 7.58% and 8.27% whereas electrical efficiency of PV varies between 7.42% and 8.35%. In the morning the efficiency of both the system is approximately same, 8.31% for PV and 8.25% for PV/T system and after 3 pm there is drop of electrical efficiency due to less sunshine.

4.4. Overall Performance

On April 18, 2014, Eight hour test is performed from 10:00 to 17:00 in accordance with the test methods of solar photovoltaic and solar thermal integrated system. The test results with the constant mass flow rate are shown in table 1. It can be seen that with the constant mass flow rate of 0.002 kg/sec, the average thermal efficiency was about 50.1% and the temperature rise in flowing water is about 18 ^{0}C. The final temperature of water exceeds 46 ^{0}C without any water consumption. The daily average electrical efficiency of PV/T system was around 7.57% whereas that of PV system was around 7.37%. The average overall efficiency and energy saving efficiency were exceeds 57.61% and 50.23% respectively.

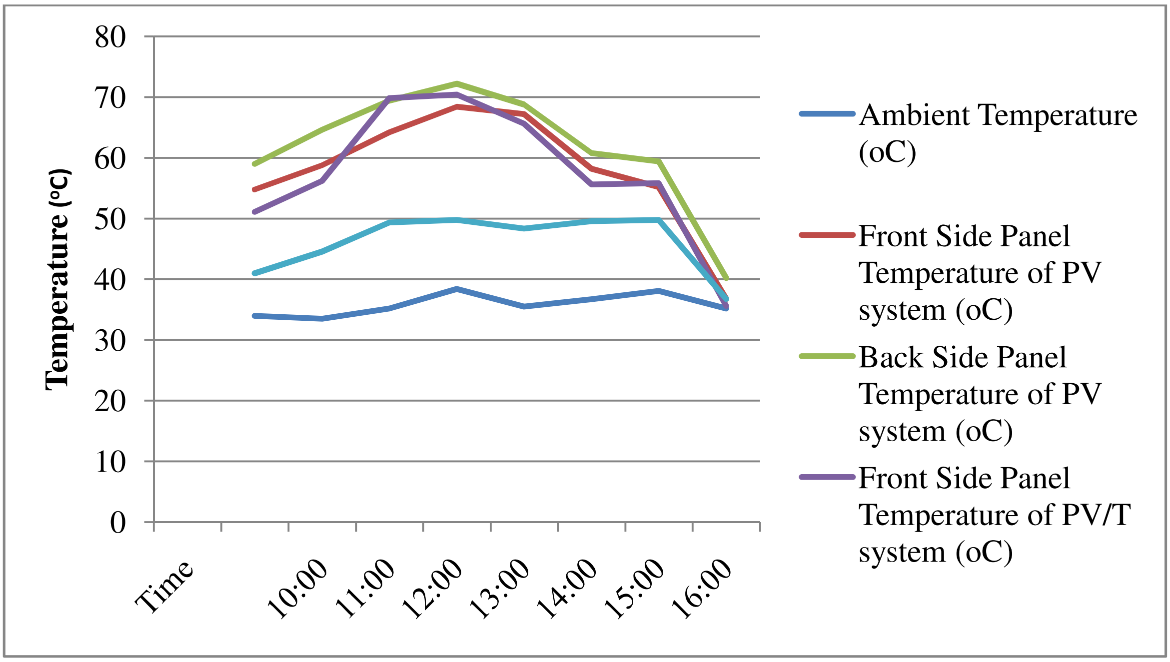


Figure 3. Comparision of module Temperature of PV and PV/T with ambient Temperature

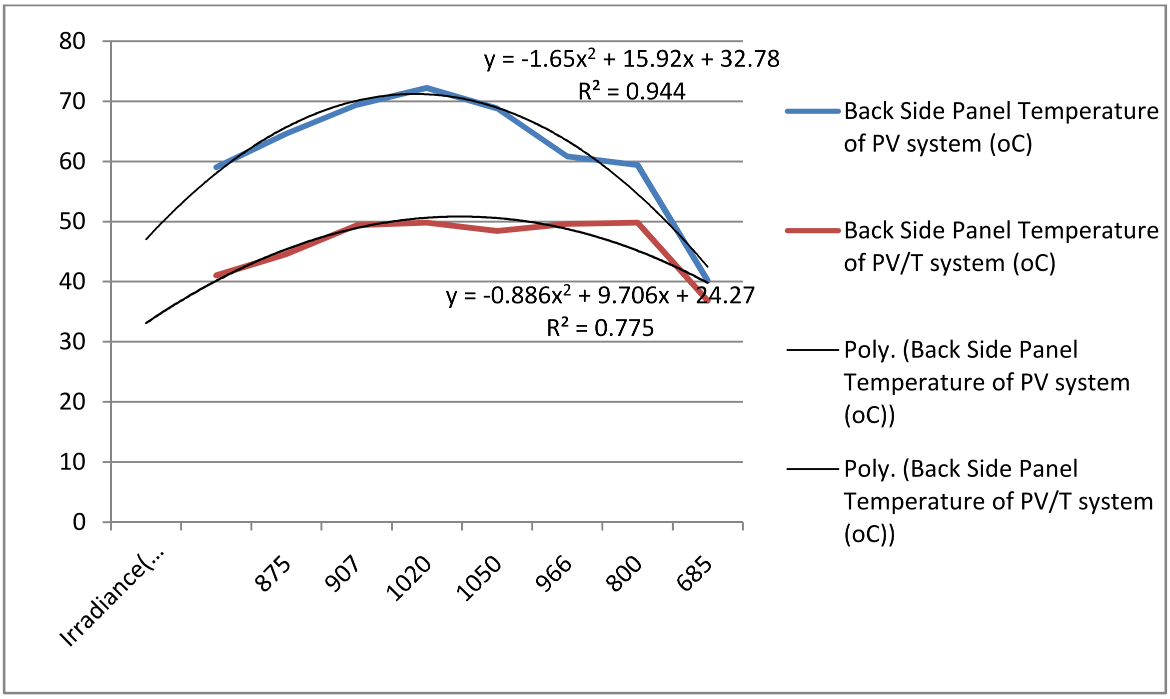


Figure 4. Comparison of module back side temperature of PV and PV/T with polynomial equations

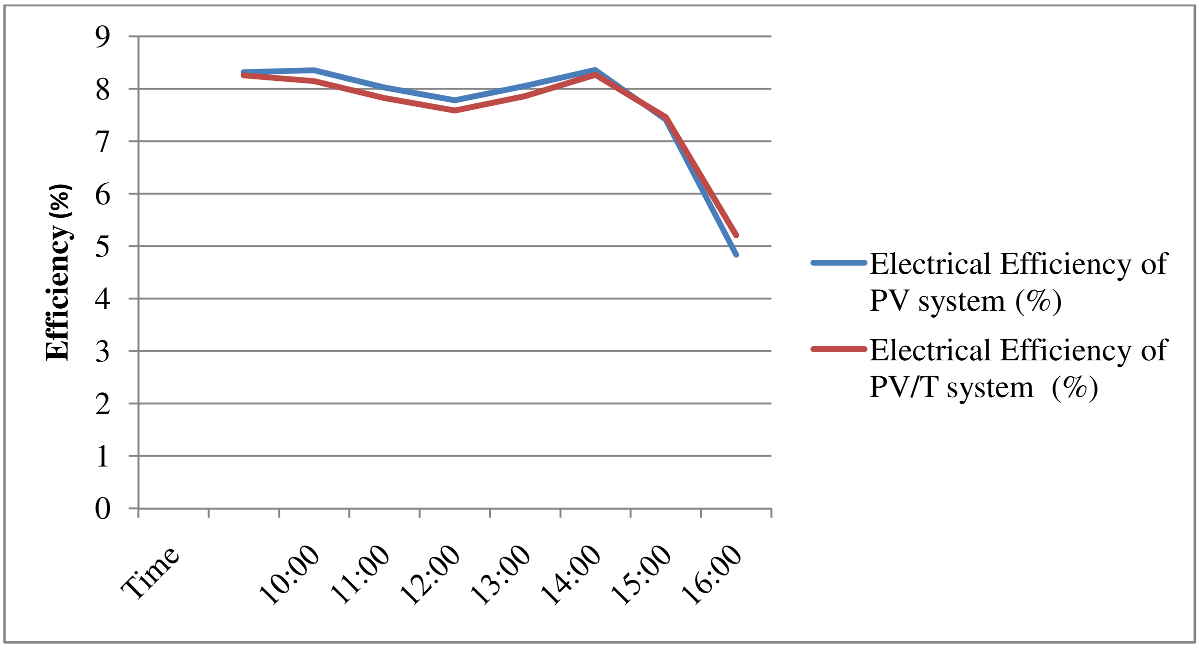


Figure 5. Comparision of Electrical Efficiency of PV and PV/T

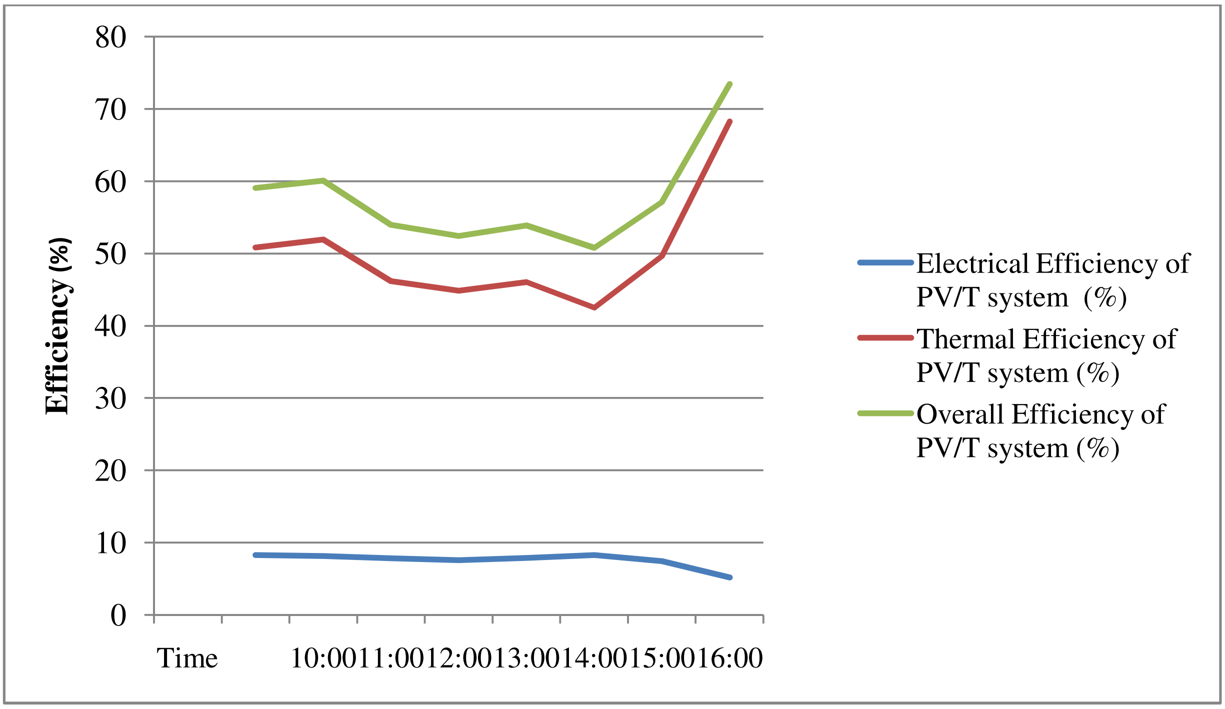


Figure 6. Comparison of Overall efficiency with thermal and electrical efficiency of PV/T

5. Conclusion

This article has presented the thermal and electrical performance of the photovoltaic/thermal water collector. A combined thermal and photovoltaic solar water heating system was successfully designed by using copper sheet as absorber on the back side of the polycrystalline silicon solar cells. A preliminary study of applying this technology in a university building of MANIT, Bhopal has been described. Experiments are conducted with fixed water flow rate of 0.002 kg/sec and different initial water temperature in the outdoor environment. With the proposed design and operating condition the daily electrical efficiency was about 7.57%, the daily thermal efficiency was about 50.1%, and the total efficiency of the system exceeded 73%. The energy saving efficiency of the PV/T system exceeded 68%. The results show that the electrical and thermal performance of the combined PV/T system is much more than that of employing the PV alone. PV/T application can offer sustainable solution for maximizing the solar energy output from building integrated photovoltaic system. This kind of PV/T system is especially suitable for low temperature applications like pre-heating of domestic water.

Nomenclature

η_f	Energy Saving Efficiency	%
η_{th}	Thermal Efficiency	%
η_e	Electrical Efficiency	%
η_o	Overall Efficiency	%
V_{oc}	Open circuit voltage	V
V	Voltage	V
V_{mp}	Voltage at maximum power point	V
I_{mp}	Current at maximum power point	A
I_{sc}	Short circuit current	A
I	Current	A
FF	Fill factor	No units
m	Mass flow rate	Kg/sec
A	Surface area of the module	m^2
G	Global irradiance	W/m^2
K	Boltzmann constant	J/K
P_{el}	Electrical power	W
P_{max}	Maximum power	W
T	Temperature	K
T_a	Ambient temperature	K
T_m	Module temperature	K
NOCT	Nominal operating cell temperature	^oC

References

[1] Wei He et.al. “Hybrid photovoltaic and thermal solar collector designed for natural circulation of water” Applied energy 83(2006) 199-210.

[2] Huang BJ et.al. Performance evaluation of solar photovoltaic/thermal systems. Sol Energy 2001;70;443-8.

[3] Huang BJ et. al. A performance test method for solar thermosyphon systems. ASME J Sol Energy 1991; 113; 172-9.

[4] P.G. Charalambous et.al. “Photovoltaic thermal (PV/T) collectors: A review”. Applied Thermal Engineering 27 (2007) 275–286.

[5] S.A. Kalogirou and Y. Tripanagnostopoulos, “Hybrid PV/T solar systems for domestic hot water and electricity production”. Energy Conversion and Management 47 (2006) 3368–3382.

[6] Kumar S, Tiwari A. An experimental study of hybrid photovoltaic thermal (PV/T)-active solar still. International Journal of Energy Research 2008;32(9):847–58.

[7] Tripanagnostopoulos Y. Aspects and improvements of hybrid photovoltaic/ thermal solar energy systems. Solar Energy 2007;81:1117–31.

[8] Deffeyes KS. Hubbert’s peak: the impending world oil shortage. Princeton, NJ: Springer Netherlands; 2002.

[9] Bardi U. Peak oil: the four stages of a new idea. Energy 2009; 34:323–6.

[10] Sadorsky P. Oil price shocks and stock market activity. Energy Economics 1999; 21:449–69.

[11] Pareto VEIV, Pareto MP. The urban component of the energy crisis. SSRN; 2008.

[12] Constatntinos A, Bouroussis FVT. Optimization of potential and autonomy of a photovoltaic system for street lighting. WSEAS Transactions on Circuits and Systems 2004; 3.

[13] Hoffmann W. PV solar electricity industry: market growth and perspective. Solar Energy Materials and Solar Cells 2006;90:3285–311.

[14] Zondag HA. Flat-plate PV-thermal collectors and systems: a review. Renewable and Sustainable Energy Reviews 2008;12:891–959.

[15] Prakash J. Transient analysis of a photovoltaic-thermal solar collector for cogeneration of electricity & hot air/water. Energy Conversion Management 1994;35(11):967–72.

[16] Bhargava AK, Garg HP, Agarwal RK. Study of a hybrid solar system—solar air heater combined with solar cells. Energy Conversion and Management 1991;31:471–9.

[17] Bakker M, Zondag HA, Elswijk MJ, Strootman KJ, Jong MJM. Performance and costs of a roof-sized PV/thermal array combined with a ground coupled heat pump. Solar Energy 2005;78:331–9.

[18] Bazilian MD. Photovoltaic cogeneration in the built environment. Fuel and Energy Abstracts 2002;43. 269.

[19] Charalambous PG, Maidment GG, Kalogirou SA, Yiakoumetti K. Photovoltaic thermal (PV/T) collectors: a review. Applied Thermal Engineering 2007;27: 275–86.

[20] Chow TT. A review on photovoltaic/thermal hybrid solar technology. Applied Energy 2009;87:365–79.