Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2015, 2(3): 69-75

Research Article ISSN: 2394 - 658X

Performance of Hybrid Air Collector under Different Condition

Deepika Chauhan[1], YS Shishodia[2] and Sanjay Agarwal[3]

[1]Department of Electrical Engineering, Jaipur National University, Jaipur, India
[2]Computer Science Engineering, Jagannath University, Jaipur, India
3Department of Electrical Engineering, IGNOU, New Delhi, India
deepika0501@gmail.com

ABSTRACT

Solar air collector which generates both thermal and electrical energies simultaneously is called Hybrid solar collector. The hybrid solar collector consists of transparent glass, air duct, absorber plate, PV module and DC fan. When solar radiation falls on PV module, it generates direct current but only a small portion of incident solar radiation gets convert into electricity while rest will increase the temperature of the module. Air flows through the duct to gain heat. The heated air is then leaving the duct which can be further used for various applications. Opaque module of hybrid PV/T air collector with air flowing above the module is considered for analysis. The performance is analyzed for the composite climate of New Delhi, Jodhpur, Bangalore, and Srinagar. Analytical expression for various parameters have been derived.

Key words: Thermal efficiency, electrical efficiency, PV module, solar collector, opaque

INTRODUCTION

As India is a developing country, it has tremendous energy demand and through the Traditional means of Power generation, it is very difficult to meet this ever increasing energy demand. Recent example of world's largest blackout was on 30 and 31 July 2012, spreading from New Delhi to Kolkata has occurred. The impact of this outage is that about 700 million people have to be without electricity. This blackout has grown the need for this massive demand of electricity and steps to be taken to generate this needful power. India has aim to increase the Power generation capacity by 44% within next 5 years. Due to Population Growth and economic development, India Electricity consumption is increasing at the very fast rate so what steps have to be taken to shorten the Power Outages and to meet the future energy demand .From the economic as well as environmental point of view, to meet the future demand for electricity, India has decided to shift to non-Polluting renewable source of energy.

Recently, Jones and Underwood [1] have studied the temperature profile of photovoltaic (PV) module in a non-steady state condition with respect to time. They performed experiments for clear as well cloudy day condition and observed that the PV module temperature varies between 300–325 K (27–52 ◦C) for an ambient air temperature of 297.5 K .The thermal energy associated with PV module may either be removed (carried away) by air or water. When thermal energy requirement is integrated with photovoltaic (PV) module, it is referred to as hybrid PV/T system. Tripanagnostopoulos et al [2] found that electrical efficiency of PV module can be increased by PV cooling and this will increase the total efficiency of PV module. Chow et al [3] developed a computational thermal model for analysing the annual performance of facade-Integrated hybrid Photo-voltaic/thermal collector system. Chow et al [4] found that forced convective cooling under a higher coolant flow velocity is better than the natural flow design. Nevertheless, the additional fan power consumption reduces the net electrical gain of the system. By studying the performance of PVT collector Coventry [5] found that the overall electrical efficiency is 11% and overall thermal efficiency is 58% which gives total of 69%. In[6] Tiwari and Sodha presented a variety of results regarding the effect of design and operation parameters on the performance of air type PVT systems. Tonui [7] uses free air convection cooling to remove heat from the back to keep the electrical efficiency at an acceptable level by taking the four weather condition and by varying number of collector. In [8] Dubey and Tiwari made a detailed analysis of thermal energy, exergy and electrical energy yield by system. Kumar & Tiwari [9] presented the life cycle cost analysis of the single slope passive and hybrid photovoltaic (PV/T) active solar stills. Dupeyrat et al [10] introduced a different approach to analyze thermal and optical properties related to both PV and solar thermal functions.

Agrawal and Tiwari [11] have presented the concept of series and parallel connections of micro-channel solar cell thermal tiles to analyze overall energy and exergy of hybrid micro-channel PVT module. Kamthania et al [12] presented the performance evaluation of a semi transparent PVT for space heating and observed that the annual thermal and electrical energy are 480.81 kWh and 469.87 kWh respectively. Vats and Tiwari [13] has done the analysis for room air temperature of BISPVT & BIOPVT system integrated to the roof of room with & without air duct and found that increase in mass flow rate increase the room temperature. Bambrook and Sproul [14] experimental PVT air system demonstrated the increasing thermal and electrical PV efficiencies with increasing air mass flow rate. Exergeoeconomic analysis of glazed hybrid PVT air collector was done by Agrawal and Tiwari [15] and they concluded that PVT module air collector offer a greater potential in comparison to PV module.

Mortezapour et al [16] analyse the performance evaluation of a two-way hybrid PV/T solar collector and found that glass-glass system has higher outlet temperature, cell temperature & thermal Efficiency in comparison to glass-Tedlar system. Agrawal and Tiwari [17] done the overall thermal energy and energy analysis for different configuration of hybrid PVT array and found that overall thermal energy gain and energy gain is highest for Bangalore city. Sharma and Tiwari [18] analyse the performance of a solar photovoltaic (PV) array system based on electrical energy output and power conversion efficiency. Agrawal and Tiwari [19] has done the comparative analysis of unglazed ,glazed tiles and conventional hybrid PVT air collectors for the composite climate of Srinagar (India) in terms of overall thermal energy and energy gain, energy efficiency and carbon credit earned . Joshi et al [20] develop thermal modelling for glass-Tedlar and glass-glass PV/T air collector system and found that back surface temperature and overall thermal Efficiency is more in glass-glass system and also overall thermal Efficiency decreases with increase in length of duct and increase with increase in air velocity. Kumar and Rosen [23]critically review photovoltaic–thermal solar collectors for air heating and found that this system in future be practicable for preheating air for many application and also found that integrated PV/T collector deliver more useful energy per unit collector area than separate PV and thermal system.

DIFFERENT CASE STUDIES

Different cities are taken for the Opaque PV module having duct above the module under different climatic conditions i.e Type a, Type b, Type c and Type d. In this paper weather condition of four different cities are considered for analysis and performance investigation. The cities considered for comparison purpose are-New Delhi, Jodhpur, Banglore and Srinagar. In this module case, solar radiation is absorbed by solar cell and EVA and then it is conducted to tedlar and then it is also transfer to air flowing in the duct of glass above the module

ENERGY ANALYSIS OF MODULE

In order to write the energy balance equation, the following assumptions have been made:

[1] The system is in quasi steady state condition.
[2] Ohmic losses in solar cell are negligible.
[3] The heat transfer coefficient is constant.
[4] The air flow through duct is uniform for the forced mode of operation for stream flow.

Following Tiwari et al [6] and Joshi [20], the energy balance equations in watts are:

At Glass of PV Module

$$P_1+P_2=P_3+P_4+P_5 \quad (1)$$

$P_1=\tau_g^2\alpha_c^2 I\,(t)\beta_c\, bd_x$ = rate of solar energy receive by solar cell after Transmission

$P_2=\tau_g^2(1-\beta_c)\alpha_T\, I\,(t)bd_x$= rate of solar energy absorbed by tedlar

$P_3=U_{ts}(T_c-T_{air})bd_x$= rate of heat loss from solar cell to air

$P_4=U_{bs}(T_c-T_a)bd_x$= rate of heat loss from solar cell to ambient through glass duct

$P_5=\eta_c\beta_c I\,(t)\,\alpha_c^2\tau_g^2\, bd_x$= rate of electrical energy produced

For Air Flowing Through the Duct

$$P_3=P_6+P_7 \quad (2)$$

$P_6=m_a c_a \dfrac{dT_{air}}{d_x} d_x$ = Heat carried away with flowing air

$P_7=h_1\,(T_{air}-T_a)bdx$=rate of heat loss from flowing air to ambient through glass duct

With the help of above Equations Solar cell Temperature Expression can be written as:

$$T_c = \frac{\left(\tau_g \beta_c \alpha_c{}^2 + \tau_g{}^2 \alpha_T (1-\beta_c) - \tau_g{}^2 \beta_c \eta_c \alpha_c{}^2\right) I(t) + U_{bs} T_a + U_{ts} T_{air}}{U_{bs} + U_{ts}} \tag{3}$$

From Equation 1, 2 &3 and rearranging them, we get

$$\frac{dT_{air}}{d_x} + \frac{(bU_{LT})}{m_a c_a}(T_{air-} T_a) = \frac{bh_{p1T}(\alpha\tau)_{effT} I(t)}{m_a c_a} \tag{4}$$

Integrating above equations with initial condition T_{air}=T_{airin} at x=0,we get an expression for temperature of flowing air inside air duct

$$T_{air} = [T_a + \frac{h_{p1T}(\alpha\tau)_{effT} I(t)}{U_{LT}}]\left(1 - e^{\frac{-bU_{LT}X}{m_a C_a}}\right) + T_{airin} e^{\frac{-bU_{LT}X}{m_a C_a}} \tag{5}$$

The average air temperature of the flowing air over the length of air duct above the PV module is obtained as:-

$$T_{airout} = [T_a + \frac{h_{p1T}(\alpha\tau)_{effT} I(t)}{U_{LT}}] \times \left[1 - \frac{1 - e^{\frac{-bU_{LT}L}{m_a C_a}}}{\frac{bU_{LT}L}{m_a C_a}}\right] + T_{airin}\left(1 - \frac{1 - e^{\frac{-bU_{LT}L}{m_a C_a}}}{\frac{bU_{LT}L}{m_a C_a}}\right) \tag{6}$$

The rate of useful thermal energy obtained from the PV/T air collector is thus obtained as:

$$Q = \frac{m_a c_a}{U_{LT}}\left[h_{p1T}(\alpha\tau)_{effT} I(t) - U_{LT}(T_{air} - T_a)\right]\left(1 - e^{\frac{-bU_{LT}L}{m_a C_a}}\right). \tag{7}$$

Daily thermal gain is calculated as-

$$Q_{thermal} = \frac{Q^{\cdot}}{1000} \tag{8}$$

The following expression for the electrical efficiency was used [21] & [22]

$$\eta_{el} = \eta_o\left[1 - \beta_o(T_c - T_a)\right]$$

$$\eta_{el} = \eta_0 \left[\frac{1 - \frac{\beta_0 (\alpha\tau)_{1effT} I(t)}{U_{ts} + U_{bs}}\left\{1 + \frac{U_{ts} h_{p1T}}{U_{LT}}\left(1 - \frac{1 - \exp(-x_0)}{x_0}\right)\right\}}{1 - \frac{\eta_0 \beta_0 \tau_g{}^2 \alpha_c{}^2 \beta_c}{U_{ts} + U_{bs}}\left\{1 + \frac{U_{ts} h_{p1T}}{U_{LT}}\left(1 - \frac{1 - \exp(-x_0)}{x_0}\right)\right\}}\right] \quad \text{Where } x_0 = \frac{bU_{LT}L}{m_a c_a} \tag{9}$$

Daily electrical energy generated in given as

$$E_{xelectrical} = \frac{\eta_{el} \times A \times I(t)}{1000} \tag{10}$$

$$E_{xThermal} = Q^{\cdot}\left[1 - \frac{Ta + 273}{Tfo + 273}\right] \tag{11}$$

$$\sum E_{xout} = \sum E_{xthermal} + \sum E_{xelectrical} \tag{12}$$

$$\sum \text{overall Thermal gain} = \sum Q_{thermal} + \frac{\sum E_{xelectrical}}{0.38} \tag{13}$$

ENERGY ANALYSIS

Annual Thermal Gain

- The rate of useful thermal energy can be obtained from Equation. (7)
- daily thermal gain in kwh of a-d type weather have been calculated using equation.(8)
- Monthly thermal gain in kwh have been calculated by multiplying daily thermal output and number of clear days in a month of a-d type weather condition of PV/T module.
- Annual thermal gain has been calculated by summing the monthly thermal gain of a-d type weather of PV/T module

Annual Electrical Gain

- Temperature dependent electrical efficiency can be calculated using equation (9) based on hourly solar radiation, ambient temperature and cell temperature.
- Daily electrical energy generated in kwh of a-d type weather of PV/T module can be calculated by using Equation (10)
- Monthly electrical output have been calculated by multiplying daily electrical energy generated and no. of clear days in a month of a-d type weather of PV/T module.
- An annual electrical output have been calculated by summing the monthly electrical output of a-d type weather

Overall Exergy Analysis

- Exergy Equivalent of daily thermal output is calculated using equation(11)
- Monthly output Exergy have been calculated by multiplying daily Exergy output and no. of clear days in a month of a-d type weather of PV/T module.
- Annual outputs Exergy have been calculated by summing the monthly Exergy output of a-d type weather.
- As electrical output is also a form of Exergy so overall Exergy is obtained from equation(12)

Overall Thermal Energy gain

- The Annual Thermal gain is obtained from above methodology.
- Electrical gain is converted into Thermal gain by dividing it by electric power generation efficiency conversion factor for a conventional power plant for India i.e by 0.38
- Overall Thermal gain is obtained from equation (13).

RESULT AND DISCUSSION

The Annual Electrical Energy gain and Thermal Energy gain obtained by four cities is shown in fig 1 & 2.It has been observed that Bangalore has got the highest value of Overall exergy gain and Thermal gain because the number of clear days available are more and this city is also having moderately high value of solar Intensity and moderate temperature. The monthly variation of Overall Exergy gain &Thermal Energy gain for Jodhpur city is shown in fig 7 &8. It was found that the highest value of both the gain is found in the Month of May while minimum in the month of December. This is due to the availability of clear days and Solar Intensity. In terms of Overall Exergy gain May has got 42.37% higher value than December while in terms of Overall Thermal gain May has got 42.62% higher value than December.

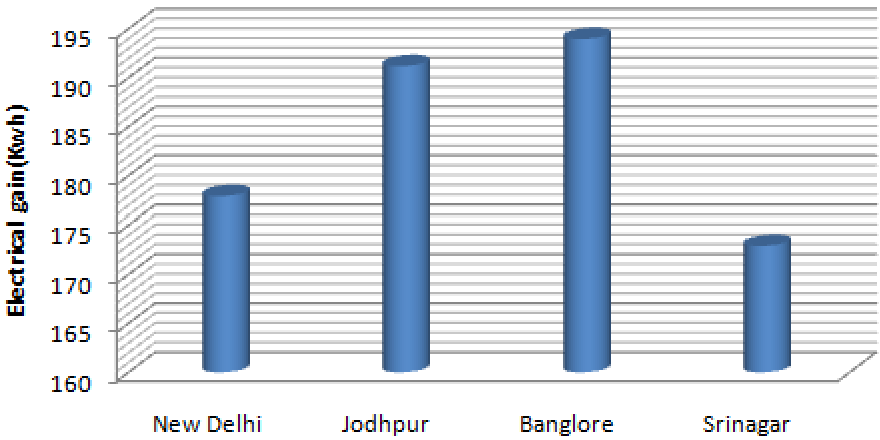

Fig. 1 Annual electrical gain (Kwh)

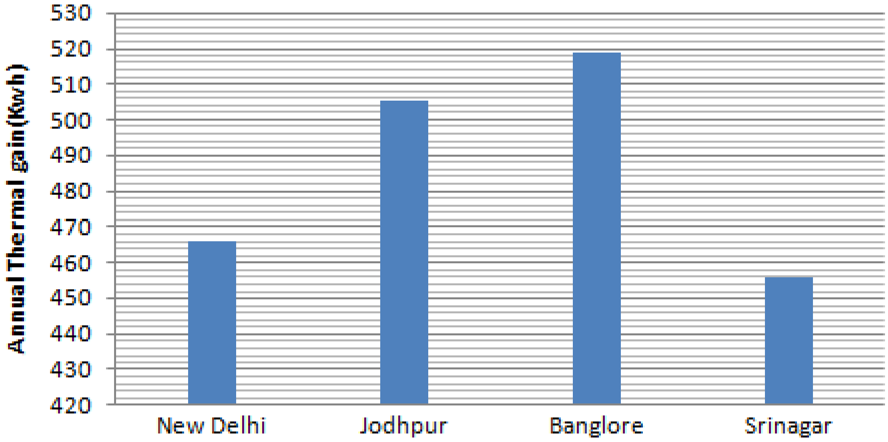

Fig. 2 Annual thermal energy gain (Kwh)

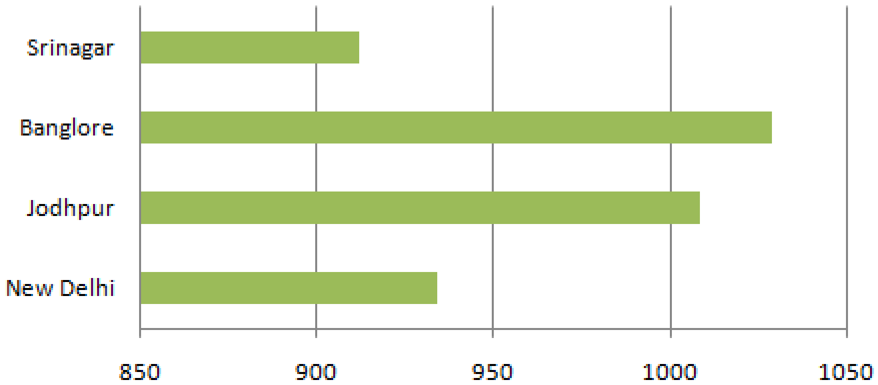

Fig. 3 Annual variation of overall exergy gain (Kwh)

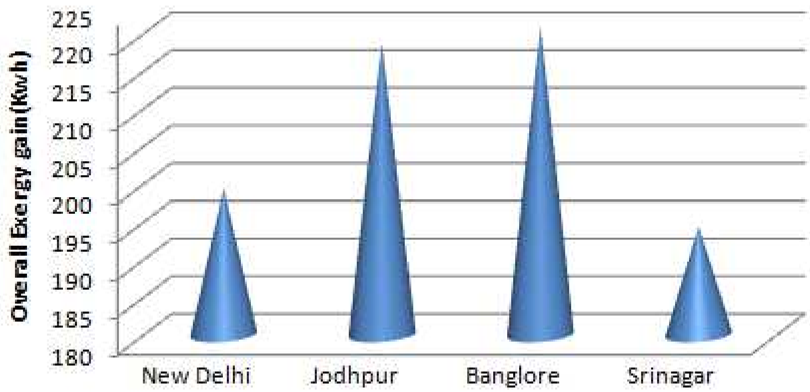

Fig. 4 Annual variation of overall thermal gain (Kwh)

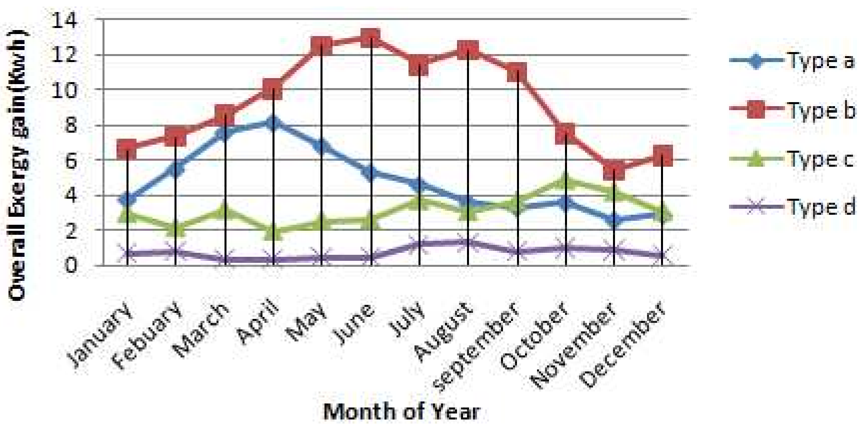

Fig. 5 Variation of overall energy gain for different type of weather condition for Jodhpur city

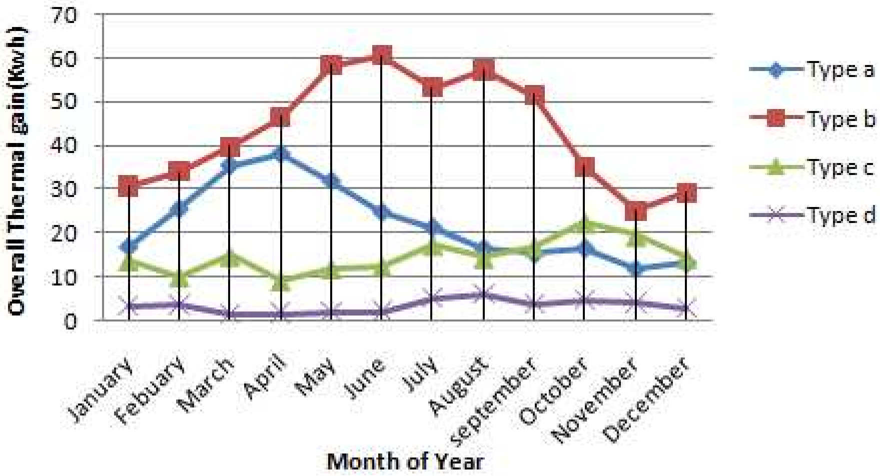

Fig. 6 Variation of overall thermal gain for different Type of weather condition for Jodhpur city

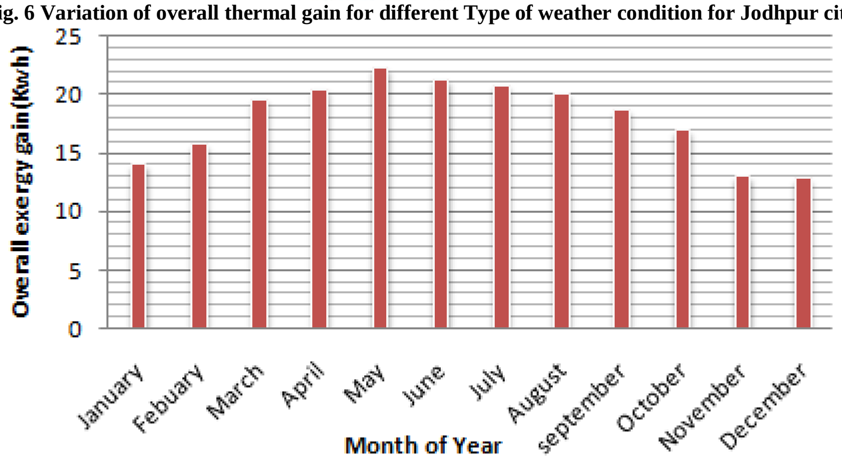

Fig. 7 Monthly variation of overall energy gain for Jodhpur city

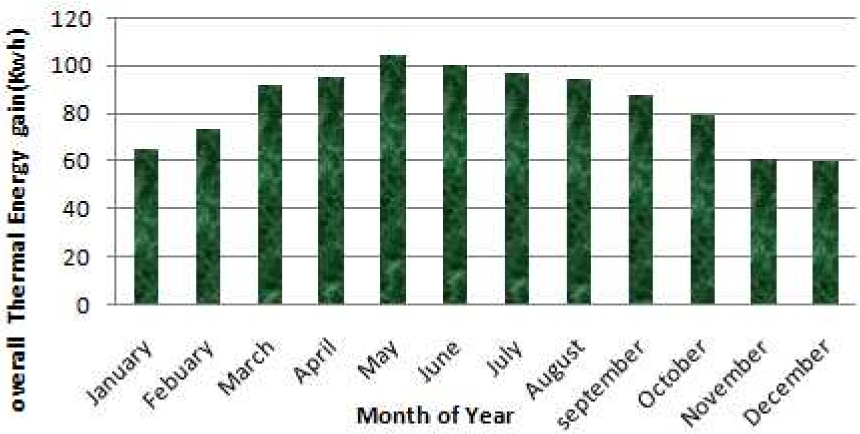

Fig.8 Monthly variation of overall thermal gain for different type of weather condition for Jodhpur city

CONCLUSION

This research study has dealt with the comparison for the module parameter under the climatic condition of New Delhi, Jodhpur, Bangalore and Srinagar city. The monthly variation of Electrical output, Thermal Energy gain, overall Thermal Energy gain and Exergy gain is shown. It has been observed that Maximum values of all the parameter are found in the month of May while Minimum are found in the month of December because output depends upon the solar radiation available in that month and the no. of clear days belonging to that month. From the study it can be concluded that Bangalore city has got highest value in terms of all respect .This type of configuration is integrated to the roof of Building in order to achieve the highest value of electrical & Thermal gain. The Thermal Energy can then be used for many applications like solar heating, space heating Agriculture crop drying. As the peak demand on the grid is during the day time and this system is also producing Energy during day hence it is helpful in reducing the peak demand on the grid during day time.

REFERENCES

[1] AD Jones and CP Underwood, A Thermal Model for Photovoltaic Systems, *Solar Energy*, **2001,** 70 (4), 349–359.

[2] Tripanagnostopoulos Y, Nousia T, Souliotis M and Yianoulis P, Hybrid Photovoltaic/Thermal Solar Systems, *Solar Energy*, **2002,** 72 (3), 217-234.

[3] Ji J, Chow TT and He W, Dynamic Performance of Hybrid Photovoltaic/Thermal Collector Wall in Hong Kong, *Building and Environment*, 2003, 38 (11), 1327-1334.

[4] Chow TT, He W and Ji J, An Experimental Study of Facade-Integrated Photovoltaic Water-Heating System, *Applied Thermal Engineering*, **2007**, 27, 37-45.

[5] Coventry SJ, Performance of a Concentrating Photovoltaic/Thermal Solar Collector, *Solar Energy*, **2005,** 78 (2), 211–220.

[6] Tiwari Arvind and Sodha MS, Parametric Study of Various Configurations of Hybrid PV Thermal Air Collector: Experimental Validation of Theoretical Model, *Solar Energy Materials & Solar Cells*, **2007**, 91, 17-28.

[7] Tonui JK and Tripanagnostopoulos Y, Performance Improvement of PVT Solar Collectors with Natural Air Flow Operation, *Solar Energy*, **2008,** 82, 1-12.

[8] Dubey S and Tiwari GN, Analysis of PVT Flat Plate Water Collectors Connected in Series, *Solar Energy*, **2009,** 83, 1485–1498.

[9] Shiv Kumar and GN Tiwari, Life Cycle Cost Analysis of Single Slope Hybrid (PV/T) Active Solar Still, *Applied Energy*, **2009,** 86, 1995–2004.

[10] Dupeyrat P, Menezo C, Rommel M and Henning HM, Efficient Single Glazed Flat Plate Photovoltaic-Thermal Hybrid Collector for Domestic Hot Water System, *Solar Energy*, **2011,** 85, 1457‒1468.

[11] Agrawal S and Tiwari A, Experimental Validation of Glazed Hybrid Micro-Channel Solar Cell Thermal Tile, *Solar Energy*, **2011,** 85, 3046-3056.

[12] Deepali Kamthania, Sujata Nayak and GN Tiwari, Performance Evaluation of a Hybrid Photovoltaic Thermal Double Pass Facade for Space Heating, *Energy and Buildings*, **2011**,43, 2274–2281.

[13] Vats Kanchan and Tiwari, GN, Performance Evaluation of a Building Integrated Semitransparent Photovoltaic Thermal System for Roof and Façade, *Energy and Building*, **2012,** 45, 211-218.

[14] Bambrook SM and Sproul AB, Maximising the Energy Output of a PVT Air System, *Solar Energy*, **2012,** 86, 1857-1871.

[15] Sanjay Agrawal and GN Tiwari, Exergoeconomic Analysis of Glazed Hybrid Photovoltaic Thermal Module Air Collector, *Solar Energy*, **2012,** 86, 2826–2838.

[16] H Mortezapour1, B Ghobadian, M H Khoshtaghaza and S Minaei1, Performance Analysis of a Two-way Hybrid PhotovoltaicThermal Solar Collector, *J Agr Sci Tech*,**2012, 1**4, 767-780.

[17] CS Rajoria, Sanjay Agrawal and GN Tiwari, Overall Thermal Energy and Energy Analysis of Hybrid Photovoltaic Thermal Array, *Solar Energy*, **2012,** 86, 1531–1538.

[18] Rakhi Sharma and GN Tiwari, Technical Performance Evaluation of Stand-Alone Photovoltaic Array for Outdoor Field Conditions of New Delhi, *Applied Energy*, **2012,** 92, 644-652.

[19] Sanjay Agrawal and GN Tiwari, Overall Energy, Exergy and Carbon Credit Analysis by Different Type of Hybrid Photovoltaic Thermal Air Collectors, *Energy Conversion and Management*, **2013,** 65, 628–636.

[20] AS Joshi, *Evaluation of Cloudiness/Haziness Factor and its Application for Photovoltaic Thermal (PV/T) System for Indian Climatic Conditions*, PhD Thesis, IIT Delhi, **2006.**

[21] T Schott, Operational Temperature of PV Modules, *Proceedings of 6th PV Solar Energy Conf.*, **1985**, 392-396.

[22] DL Evans, Simplified Method for Predicting PV Array Output, *Solar Energy*, **1981, 27**, 555-560.

[23] Kumar Rakesh and Rosen Marc A, A Critical Review of Photovoltaic–Thermal Solar Collectors for Air Heating, *Applied Energy*, **2011**, 88, 3603-3614.