Thermal Modeling and Experimental Study of a Hybrid Solar Photovoltaic and Earth Air Heat Exchanger System as an Alternative Energy Source for Greenhouse

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Abstract: Solar photovoltaic (SPV) is one of the technologies, which utilizes the nature’s gift (solar energy) in the form of electrical as well as thermal energy. Heating of greenhouse is one of the most energy consuming activities during winter periods. Lack of required heating of surrounding environment inside greenhouse creates the adverse effects on the yield, cultivation time, quality and quantity of the products. The photovoltaic system combined with buried pipe system is a feasible method not only to provide thermal energy obtained from the earth at a certain depth to the greenhouse but also to supply electrical energy for the blower used in the buried pipe system resulting in the indirect way of increasing the overall thermal and electrical efficiency of photovoltaic system. Hence considering the importance of buried pipe system (also called Earth air heat exchanger system; EAHE) as a simple, inexpensive and alternative source of energy, the system has been integrated with photovoltaic system in OUAT, Bhubaneswar, Odisha, India during the whole winter period in the year 2010 with a view to study its thermal performance for heating of the greenhouse through a model, developed, for the composite climate of India. The application of solar energy through photovoltaic system and earth air heat exchanger (EAHE) has been studied with the help of a simplified mathematical model for heating of a greenhouse. In a hybrid photovoltaic thermal (PV/T) system, air is taken as the medium for transport of thermal energy. The temperatures of air inside the greenhouse have been compared from the photovoltaic thermal system without air collector, with air collector (during sun shine hours) and with EAHE (during off sun shine hours) along with the overall efficiency (thermal and electrical) of PV/T system. Numerical computations have been carried out for a typical winter day of composite climate of India. The heating potential of the system is evaluated in terms of coefficient of performance (COP) and thermal load levelling (TLL). The results showed that the required temperature for air inside the greenhouse could be maintained during the winter period and overall efficiency could also be increased if the system is operated with PV/T device (with air collector) during day time and EAHE in night time. The electrical efficiency of a hybrid photovoltaic thermal system with air collector was found to be higher due to low operating temperature. There occurred 7-8 °C rise of temperatures for greenhouse air during winter period particularly in night time due to the incorporation of EAHE as compared to without EAHE. Also there occurred 6-7 °C decrease of air temperature during day time by use of PV/T system integrated with greenhouse.

Keywords: Solar energy, Green House, photovoltaic system, Earth air Heat Exchanger, Thermal Modeling.

Nomenclature

A- Area (m2); B- Breadth (m); c- Specific heat (J kg-1oC-1); dx- Elemental length (m); Fn- Fraction of solar radiation falling on north wall, dimensionless, decimal; FR- Heat re-moval factor for EAHE from underground earth’s surface; h- Convective heat transfer coefficient (Wm-2 oC); hi- Heat transfer coefficient from greenhouse cover to inside greenhouse air, W/m20C, (2.8 [3.0 v ]; ho- Heat transfer coefficient from greenhouse cover to ambient, W/m20C, (5.7 [3.8 v ]; hfg- Convective heat transfer coefficient from underground earth’s surface to flowing air inside the buried pipes, W/m20C; hgr - Heat transfer coefficient from floor to larger depth of ground, W/m20C; hna - Heat transfer coefficient from north brick wall to ambient, W/m20C; hnr- Heat transfer coefficient from north wall to greenhouse air, W/m20C; hgr - Heat transfer coefficient from floor to greenhouse air, W/m20C; hp1- Penalty factor due to presence of solar cell material, Tedlar and EVA; hp2 - Penalty factor due to presence of interface between Tedlar and working fluid through ab-sorber plate; H- Constants defined in Eq. (18b); I (t) Incident solar intensity on inclined (Wm-2); K- Thermal conductivity (Wm-1 °C); L- Length of module (m); ma- Mass flow rate of air (kg); M- Mass (kg); N- Number of air changes per hour; qu- Rate of useful thermal energy obtained from photovoltaic system (W); Qh- Heating potential of- fered by EAHE for greenhouse air, J; & Qu Useful thermal energy obtained from EAHE for greenhouse air, W; r -Reflectivity from greenhouse cover, dimensionless, decimal; rg - Reflectivity from greenhouse floor, dimensionless, decimal; rn - Reflectivity from north wall, dimensionless, decimal; r1 - Radius of buried pipe in EAHE, m; T- Temperature (oC); Td- Delivery temperature, °C; T- Temperature of inlet fluid or temperature at suction point, °C for EAHE, tsc- Suction temperature, °C; U- Overall heat transfer coefficient; Ub- Overall heat transfer coefficient from bottom to ambient air (W/m2 oC); Ug- Overall heat transfer coefficient from greenhouse air to floor, W/m20C; UT- Conductive heat transfer coefficient from solar cell to ambient through top and back surface (W/m2 oC); (UA) - Overall heat loss from greenhouse, W/ °C; v- Wind velocity (m sec-1); u- Duct air velocity (m sec-1); V- Volume of green house (m3); Greek Letters, β- Packing factor; τ- Transmissivity; α- Absorptivity; η- Efficiency of solar cell; ∞- Infinity (at larger depth); Subscripts, a- Ambient; bs- Tedlar back surface; c- Solar cell; e- to
1. Introduction

India receives enormous amount of solar energy on an average of 5 kWh/m²/day for about 300 days in a year. It can be used as thermal energy to produce hot water/air, to heat indoor space, to dry the industrial and agricultural products etc. It can also be used to convert sunlight directly to electricity by photovoltaic (PV) and is now being used for a variety of applications. Hence solar photovoltaic (SPV) is one of the technologies, which utilizes the nature’s gift (solar energy) in the form of electrical as well as thermal energy. The carrier of thermal energy associated with the PV module can be air or water. The integrated arrangements for utilizing thermal energy as well as electrical energy, with a photovoltaic module are referred to as the hybrid photovoltaic thermal (PV/T) system. The thermal energy obtained from hybrid (PV/T) system is supplied to the greenhouse for heating purpose. Tiwari and Sodha (2006) have studied the thermal performance of a hybrid photovoltaic thermal (PV/T) air collector for New Delhi climatic condition in India. Heating of greenhouse is also one of the most energy consuming activities during winter periods. Lack of heating has adverse effects on the yield, cultivation time, quality and quantity of the products in the greenhouse (Santamouris et al., 1994). Efforts to decrease energy consumption have directed the researchers to use alternative energy sources for heating of greenhouse. As solar energy is the ideal source of energy for space heating particularly in the northern hemisphere where it is available sufficiently, efforts to harness solar energy have been accelerated during the last decade as world demand for energy is growing at a faster rate (Saravia et al., 1997). The photovoltaic system combined with buried pipe system is also a feasible method not only to provide thermal energy to the greenhouse but also to supply electrical energy for the blower used in the buried pipe system resulting in the indirect way of increasing the overall thermal and electrical efficiency of photovoltaic system.

Hence considering the importance of buried pipe system (Earth air heat exchanger system; EAHE) as a simple, inexpensive and alternative source of energy, the system has been integrated with photovoltaic system in Indian Institute of Technology, model greenhouse, New Delhi, India during the whole winter period with a view to study its thermal performance for heating of the greenhouse through a model, developed in the composite climate of New Delhi, India.

2. Methodology

An air was taken as the medium for transport of thermal energy in hybrid PV/T air collector. Sixteen PV modules with each having an effective area of 0.605 m² were connected in series. The panel with effective area of 1.62 m × 6.5 m was mounted on a galvanized iron structure with the air duct below the module. The inclination of the iron structure supporting PV modules could be varied to receive maximum solar intensity and also heat-ing/cooling of the greenhouse as per requirement during winter and summer periods respectively. In winter, the inclination of PV/T was kept in such a manner that it closes the gap between duct and roof of the greenhouse to increase the inside temperature of greenhouse. In summer, the gap was introduced to lower the inside temperature of greenhouse. There was provision to measure the temperature of the inlet and outlet air by using temperature sensors. The fans of capacity 12W each have been provided at the inlet to induce the flow of air below the duct for extracting thermal energy available at the back of PV module. The fans were run by a DC battery (12V and 120Ah) charged by the electrical energy generated from PV system. A part of electrical energy generated was used to operate the fans to be used for forced air circulation inside the duct and supplied to the greenhouse for heating purpose as shown in Fig. 1.

![Fig. 1. Front view of PV/T integrated greenhouse](http://www.ijser.org)
sure, suction end and delivery end were recorded during the experimentation with the help of calibrated solarimeter and mercury thermometer, respectively. PV panel has been integrated with greenhouse to fulfill the electrical energy demands in the greenhouse. A part of electrical energy generated is used to operate the fans to be used for forced air circulation inside the duct. The rest of electrical energy is utilized for blower of earth air heat exchanger. The specifications of the silicon solar cell at 1000 W/m² at 25°C (standard test conditions) used in the PV module were as follows. (i) Fill factor = 0.72; (ii) Short circuit current (Isc) = 4.8 A; (iii) Open circuit voltage (Voc) = 21.7 V; (iv) Area of single solar cell = 0.0139 m² and (v) Efficiency of solar cell = 15%.

![PV panel](image)

**Fig. 2.** Isometric view of even span greenhouse integrated with PV/T and EAHE arrangement

### 2.1 Thermal analysis

Thermal modeling has been carried out for hybrid PV/T air collector and EAHE to find out the outlet air temperature from both the system and then utilization of this useful thermal energy for greenhouse heating during winter season. In order to write an energy balance equations for different components of hybrid photovoltaic air collector the following assumptions have been made:

(i) The system is in quasi steady state condition.
(ii) The transmissivity of EVA is approximately 100%.
(iii) The temperature variation along the thickness as well as along the width is negligible.
(iv) Airflow between the tedlar base and wood structure is uniform for the forced mode of operation and,
(v) The Ohmic losses in solar cells are negligible.

Energy balance for different components of hybrid PV/T air collector can be written as:

1. For PV Module:
   \[ t_{\text{PV}}(a, b, c) + (1 - \beta_1)\text{m}(b, c) bdx - h_b(U_2(T_r - T_i) + h_1(T_e - T_{in})) + \beta_1 \text{m}(b, c) bdx]\n
2. For Back Surface of tedlar:
   \[ bdh_2(T_e - T_{in}) + bdh_1(T_r - T_{in}), \text{ with air flow}\]
   \[ bdh_2(T_e - T_{in}) + bdh_1(T_r - T_{in}), \text{ without air flow}\]

3. For airflow below the tedlar:
   \[ bdh_1(T_e - T_{in}) = \alpha h_1 \frac{dT}{dx} + bdh_1(T_e - T_{in})\]

The useful thermal energy obtained from hybrid PV/T air collector with and without airflow is

\[ q_t = \alpha h_1 \frac{dT}{dx} + bdh_1(T_e - T_{in})\]

The thermal efficiency of hybrid PV/T collector is

\[ \eta_h = \frac{\sum h_i}{\sum h_i + h_0 L}\]

The temperature dependent efficiency of PV system is

\[ \eta_{PV} = 1 - 0.0045(T_r - 25)\]

The energy balance equations for north wall, floor and room air of greenhouse are as follows:

a) North wall

\[ a_1(T_e - T_{in}) + b_1(T_e - T_{in}) + h_1(T_e - T_{in}) + M_r \frac{dT}{dt}\]

The term \( a_1 \) in Eq. (15) is the useful thermal energy obtained from earth air heat exchanger arrangement and is expressed by the equation.

\[ a_1 = F_r h_0 C_r (T_e - T_{in})\]

where \( F_r = 1 - \frac{1}{a_1} \) and \( T_e = \frac{1}{T_e} (e^{-T_e} - 1)\).
3. Results and discussion

The energy balance equations derived for greenhouse with photovoltaic system and EAHE have been solved with the help of a computer program based on Matlab software. The closeness of predicted and experimental values has been presented with coefficient of correlation (cr) and root mean square of percent deviation (er). The mass flow rate of the circulating air was kept constant with 100 kg/hour. The performance of EAHE has been evaluated in terms of thermal load leveling (TLL), heating potential and coefficient of performance (COP) as per the following expressions:

\[ TLL = \frac{T_{r,\text{max}} - T_{r,\text{min}}}{T_{r,\text{max}} + T_{r,\text{min}}} \]

\[ Q_h = \sum m_{b} C_{a} (T_{d} - T_{\text{in}}) \Delta t \]

and \[ COP = \frac{\text{output energy}}{\text{Energy spent to get output energy}} \]

Equation above has been used to calculate solar cell temperature and results are shown in Fig.3. It has been observed that solar cell temperature of photovoltaic/thermal (PV/T) without airflow is higher than the solar cell temperature of hybrid PV/T air collector due to low values of heat transfer from the back surface unlike PV/T air collector. It was also seen that there was rise of around 10°C solar cell temperature of PV/T without airflow. The hourly variation of outlet air temperature is shown in Fig.4. It was observed that outlet air temperature of hybrid PV/T air

Fig. 4. Hourly variation of outlet air temperature

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case of (PV/T) without airflow due to direct transfer of thermal energy into the greenhouse.

- The thermal efficiency of a hybrid photovoltaic thermal (PV/T) air collector is higher due to low operating temperature.
- There occurred 7 - 8 °C rise of temperatures for greenhouse air during winter night time due to incorporation of EAHE compared to without EAHE.
- Decrease of air temperature by 6 - 7 °C was in day time due to PV/T air collector.
- Relative fluctuations of temperature for greenhouse air are less by use of PV/T air collector in day time and EAHE in night time.

References