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Performance Evaluation of an Integrated Hybrid Photovoltaic/Thermal (PV/T) Greenhouse

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2.1 Abstract

The Solar photovoltaic (SPV) is one of the technologies, which address itself to consume the nature's gift (solar energy) in the form of electrical as well as thermal energy. Hegazy (2000) has studied the performance of four configurations of photovoltaic/thermal (PV/T) solar air collectors. He observed that the configurations with airflow between the top glass cover and a solar cell gives an overall (electrical and thermal) efficiency of about 55% at 0.04 kg/m^2. Sandnes and Rekstad (2002) have studied the performance of a combined photovoltaic/thermal (PV/T) collector, which was constructed by pasting single crystal silicon cells onto a black plastic solar heat absorber (unglazed PV/T system). They suggested that the combined photovoltaic/thermal (PV/T) concept must be used for low temperature thermal applications and for growing electrical efficiency of the PV system. Tiwari and Sodha (2006) have studied the thermal performance of a hybrid photovoltaic/thermal (PV/T) air collector for New Delhi climatic condition. Indoor simulation and testing of photovoltaic/thermal (PV/T) air collectors has been studied by Solanki et al (2009). The results show that the thermal and electrical efficiency of the solar heater is 42% and 8.4% respectively

Keywords: Hybrid Photovoltaic/Thermal, Solar energy, electrical and thermal energy

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2.2 Introduction

In hybrid PV/T air collector, where air is taken as the medium for transportation of thermal energy. Sixteen PV modules with each having an effective area of 0.605 m^2 are linked in series. The panel with an effective area of 1.62 m × 6.5 m is mounted on a wooden structure with the air duct below the module as shown in Fig. 2.1(a). There is a provision for the inlet and outlet air to flow through the duct. The inclination of the structure supporting PV modules which can be varied to received highest solar strength and also heating/cooling of the greenhouse as per requirement during winter and summer periods respectively. In winter, the inclination of PV/T is kept in such a approach that it closes the gap between duct and roof of the greenhouse to increase the inside temperature of greenhouse. In summer, the gap is introduced to lower the inside temperature of greenhouse. The duct is sealed with the help of putty and double side tape to avoid any leakage of hot air. There is a provision to measure the temperature of the inlet and outlet air by using temperature sensors. The fans can be used at the inlet to induce the flow of air below the channel for extracting thermal energy available at the back of PV module. The fans are run by a DC battery (12V and 120Ah). The outlet air coming from the PV/T air collector is supplied to the greenhouse through the air duct.

Essentially a well-designed greenhouse should be able to maintain a required environment inside a greenhouse enclosure for healthy growth of plants and to maximize the yield. A mathematical model has been developed for describing heat and mass transfer processes in a greenhouse. The energy balance equations used in modeling heat and mass transfer process in greenhouse expects ambient conditions within a greenhouse based on outside climatic condition. To facilitate the modeling procedure, a greenhouse is considered to consist of a number of separate but interactive components. These are cover, floor, growing medium, walls/roof and crop. Crop production depends on the proper environment within greenhouse and more specifically on the thermal performance of the system. The performance can be predicted using mathematical model with proper assumptions.

In current research, the effect of evaporative and conductive losses from the plant and floor respectively is considered to predict the performance of a particular greenhouse in terms of various design and

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climatic parameters; namely greenhouse efficiency factors, overall total heat loss coefficient and effective reference temperature.

2.3 PV based greenhouse

PV panel has been integrated with greenhouse to fulfill the electrical energy demands in the greenhouse. PV panel supplies the power to the exhaust fan, tube-light and water pump.

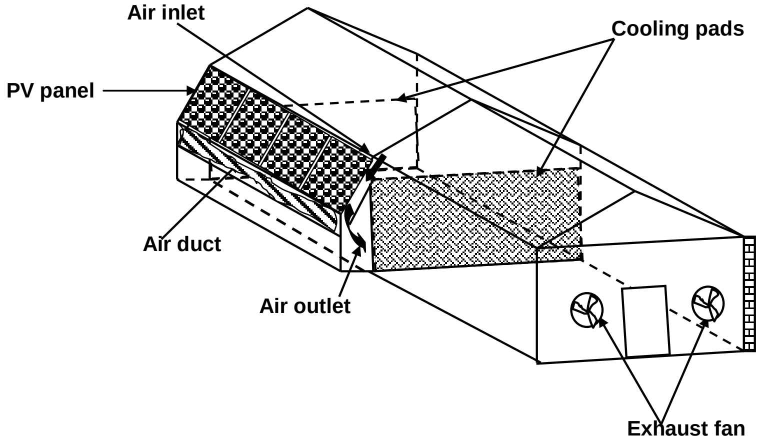

Fig. 2.1(a) PV based greenhouse with evaporative cooling

Specification of PV Panel

Peak Power	1200 W_P
Battery Capacity	14 kWh
Load	
Number of Tube-light	4 (2 in each Phase)
Number of Exhaust Fan	4 (2 in each Phase)
Number of blower	1

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 other purposes such as operating tube lights and blower for earth air heat exchanger. Front view of PV/T integrated air collector cum greenhouse has been shown in Fig. 2.1(b)

2.4 Thermal modeling

Thermal modeling has been carried out for hybrid PV/T air collector to find out the outlet air temperature and then operate this rate of useful thermal energy for greenhouse heating in winter season or for drying purpose.

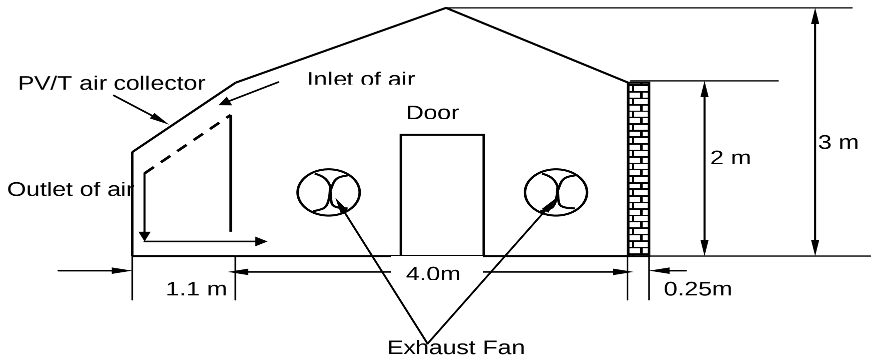

Fig. 2.1(b) Front view of PV/T integrated greenhouse

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In sequence to write an energy balance for another components of hybrid photovoltaic air collector as shown in the Fig. 2.1(c), the following assumptions have been made:

(i) The system is in quasi-steady state.
(ii) The transmissivity of EVA is approximately 100%.
(iii) The temperature variant 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.

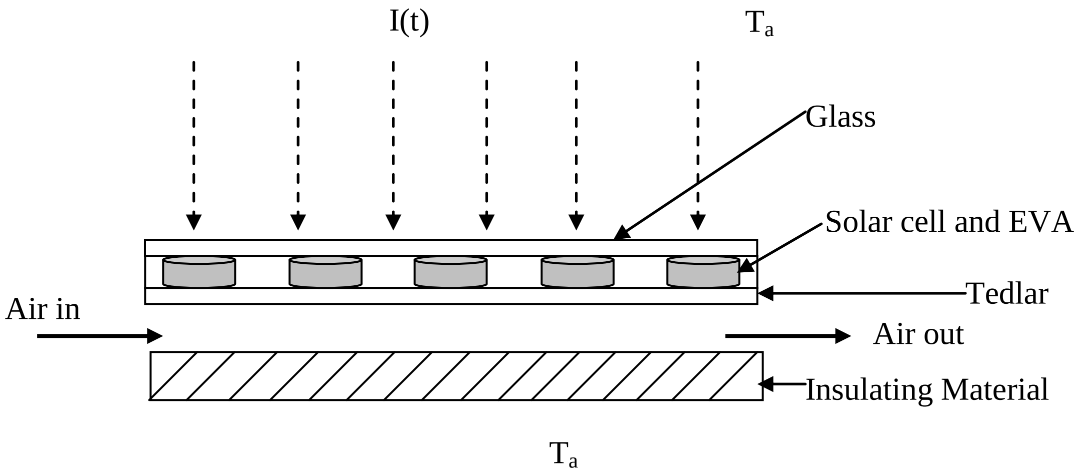

Fig. 2.1(c) A cross-sectional view of an integrated photovoltaic/thermal system

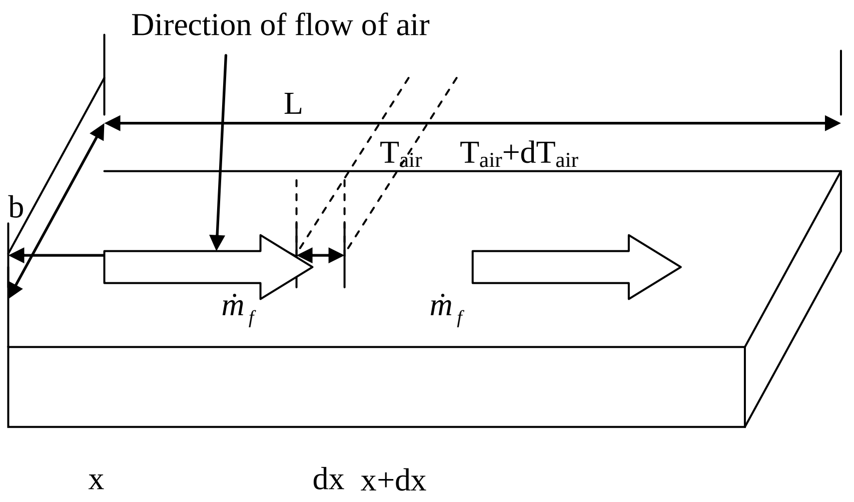

Fig. 2.1(d) An elemental length ‘dx’ shows flow pattern of air below tedlar

2.5 Software description

Matlab 7.0 is used for computation of rate of useful thermal energy from hybrid PV/T air collector, to evaluate the theoretical performance of greenhouse integrated with hybrid PV/T air collector and to study the effect of design parameters on performance of this system. The design parameters of PV/T air collector and greenhouse have been given in Table 2.1. The hourly variation of beam and diffuse radiation has been shown in Fig. 2.3. The data of Fig. 2.3 has been used to calculate hourly variation of solar intensity on different greenhouse walls and roofs and PV module by using Liu and Jordan formula, 1962; Duffie and Beckman, 1991, Tiwari, 2002 and Norton, 1992.

2.6 Results and Discussion

Eq. 2.4 has been used to calculate the solar cell temperature and results are shown in Fig. 2.4. It has been observed that the solar cell temperature of

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photovoltaic/thermal (PV/T) without airflow is higher than the solar cell temperature of hybrid PV/T air collector due to lower values of heat transfer from the back surface unlike PV/T air collector.

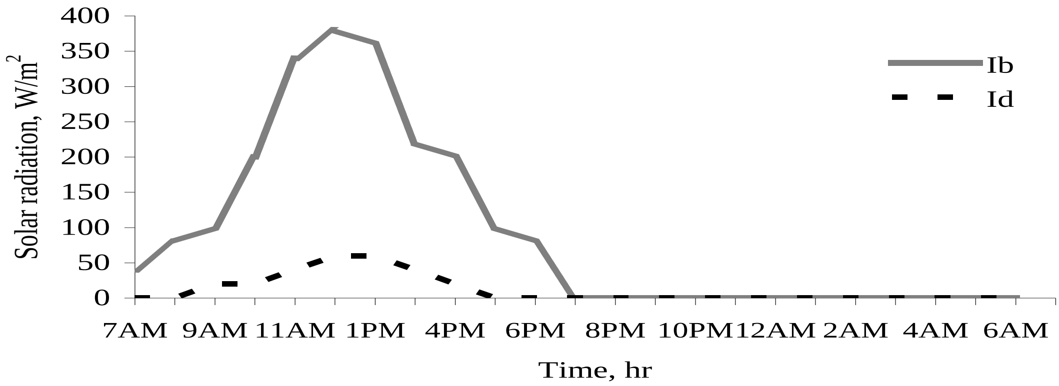

Fig. 2.3 Hourly variation of beam and diffuse radiation for a typical day of August, 2006

It is also seen that there is rise of around 10ºC solar cell temperature of PV/T without airflow. Fig. 2.5 shows the hourly variation of tedlar back surface temperature. It is found that tedlar back surface temperature of PV/T without airflow is advanced than tedlar back surface temperature of hybrid PV/T air collector as no withdrawal of air is taking place. The hourly variation of outlet air temperature is shown in Fig. 2.6. It is observed that outlet air temperature of hybrid PV/T air collector is higher than the ambient air temperature of PV/T air collector without airflow due to faster heat transfer from the back surface. It has been also observed that the plant temperature (Fig. 2.7) of photovoltaic/thermal (PV/T) without airflow is higher than the plant temperature of hybrid PV/T air collector due to direct transfer of thermal energy into the greenhouse. It is seen that there is rise of around 5ºC plant temperature of PV/T without airflow. Fig. 2.8 shows the hourly variation of greenhouse room air temperature. It is fulfilled that greenhouse air temperature of photovoltaic/thermal (PV/T) without airflow is higher than the greenhouse air temperature of hybrid PV/T

Table 2.1 Input parameters used for computations

Hybrid PV/T air collector

Parameters	Values
C_a	1012 J/kg ^oC
τ_i	0.5
τ_G	0.95
β_c	0.83
η_c	0.12
h_p	30.25 W/m^2 ^oC
α_T	0.5
α_c	0.9
k_g	0.52 W/m ^oC
L_g	0.003 m
k_G	1.0 W/m ^oC
N	0-10 rpm
U	3.5 W/m^2 ^oC

Greenhouse

Parameters	Values
A_1	10 m^2
A_2	10 m^2
A_3	24 m^2
A_4	24 m^2
A_5	15 m^2
A_6	26.83 m^2
α_p	0.5
α_g	0.4
h_{ga}	1.3 W/m^2 ^oC
h_{gr}	5.7 W/m^2 ^oC
F_p	0.3
A_p	10-200 m^2
A_g	24 m^2

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M_p	50-250 kg
V	144 m^3
C_p	4910 J/kg ^oC
h_p	30.25 W/m^2 ^oC

air collector due to direct transfer of thermal energy from rear surface of tedlar to the greenhouse air. It has been found that the floor temperature (Fig. 2.9) of photovoltaic/thermal (PV/T) without airflow is higher than the floor temperature of hybrid PV/T air collector due to reason explained earlier for Fig. 2.8. The rate of useful thermal energy is calculated using Eqs. 2.9(a) and 2.9(b) and the results have been shown in Fig. 2.10. It has been found that rate of useful thermal energy of hybrid photovoltaic/thermal (PV/T) air collector is higher than the rate of useful thermal energy of PV/T without airflow due to faster transfer of thermal energy from the back surface of tedlar under forced mode of operation. Fig. 2.11 shows the hourly difference of thermal efficiency. It can be concluded that thermal efficiency of hybrid photovoltaic/thermal (PV/T) air collector is higher than the thermal efficiency of photovoltaic/thermal (PV/T) without airflow due to lower operating temperature. Effect of length of PV module has also been studied for overall thermal energy, thermal competence and overall efficiency (Figs. 2.12-2.13). It has been seen that the rate of useful thermal energy of hybrid photovoltaic/thermal (PV/T) air collector is higher than the rate of useful energy of photovoltaic/thermal (PV/T) without airflow with respect to length of PV module (Fig. 2.12) as expected. However, the rate of useful thermal energy increases faster in case of flow with length of PV module. It is also observed that overall efficiency of hybrid photovoltaic/thermal (PV/T) air collector is higher than the overall efficiency of photovoltaic/thermal (PV/T) without airflow with respect to the length of PV module (Fig. 2.14) due to lower operating temperature. It has been observed that overall efficiency of hybrid photovoltaic/thermal (PV/T) air collector is 72% at 3.0m length of PV module and overall efficiency of photovoltaic/thermal (PV/T) without airflow 41% at 3.0m length of PV module.

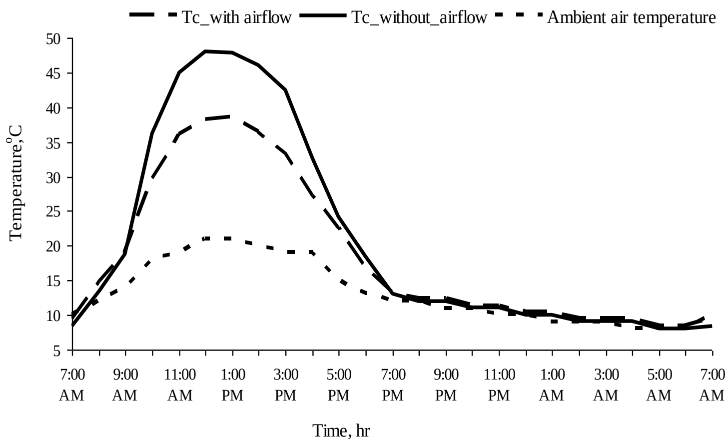

Fig. 2.4 Hourly variation of solar cell temperature for a typical day of August, 2006.

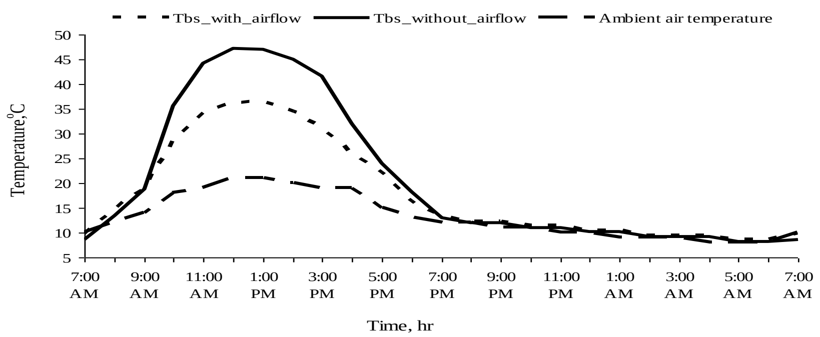

Fig. 2.5 Hourly variation of tedlar back surface temperature for a typical day of August, 2006.

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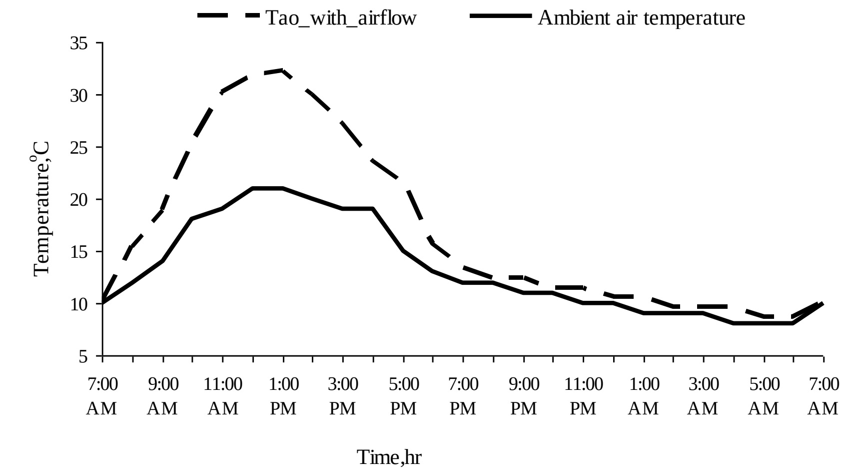

Fig. 2.6 Hourly variation of outlet air temperature for a typical day of August, 2006.

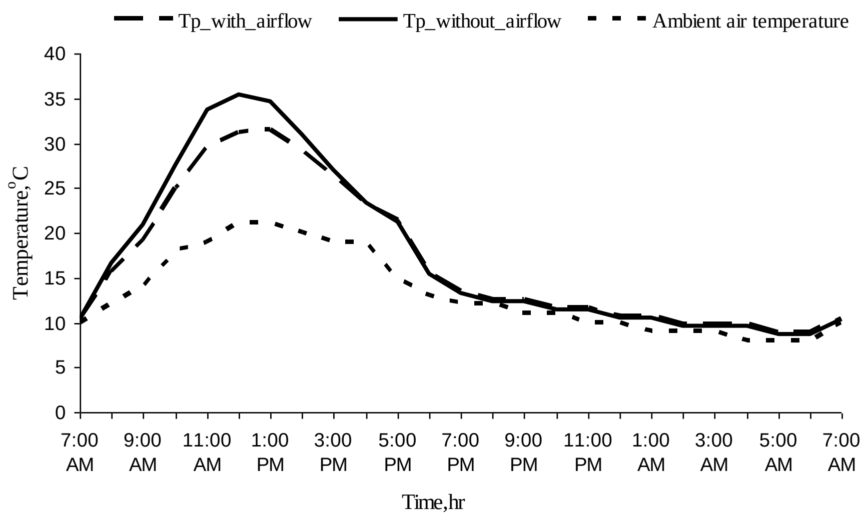

Fig. 2.7 Hourly variation of plant temperature for a typical day of August, 2006.

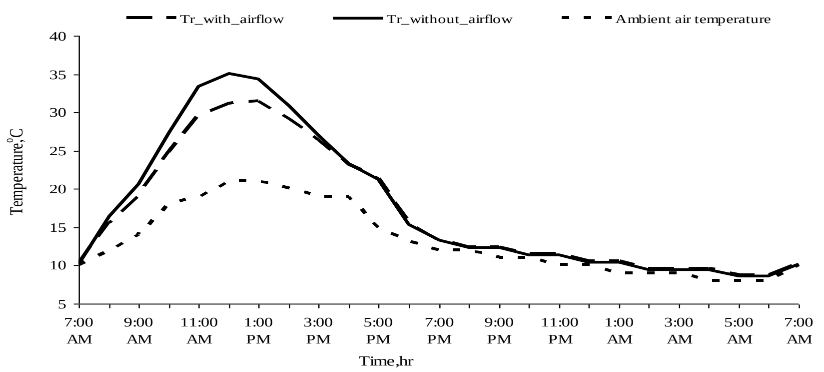

Fig. 2.8 Hourly variation of greenhouse room air temperature for a typical day of August, 2006.

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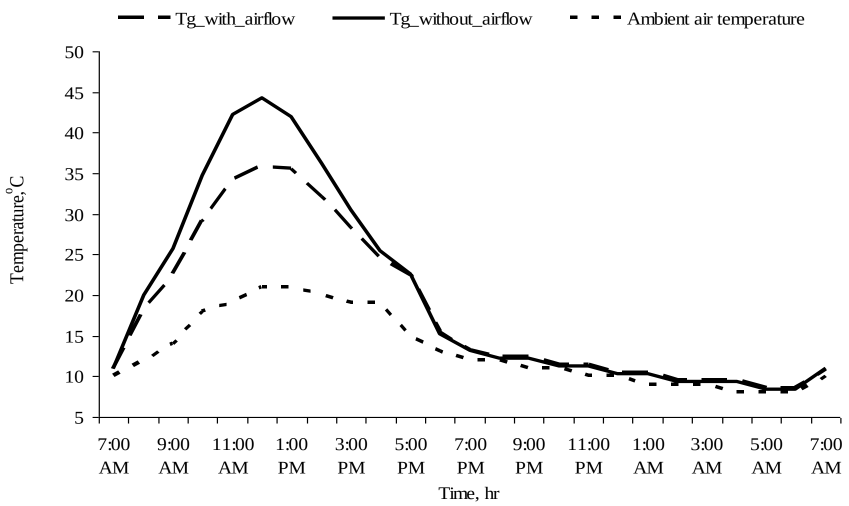

Fig. 2.9 Hourly variation of floor temperature for a typical day of August, 2006.

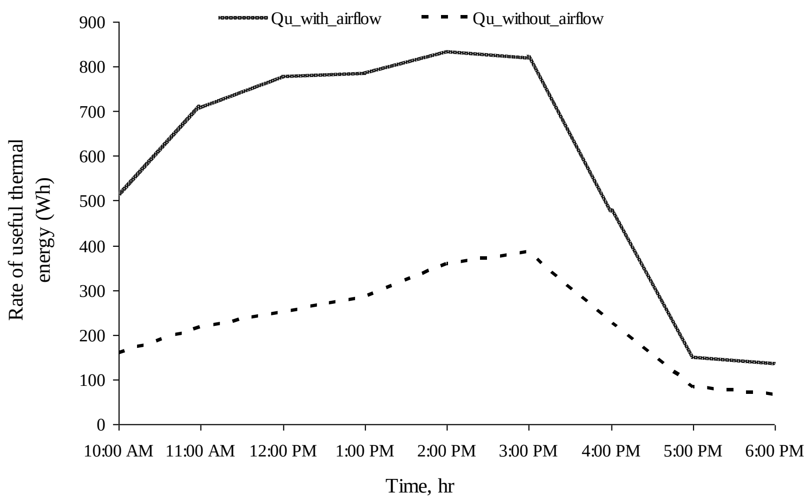

Fig. 2.10 Hourly variation of rate of useful thermal energy for a typical day of August, 2006.

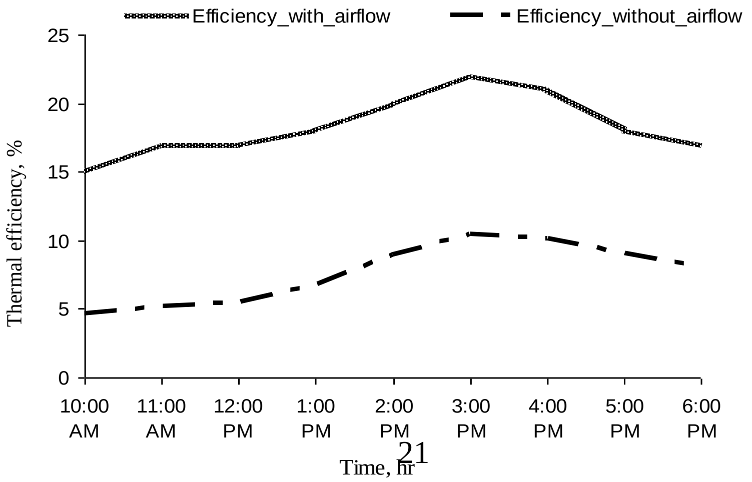

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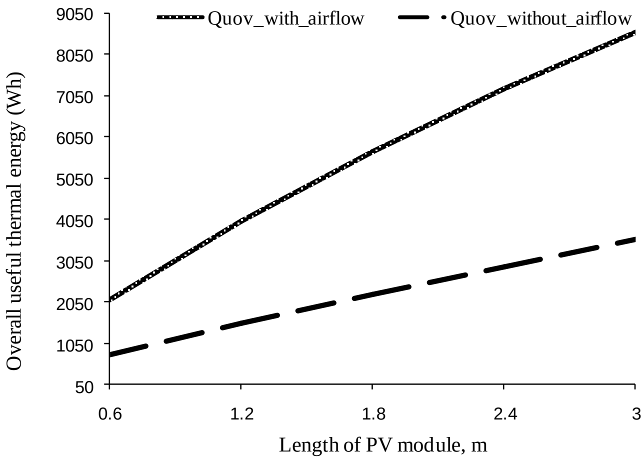
Fig. 2.11 Hourly variation of thermal efficiency for a typical day of August, 2006.

Fig. 2.12



Variation of overall useful thermal energy with respect to the length of PV module

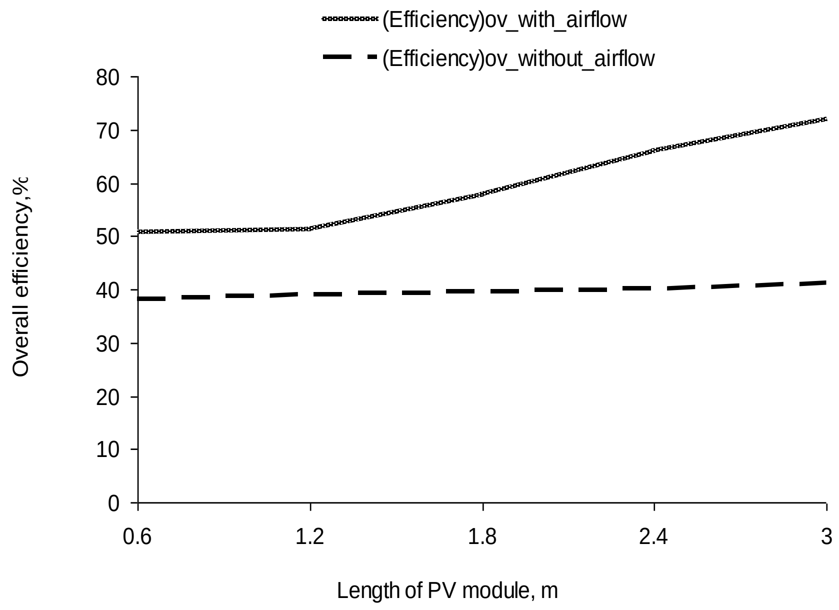


Fig. 2.13 Variation of overall efficiency with respect to length of PV module

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2.7 Conclusions

On the basis of present study following conclusions have been made.

(i) Solar cell and tedlar back surface temperature are higher in case of photovoltaic/thermal (PV/T) without airflow due to direct transfer of thermal energy into the greenhouse. There is an increase of around 10ºC solar cell temperature and 3-4ºC tedlar back surface temperature of PV/T without airflow.

(ii) Plant and greenhouse room air temperatures are advanced in the case of photovoltaic/thermal (PV/T) without airflow because of direct transfer of thermal energy into the greenhouse. There is an increase of around 5ºC plant temperature and 2-3ºC greenhouse room air temperatures of PV/T without airflow.

(iii) Similarly, the thermal efficiency of a hybrid photovoltaic/thermal (PV/T) air collector is higher due to lower operating temperature. It is calculated that thermal efficiency of hybrid photovoltaic/thermal (PV/T) air collector is around 24% and the thermal efficiency of photovoltaic/thermal (PV/T) without airflow is around 8.5%. An increase of 15.5% occurs in thermal efficiency of PV/T air collector when air is made to flow. It is also concluded that overall efficiency of hybrid

(iv) Photovoltaic/thermal (PV/T) air collector is higher than the overall efficiency of photovoltaic/thermal (PV/T) without airflow with respect to the length of PV module. It has been pragmatic that overall efficiency of hybrid photovoltaic/thermal (PV/T) air collector with and without airflow is 72% and 41% correspondingly for 3.0m length of PV module.

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