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Research Article

Analysis of Different Types of Hybrid Photovoltaic Thermal Air Collectors: A Comparative Study*

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Abstract In this paper, a comparative analysis of different types of photovoltaic thermal (PVT) air collectors, namely: (i) unglazed hybrid PVT tiles, (ii) glazed hybrid PVT tiles, and (iii) conventional hybrid PVT air collectors, has been carried out for the composite climate of Srinagar, India. It has been observed that the overall annual thermal energy and exergy gain of unglazed hybrid PVT tiles air collector are higher by 27% and 29.3%, respectively, as compared to glazed hybrid PVT tiles air collector and by 61% and 59.8%, respectively, as compared to conventional hybrid PVT air collector. It has also been observed that the overall annual exergy efficiency of unglazed and glazed hybrid PVT tiles air collectors is higher by 9.6% and 53.8%, respectively, as compared to conventional hybrid PVT air collector. On the basis of a comparative study, it has been concluded that CO_2 emission reduction per annum on the basis of overall thermal energy gain of unglazed and glazed hybrid PVT tiles air collectors is higher by 62.3% and 27.7%, respectively, as compared to conventional hybrid PVT air collector, and on the basis of overall exergy gain it is 59.7% and 22.7%.

Keywords thermal energy gain; exergy gain; exergy efficiency; carbon credit

1 Introduction

The overall photovoltaic thermal (PVT) performance can be evaluated by the energetic (first law) efficiency. This is in fact the major evaluation approach of PVT systems in the previous studies, like the works of Garg and Agrawal [7] and Sopian et al. [11] which have been on energy based. The energy analysis alone does not encounter the internal losses. It cannot be a sufficient criterion for the performance evaluation. An exergy analysis is a useful method to complement not to replace the energy analysis. Exergy analysis yields useful results because it deals with irreversibility minimization or maximum exergy delivery. The popularity of the exergy analysis method has grown consequently and is still growing [8, 10]. The applications of roof mounted, multi-operational ventilated photovoltaic and solar air collector were studied by Cartmell et al. [3]. He has concluded that the cell efficiency was marginally improved, while in addition, an average thermal efficiency of about 50–70% for water heating and 17–51% for air heating was obtained. Exergy losses due to irreversibility in collector act as the driving force for the system while exergy losses due to irreversibility in storage barrel are of little contribution [12]. Chow et al. [5] have carried out the thermodynamic analysis of a thermosyphon flat-plate PVT collector system with and without glass cover in Hong Kong. They concluded that the energetic efficiency of the glazed collector was found always better than that of the unglazed collector. However, the exergetic efficiency of the unglazed condition has been found better than the glazed condition. Prabhakant and Tiwari [9] calculated the carbon credit earned by solar energy park, at IIT Delhi, New Delhi, India, including PVT system and recommended to develop such type of parks in country to mitigate the carbon dioxide and earn the carbon credit. Chauray and Kandpal [4] have attempted to estimate the CO_2 mitigation potential of solar home system (SHS) in India by studying the potential for their diffusion and the appropriate baseline. They found that carbon finance could reduce the effective burden of SHS to the user by 19% if carbon prices were \$10/tCO_2 without transaction costs.

2 System description

There are three types of hybrid PVT air collectors that have been considered.

2.1 Unglazed hybrid PVT tiles air collector

A photovoltaic solar cell with duct which is encapsulated in between solar cell and tedlar is considered for the study.

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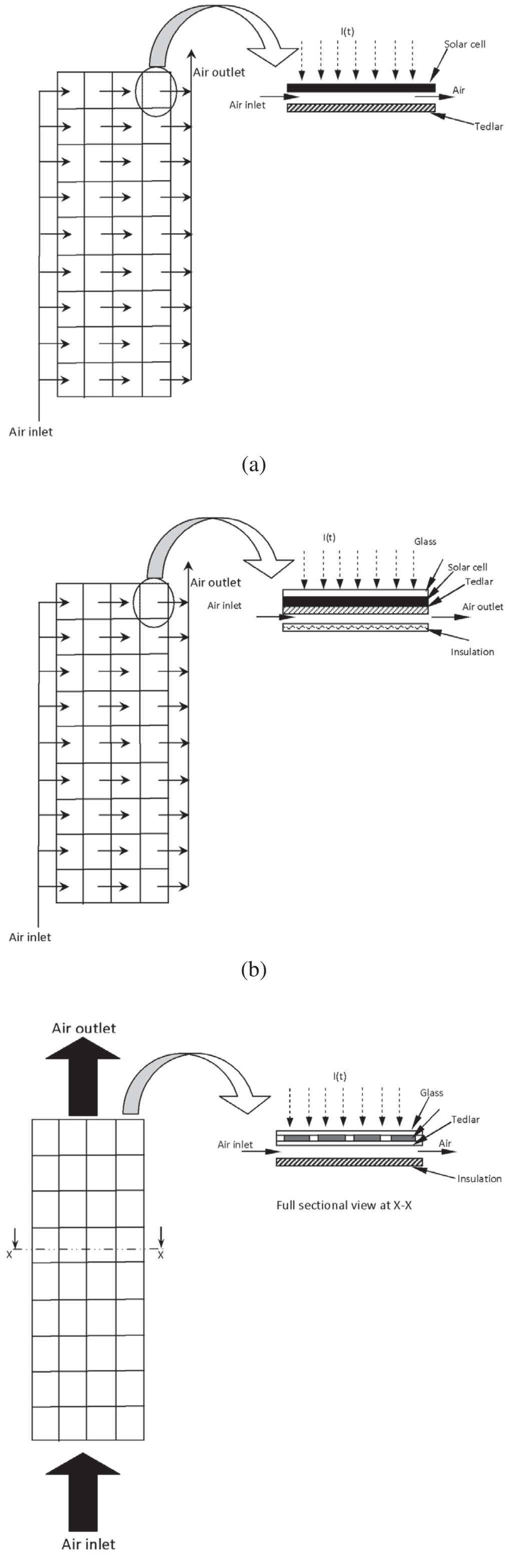

Figure 1: (a) Schematic diagram of unglazed hybrid PVT tiles air collector. (b) Schematic diagram of glazed hybrid PVT tiles air collector. (c) Schematic diagram of conventional hybrid PVT air collector.

Such system has been proposed and will be referred to as unglazed hybrid PVT tile. The unglazed PVT tile consists of a single solar cell (mono crystalline silicon), rated at 2.2 Wp having dimensions 0.12 m length and 0.12 m width, has been considered and it has been mounted on a rectangular wooden channel. There is provision for the inlet and outlet air to flow through the duct of solar cell. For the analysis, PVT tiles air collector of 9 rows, each having 4 cells with duct in series, connected in parallel as shown in Figure 1(a), has been considered. An effective area of unglazed hybrid PVT tiles air collector is 0.61 m^2.

2.2 Glazed hybrid PVT tiles air collector

A glazed hybrid PVT tile having duct below the tedlar with air flow below the tedlar has been considered. The channel has dimensions $0.12\,m \times 0.12\,m \times 5\,mm$. To obtain maximum electrical and thermal efficiency series; parallel combinations of unglazed PVT tiles have been considered, which is referred to as glazed hybrid PVT tiles air collector as shown in Figure 1(b). An effective area of unglazed hybrid PVT tiles air collector is 0.61 m^2.

2.3 Conventional hybrid PVT air collector

A conventional hybrid PVT air collector consists of glass to tedlar type (Type PM75, manufactured using monocrystalline silicon solar cells by Central Electronics Limited, Sahibabad, U.P., India) with an effective area of 0.61 m^2 of one PV module. The modules are mounted on a single rectangular PVC sheet air duct which has dimensioned $0.54\,m \times 1.12\,m \times 5\,mm$. There is provision for the inlet and outlet air to flow through the single duct below the module, as shown in Figure 1(c).

3 Thermal modeling

Following Agrawal and Tiwari [1,2], expression for the outlet air temperature (T_{foN}), thermal energy gain ($\dot{Q}_{U,N}$) and electrical efficiency (η) at Nth number of unglazed and glazed hybrid PVT tiles air collectors have been used.

Following Dubey and Tiwari [6], the outlet air temperature (T_{foN}), useful heat gain ($\dot{Q}_{u,N}$), temperature-dependent electrical efficiency (η) from conventional hybrid PVT air collectors are derived as

$$T_{fo} = \left[\frac{(\alpha\tau)_{eff}\, I(t)}{U_L} + T_a\right]\left[1 - \exp\left(-\frac{bLU_L}{\dot{m}_f C_f}\right)\right] + T_{fi}\exp\left(-\frac{bLU_L}{\dot{m}_f C_f}\right),$$

$$\dot{Q}_u = \left[N.A.F_R(\alpha\tau)_{eff}\left\{\frac{1-\left(1-K_K\right)}{K_K}\right\}\right] I(t) - \left[A.F_R U_L\left\{\frac{1-\left(1-K_K\right)}{K_K}\right\}\right]\left(T_{fi} - T_a\right),$$

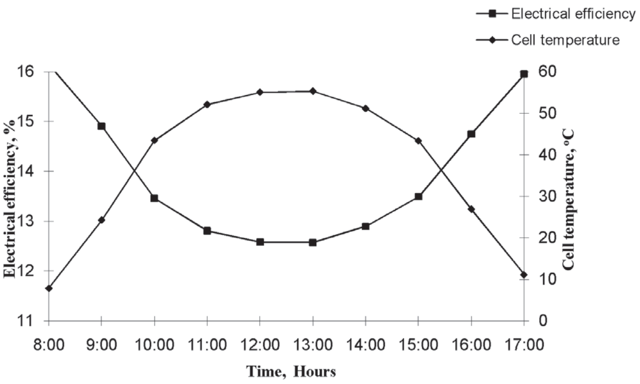

Figure 2: Hourly variation of electrical efficiency and cell temperature of unglazed hybrid PVT tiles air collector.

where $K_K = \left[\frac{b.L.F_R U_L}{\dot{m}_f C_f}\right]$

$$\eta = \frac{\eta_0 \left[1 - \frac{\beta_o \tau_g [\alpha_c \beta + \alpha_T (1-\beta)] I(t)}{U_{tc,a} + U_T} \left\{1 + \frac{U_T h_{p1}}{h_T + U_{tT}} + \frac{U_T h_T h_{p1} h_{p2}}{(U_T + U_{tT}) U_L} \left(1 - \frac{1-\exp(-X_o)}{X_o}\right)\right\}\right]}{1 - \frac{\beta_o \eta_0 \tau_g \alpha_c \beta I(t)}{U_{tc,a} + U_T} \left[1 + \frac{U_T h_{p1}}{h_T + U_{tT}} + \frac{U_T h_T h_{p1} h_{p2}}{(U_T + U_{tT}) U_L} \left(1 - \frac{1-\exp(-X_o)}{X_o}\right)\right]}$$

where $X_o = \frac{b U_L L}{\dot{m}_f C_f}$.

The rate of electrical energy gain (W) of hybrid PVT air collectors can be evaluated by

$$\dot{E}x_{\text{electrical}} = \eta I(t) A.$$

4 Results and discussion

MATLAB 7.0 software has been used to solve the mathematical models of the proposed system. The hourly variations of electrical efficiency and cell temperature of unglazed hybrid PVT tiles air collector has been shown in Figure 2. It has been observed that the electrical efficiency decreases with the increase of solar cell temperature and vice versa. It has also been observed that the solar cell temperature is maximum and electrical efficiency is minimum between 12:00 and 13:00 hours.

Overall thermal energy and exergy gain for Srinagar, Indian climatic condition for unglazed hybrid PVT tiles, glazed hybrid PVT tiles, and conventional hybrid PVT air collectors have been computed and monthly variations of overall thermal energy and exergy gain have been shown in Figures 3 and 4, respectively. It has been observed that overall annual thermal energy and exergy gain of unglazed hybrid PVT tiles air collector is higher by 27% and 29.3%, respectively, as compared to glazed hybrid PVT tiles air collector and by 61% and 59.8%, respectively, as compared to conventional hybrid PVT air collector. It is to be noted that maximum and minimum overall thermal energy and exergy gain have been found in the months of May and December, respectively.

The CO_2 emission reduction per annum on the basis of overall thermal energy and exergy gain for Srinagar climatic condition has been evaluated and variation of CO_2 emission reduction per annum has been shown in Figure 5. It has been observed that CO_2 emission reduction per annum on the basis of overall thermal energy gain of unglazed and glazed hybrid PVT tiles air collectors is higher by 62.3% and 27.7%, respectively, as compared to conventional hybrid PVT air collector and on the basis of overall exergy gain it is 59.7% and 22.7%. Cost to reduce tCO_2 emission reduction per annum on the basis of overall thermal energy and exergy gain for Srinagar climatic condition has also been shown in Figure 6.

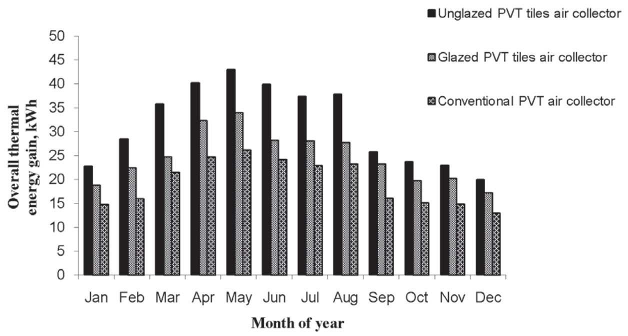

Figure 3: Comparison chart on the basis of monthly variation of overall thermal energy gain for Srinagar climatic condition.

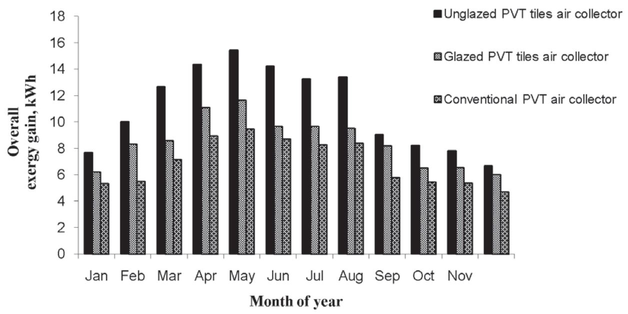

Figure 4: Comparison chart on the basis of monthly variation of overall exergy gain for Srinagar climatic condition.

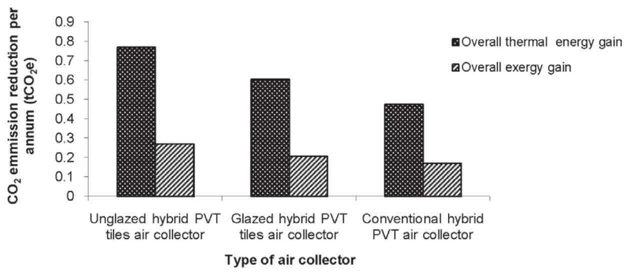

Figure 5: CO_2 emission reduction per annum on the basis of overall thermal energy and exergy gain for Srinagar climatic condition.

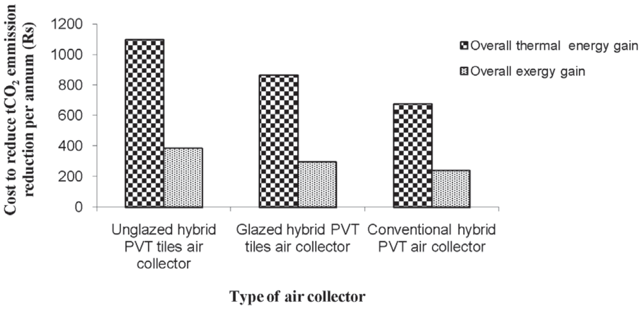

Figure 6: Cost to reduce tCO_2 emission reduction per annum on the basis of overall thermal energy and exergy gain for Srinagar climatic condition.

It has been seen that net saving to reduce CO_2 emission reduction per annum is Rs 1099.4, Rs 865.1, and Rs 677.3 by unglazed hybrid PVT tiles, glazed hybrid PVT tiles, and conventional hybrid PVT air collector, respectively, on the basis of overall thermal energy gain and Rs 387.1, Rs 297.4, and Rs 242.3 on the basis of overall exergy gain.

5 Conclusion

The following conclusions have been drawn.

(i) Overall annual thermal energy, exergy gain, and exergy efficiency of unglazed hybrid PVT tiles air collector have been improved by 32%, 55.9%, and 53%, respectively, over conventional PVT air collector.

(ii) For the life time (30 year) analysis, cost of the carbon emission reduction of unglazed and glazed hybrid PVT tiles air collectors is 62.3% and 27.7%, which is more than that of conventional hybrid PVT air collector.

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