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Research Communication

Study of Hybrid Photovoltaic Thermal (HPVT) Solar Water Heater at Constant Collection Temperature for Indian Climatic Conditions*

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Abstract In this communication, two different cases, case A (collectors partially covered by PV modules; 30% PV) and case B (collectors fully covered by PV modules), connected in series have been considered for the study. The analysis has been based on the thermal energy, exergy, and electrical energy analysis. The whole study has been done by considering four weather conditions (a, b, c, and d types) for five different cities (New Delhi, Jodhpur, Bangalore, Mumbai, and Srinagar) of India. Comparison of conventional flat-plate collectors (FPC) with case A and case B has also been done for New Delhi weather conditions. Based on numerical calculations, it has been found that the total annual gain is maximum for the Jodhpur city and minimum for the Srinagar. The percentage variation between Jodhpur and Srinagar city is 25% and 23.4% for case A and case B, respectively. The annual gain for New Delhi, Mumbai, and Bangalore is nearly the same. The percentage variation between these three cities and Srinagar is 12%, 15.2%, and 10.4% for case A and 10.2%, 14%, and 9.3% for case B, respectively.

Keywords constant collection temperature; energy and exergy; hybrid PVT

1 Introduction

At the beginning, Wolf [14] has done the work on a flat-plate PV/T-liquid collector. He has analyzed a silicon solar array mounted inside a stationary non-concentrating thermal collector using a lead-acid battery as the storage element for residential heating and concluded that the system was technically feasible and cost effective. Kern and Russell [7] have reported the main concepts of these systems with results by the use of water or air as a heat removal fluid. Hendrie [5] has presented a theoretical model on PV/T systems using conventional thermal collector techniques. Florschuetz [3] has suggested an extension of the Hottel-Whillier model for the analysis of PV/T systems and Raghuraman [12] has presented numerical methods predicting the performances of liquid and air photovoltaic/thermal flat-plate collectors. Younger et al. [15] have reported a PV/T-liquid system consisting of silicon cells laminated with EVA on a copper absorber that is covered with a Mylar sheet of 50 mm thickness to provide electrical insulation. Lalovic [8] has proposed a novel transparent type of a-Si cell as a low-cost improvement of hybrid systems. Loferski et al. [9] have reported results for a hybrid system with air circulation installed on a residential building, by using two separate one-dimensional analyses compared with test measurements. Hayakashi et al. [4] have presented a system in which a roof has been covered by 48 m^2 of PV-modules which were connected to transparent tubes and filled with a black fluid. The electrical energy and thermal energy have been stored in batteries and two water tanks of 1 m^3 each, respectively.

Kalogirou [6] has calculated the yield of a 4 m^2 PV/T thermosyphon system for different climates. Zondag [16] has carried out a rigorous review on research work of PV-thermal collectors and systems, carried out by various scientists till 2006. His review includes the history and importance of a photovoltaic hybrid system and its applications in various sectors. Energy and exergy analysis of photovoltaic thermal collector with and without glass cover has been studied by Chow et al. [2]. They concluded that the increase of on-site solar radiation or ambient temperature has been seen as the favorable factor for selecting a glazed PV/T system. Chow [1] has carried out a review work on the research work of hybrid PVT technology. He recommended carrying out the work regarding thermal absorber design and fabrication, material and selective coating, energy conversion and effectiveness, performance testing, system optimization, control, and reliability. Hybrid PVT is expected to have a significant market expansion potential in the near future. Norton et al. [11] have given the solution to enhance the performance of building integrated photovoltaic systems. Recently, Tiwari et al. [13] have

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made a review on the thermal modeling of the hybrid PVT systems. Based on their review, it was concluded that PVT modules are very promising devices and there exists a lot of scope to further improve their performances.

2 Energy and exergy analysis

Two different configurations, namely, collectors partially covered by PV module and collectors fully covered by PV modules, of hybrid PVT water heating system have been discussed by Mishra and Tiwari [10]. Design specifications considered for the study have been taken from Mishra and Tiwari [10]. These have been used as input parameters for energy and exergy analysis.

2.1 Overall thermal energy gain

The energy analysis is based on the first law of thermodynamics, and the expression for total thermal gain can be defined as

$$\sum \dot{Q}_{u,total} = \sum \dot{Q}_{u,thermal} + \frac{\sum \dot{Q}_{u,net\ electrical}}{0.38}. \quad (1)$$

Here,

$$\dot{Q}_{u,thermal} = \dot{m}_f C_f (T_o - T_a), \quad (2)$$

$$\dot{Q}_{u,electrical} = \eta_c \times A_m \times N_m \times I(t). \quad (3)$$

Overall thermal output from a PVT system = thermal energy collected by the PVT system + (net electrical output/ς_{power}), where ς_{power} is the electric power generation efficiency of a conventional power plant for India.

2.2 Overall exergy gain

The exergy analysis is based on the second law of thermodynamics, which includes accounting the total exergy inflow, exergy outflow, and exergy destructed from the system as follows:

$$\sum \dot{E}x_{in} - \sum \dot{E}x_{out} = \sum \dot{E}x_{dest} \quad (4)$$

or

$$\sum \dot{E}x_{in} - \sum (\dot{E}x_{thermal} + \dot{E}x_{net\ electrical}) = \sum \dot{E}x_{dest},$$

where exergy of radiation can be given as [10]

$$\dot{E}x_{in} = A_c \times N_c \times I(t) \times \left[1 - \frac{4}{3} \times \left(\frac{T_a}{T_s}\right) + \frac{1}{3} \times \left(\frac{T_a}{T_s}\right)^4\right], \quad (5a)$$

$$\textit{Thermal exergy} = \dot{E}x_{thermal} = \dot{Q}_u \left[1 - \frac{T_a + 273}{T_{fo} + 273}\right], \quad (5b)$$

$$\textit{Net electrical exergy} = \dot{E}x_{net\ electrical} = \eta_c \times A_c \times N_c \times I(t) - P_W, \quad (5c)$$

$$\textit{Overall exergy} = \dot{E}x_{thermal} + \dot{E}x_{net\ electrical}, \quad (6)$$

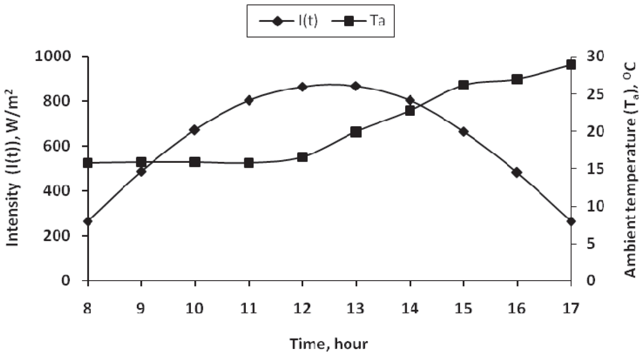


Figure 1: Hourly variation of solar intensity and ambient temperature of a typical day in the month of March.

where A_c is the area of collector, T_s is the sun temperature in Kelvin, and P_W is the pump power.

3 Methodology

The annual thermal energy gain, electrical energy gain and exergy gain for five different cities in India for hybrid PVT water collector can be obtained in the following steps.

Step 1. The hourly rate of useful thermal energy gain for a clear day of each month for all the cases can be obtained by using (2) by considering $N = 3$ and $T_o = 40$ °C.

Step 2. Daily thermal gains for a–d types weather conditions have been calculated by summing the hourly useful thermal energy gains as evaluated in Step 1.

Step 3. Monthly thermal gain has been calculated by multiplying the daily thermal energy gain and number of clear days in a month for a–d types weather conditions.

Step 4. The annual thermal gain has been calculated by summing the monthly thermal energy gain for a–d types weather conditions.

For evaluating annual electrical energy and exergy gains for five different cities in India, a similar methodology has been adopted as for annual thermal energy gains (Steps 1–4) by using (3), (4), (5a), (5b), (5c), and (6).

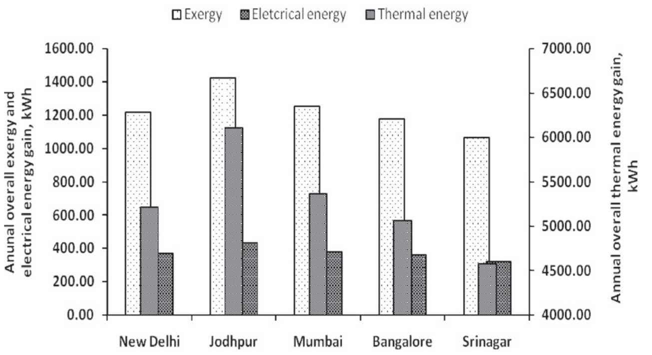
4 Results and discussions

The variation of solar intensity and ambient temperature for a typical day in the month of March is shown in Figure 1. The values of design parameters of a hybrid PVT water collector are given in Table 1.

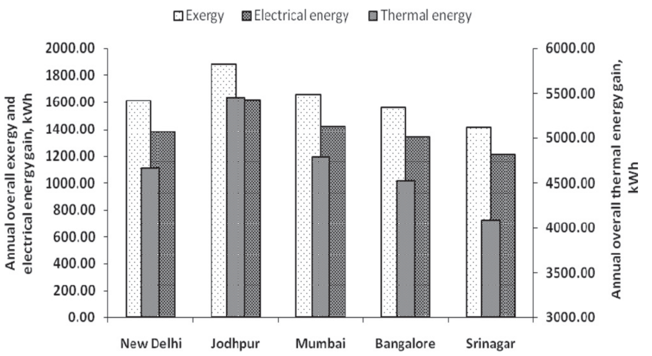
The annual gain by considering the four types of weather conditions for five different cities of India (New Delhi, Bangalore, Mumbai, Srinagar, and Jodhpur) for case A and case B is shown in Figures 2(a) and 2(b), respectively. From the figures, it is clear that the total annual gain is maximum for the Jodhpur city and minimum for the Srinagar city for both

Table 1: Design parameters of photovoltaic thermal (PVT) collector.

Parameters	Values	Parameters	Values
A_C	2.0 m^2	U_{LC}	3.0 W/m^2 °C
A_m	0.605 m^2	U_{Lm}	3.44 W/m^2 °C
C_f	4190 J/kgK	$U_{tc,a}$	9.5 W/m^2 °C
F'	0.968	V	1.0 m/s
F_{Rc1}	0.95	W	0.125 m
F_{Rc2}	0.94	α_c	0.90
F_{Rm}	0.96	τ_c	0.95
$h_{c,p}$	5.7 W/m^2	β_c	0.89
$h_{p,f}$	100 W/m^2	η_o	0.12
PF_1	0.357	α_p	0.80
PF_2	0.965	τ_g	095
K	204 W/m°C		



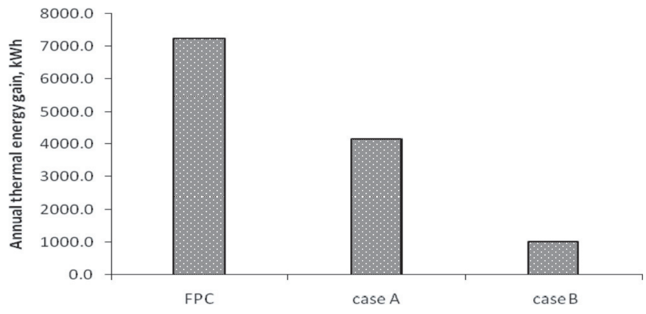
(a)



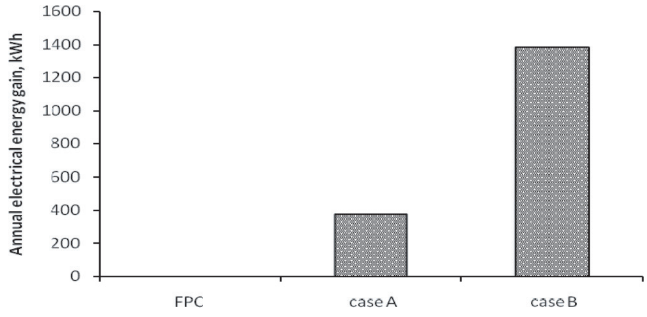
(b)

Figure 2: (a) Annual gain in overall thermal energy, exergy, and electrical energy for five different cities of India for case A ($N = 3$ and $T_{fo} = 40$ °C). (b) Annual gain in overall thermal energy, exergy, and electrical energy for five different cities of India for case B ($N = 3$ and $T_{fo} = 40$ °C).

cases. The percentage variation between Jodhpur and Srinagar is 25% and 23.4% for case A and case B respectively. The annual gain for New Delhi, Mumbai, and Bangalore is nearly the same. The percentage variation between the three cities and Srinagar is 12%, 15.2%, and 10.4% for case A and 10.2%, 14%, and 9.3% for case B, respectively.



(a)



(b)

Figure 3: (a) Variation of annual thermal energy gain for FPC, case A, and case B for New Delhi weather conditions ($N = 3$ and $T_{fo} = 40$ °C). (b) Variation of annual electrical energy gain for FPC, case A, and case B for New Delhi weather conditions ($N = 3$ and $T_{fo} = 40$ °C).

Variation of annual thermal and electrical energy gain for cases A, B, and flat-plate collector (FPC) considering three collectors connected in series and $T_{fo} = 40$ °C for New Delhi weather conditions is shown in Figures 3(a) and 3(b), respectively. Results show that FPC is better for thermal point of view and case B is better for electrical point of view. Depending upon the user's requirement, different hybrid combinations can be made.

5 Conclusion

The total annual gain is maximum for the Jodhpur city and minimum for the Srinagar city. The percentage variation between Jodhpur and Srinagar is 25% and 23.4% for case A and case B, respectively. The annual gain for New Delhi, Mumbai, and Bangalore is nearly the same. The percentage variation between the three cities and Srinagar is 12%, 15.2%, and 10.4% for case A and 10.2%, 14%, and 9.3% for case B, respectively.

References

[1] T. T. Chow, *A review on photovoltaic/thermal hybrid solar technology*, Applied Energy, 87 (2010), 365–379.

[2] T. T. Chow, W. He, and J. Ji, *Hybrid photovoltaic-thermosyphon water heating system for residential application*, Solar Energy, 80 (2006), 298–306.

[3] L. W. Florschuetz, *Extension of the Hottel-Whillier model to the analysis of combined photovoltaic/thermal flat plate collectors*, Solar Energy, 22 (1979), 361–366.
[4] B. Hayakashi, K. Muzusaki, T. Satoh, and T. Hatanaka, *Research and development of photovoltaic/thermal hybrid solar power generation system*, in Proc. of ISES Solar World Congress, Kobe, Japan, 1990, 302–306.
[5] S. D. Hendrie, *Evaluation of combined photovoltaic/thermal collectors*, in Proc. International Solar Energy Society, vol. 3, Atlanta, Ga, 1979, 1865–1869.
[6] S. A. Kalogirou, *Use of TRNSYS for modelling and simulation of a hybrid pvthermal solar system for Cyprus*, Renewable Energy, 23 (2001), 247–260.
[7] E. C. Kern Jr. and M. C. Russell, *Combined photovoltaic and thermal hybrid collector systems*, in Proc. 13th IEEE Photovoltaic Specialists, Washington, DC, 1978, 1153–1157.
[8] B. Lalovic, *A hybrid amorphous silicon photovoltaic and thermal solar collector*, Solar Cells, 19 (1986), 131–138.
[9] J. J. Loferski, J. M. Ahmad, and A. Pandey, *Performance of photovoltaic cells incorporated into unique hybrid photovoltaic/thermal panels of a 2.8 KW residential solar energy conversion system*, in Proc. of the 1988 Annual Meeting of the American Solar Energy Society, Cambridge, MA, 1988, 427–432.
[10] R. K. Mishra and G. N. Tiwari, *Evaluation of an integrated photovoltaic thermal solar (IPVTS) water heating system for various configurations at constant collection temperature*, in World Renewable Energy Congress, Linkōping, Sweden, 2011, 3749–3756.
[11] B. Norton, C. Philip, K. M. Tapas, M. J. Huang, S. J. McCormack, J. D. Mondol, et al., *Enhancing the performance of building integrated photovoltaics*, Solar Energy, 85 (2011), 1629–1664.
[12] P. Raghuraman, *Analytical predictions of liquid and air photovoltaic/thermal flat plate collector performance*, Journal of Solar Energy Engineering, 103 (1981), 291–298.
[13] G. N. Tiwari, R. K. Mishra, and S. C. Solanki, *Photovoltaic modules and their applications: A review on thermal modelling*, Applied Energy, 88 (2011), 2287–2304.
[14] M. Wolf, *Performance analyses of combined heating and photovoltaic power systems for residences*, Energy Conversion, 16 (1976), 79–90.
[15] P. R. Younger, W. S. Kreisman, M. J. Nowlan, J. S. Solomon, and S. J. Strong, *Combination photovoltaic/thermal solar collectors for residential applications*, in Proc. 15th IEEE Photovoltaic Specialists, Kissimmee, FL, 1981, 959–963.
[16] H. A. Zondag, *Flat-plate PV-Thermal collectors and systems: A review*, Renewable and Sustainable Energy Reviews, 12 (2008), 891–959.