Performance evaluation of photovoltaic ventilated hybrid greenhouse dryer under no-load condition

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Abstract: Photovoltaic ventilated hybrid greenhouse dryer was designed and fabricated using 50.8 × 25.4 mm mild steel (MS) pipe and 19 × 30.2 mm MS angles for drying of food grains. Greenhouse dryer is having floor size of 446.7 × 213.4 cm with a central height of 259 cm. Twin wall, clear polycarbonate sheet of 6 mm thick was used to insulate the greenhouse dryer structure. Performance evaluation was conducted under no-load test condition showed that the average temperature inside the dryer was 7.6°C-13.4°C and 6.3°C-13.2°C (22%-43%) higher and average relative humidity of 26%-47% and 23%-40% lower than ambient temperature and relative humidity during the months of May and December respectively. The exhaust air flow rate varied in the range of 38.93-81.95 m^3 min^{-1} and 28-63 m^3 min^{-1} during the months of May and December respectively. The elevated greenhouse of air temperature and reduced relative humidity would reduce the drying time considerably.

Keywords: greenhouse dryer, photovoltaic, forced ventilation, performance evaluation

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1 Introduction

The primary objective of drying is to enhance the quality of food apart from extending shelf life, ease of handling, further processing, and sanitation. In India, drying is done primarily under the sun at the farm level, convective drying confined to commercial scale applications. Solar radiation in the form of solar thermal energy is an alternative source of energy for drying of food; it is an economical procedure especially for medium to small quantities of food products. Solar drying is still used at a domestic level up to small commercial size drying contributing significantly to the economy of agriculture at the micro level. Sun drying has the problems such as unreliability, uncontrolled heating of grains, thus leading to grain fissures and breakage during milling, vulnerability to infestation and losses due to birds, rodents, etc (Kadam and Samuel, 2006; Dwivedi et al., 2003). These problems are further aggravated by rains, floods and cyclones to which farmers in the vast Indian coastal belt are most prone (Shankar et al., 1989). Solar drying is having varied levels of technological sophistication as compared to conventional drying. Several forced convection solar dryers (both the cabinet-type and the tunnel-type) were investigated (Bena and Fuller, 2002; Hossain and Bala, 2007). Solar drying of food products in enclosed structures by forced convection is an attractive way of reducing post-harvest losses (Muhlbauer, 1986; Forson et al., 1996; Bena and Fuller, 2002; Chua and Chou, 2003; Sacilik et al., 2006; and Forson, 2007). A greenhouse dryer is a unique and cost efficient method of drying food products on a commercial scale; it consists of a drying chamber and an exhaust fan. Hybrid greenhouse dryers use the photovoltaic (PV) module to generate direct current (DC) electrical power to drive a DC fan for maintaining the desired temperature inside the chamber used (Barnwal and Tiwari, 2008). Major applications of hybrid

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greenhouse dryers are in large scale commercial drying operations where mechanical drying is costly in terms of both capital and operational cost (Amer et al., 2010). Compared to the conventional dryer, the solar greenhouse dryer had a low cost and it was helpful in decreasing the consumed by 50%-70% time for drying. Keeping in view all these facts, a study was initiated to develop and evaluate a hybrid greenhouse type drier.

2 Materials and methods

Photovoltaic ventilated hybrid greenhouse dryer was developed for drying of food grains at College of Agricultural Engineering; Bapatla is shown in Figure 1. The foundation of the dryer was laid in east-west orientation, greenhouse dryer with 446.7 × 213.4 cm size and 259 cm central height has been using 50.8 × 25.4 mm MS pipe, 19 × 30.2 mm MS angles. Clear twin wall polycarbonate sheet with 6 mm thick was also used to insulate the structure of the greenhouse dryer. North wall of the greenhouse dryer was insulated with a thermocol sheet to reduce the heat loss. Drying chamber of the solar greenhouse dryer is divided into multiple tiers. The trays were used for holding the food grains inside the drying chamber. The each tray is having 142.5 × 80 × 17.5 cm size. Tray frame was fitted with the best quality stainless steel woven mesh having specifications of 0.8 mm diameter, 2.83 mm aperture and open area 61%. Forced ventilation was provided with 9-inch diameter, 1200 RPM, 40 watt DC power operated exhaust fan (Figure 2). Two 150 watt power capacity solar photovoltaic panels with 18.5 V rated voltage and 8.10 A rated current were used to drive the DC exhaust fans.

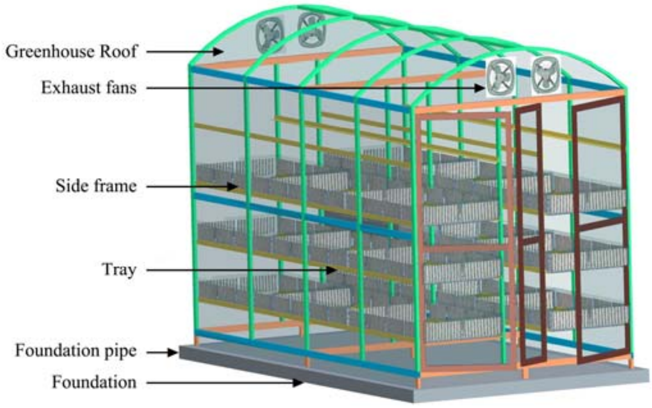

Figure 1 Structural details of designed PV ventilated hybrid greenhouse dryer

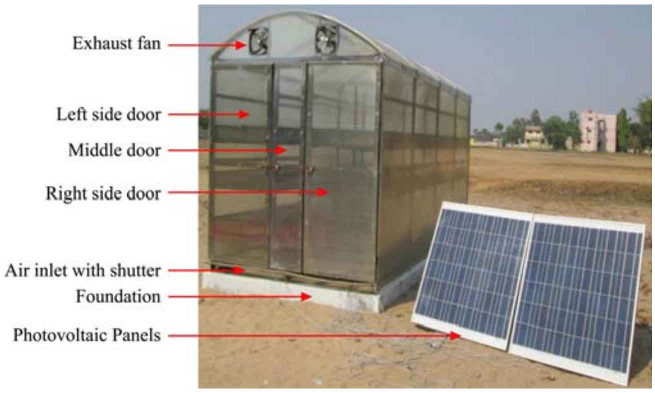

Figure 2 Fabricated PV ventilated hybrid greenhouse dryer

The performance PV ventilated hybrid greenhouse dryer was evaluated under no-load mode during crop harvesting months of two crop seasons, namely Rabi and Kharif with to find out temperature, relative humidity profiles at different positions inside the hybrid greenhouse dryer. About six representative points were selected inside the hybrid greenhouse dryer, among them; each two point is located at lower, middle and top trays of the dryer. An average of two points in each tier represented the corresponding position values. Experiments were carried out between 9:00 a.m. and 5:00 p.m. Solar radiation, greenhouse air temperature, relative humidity, exhaust air velocity was recorded at every one-hour interval.

Greenhouse dryer air temperature and ambient temperature was measured with T-type thermocouples (Range: –200°C to 350°C). Relative humidity was measured using a hygrometer which has a measuring range of 0%-100%. Sixteen channel data loggers (Process precision instruments (PPI), India) were used to record the temperature and relative humidity at one minute interval. First, eight channels are connected to thermocouples, which are used to measure the greenhouse air temperature at six locations, ambient and exhaust air temperature. Remaining eight channels are connected to hygrometers, which are used to measure the greenhouse air relative humidity at six locations, ambient and exhaust air relative humidity. Anemometer (Lutran 4201) was used to measure the exhaust air velocity. Pyranometer (Apogee SP 110) was used to measure global solar radiation.

3 Results and discussion

Solar radiation, greenhouse air temperature, relative humidity and airflow rate variation during no-load condition on different days of May 2016 and December 2015 at different locations inside and the outside the dryer was studied and reported.

3.1 Variation of greenhouse air temperature

Temperature variation inside of the hybrid greenhouse dryer was studied on clear, sunny days during the month of May and December has shown in Figure 3 and Figure 4. It was observed that the greenhouse air temperature and ambient temperature increased till 1:00 p.m. later decreased from 5:00 p.m., it happened due to increasing incident solar radiation from morning to afternoon 1:00 p.m. and then decrease from 5:00 p.m. The greenhouse air temperature varied in the range of 37.7°C-50.4°C and 35.25°C- 48.58°C during the month of May and December respectively. During the same period, ambient temperature varied in the range of 29°C-38°C and 25°C-36°C. An average greenhouse air temperature was 7.6°C-13.4°C (26.4%-35%) and 6.3°C-13.2°C (22%-43%) higher than the ambient temperature during May and December respectively. It was also observed that the solar radiation varied during May was 413.6-881.73 W m^{-2} and 291.84-562.13 W m^{-2} during the month of December.

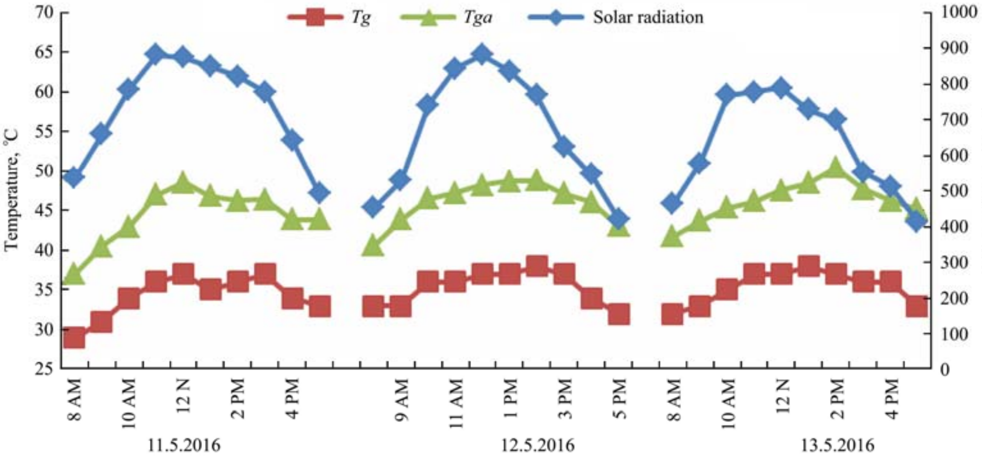

Figure 3 Variation of average greenhouse air temperature, ambient temperature and solar radiation with respect to time during the month of May

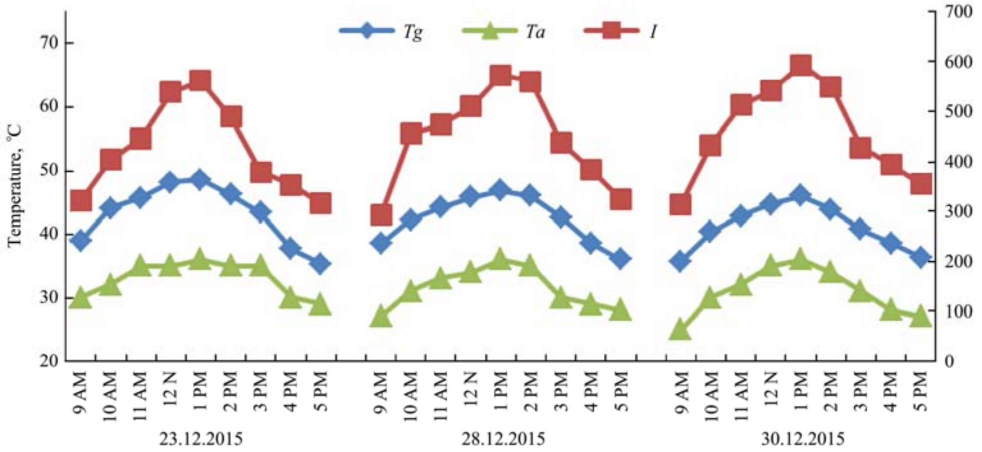

Figure 4 Variation of average greenhouse air temperature, ambient temperature and solar radiation with respect to time during the month of December

There was a great variation in ambient and greenhouse air temperature under forced ventilated condition. A second order polynomial relationship was established between greenhouse air temperatures (Tg) as a function of ambient air temperature (Ta) as shown in Figure 5 and Figure 6 and Equation (1) and Equation (2) during May and December respectively.

$$Tg = -0.054Ta^2 + 4.941Ta - 60.02, \quad R^2 = 0.861 \tag{1}$$

$$Tg = 0.022Ta^2 - 0.228Ta + 26.85, \quad R^2 = 0.862 \tag{2}$$

Variation in greenhouse air temperature at different locations within the greenhouse dryer was studied and presented in Figure 7 and Figure 8. It was observed that, there was considerable variation among the different points of the greenhouse dryer. At any point of timing the temperatures in three different positions varied within a narrow range. In addition, temperatures at each of the locations differed significantly from the ambient air temperature. It was found that the temperature at upper layer was always higher than corresponding to the lower layer. This was due to shading effect of the upper tray on corresponding lower trays; however overall cyclic patterns of the temperature profiles were similar at all three locations along the length of the day.

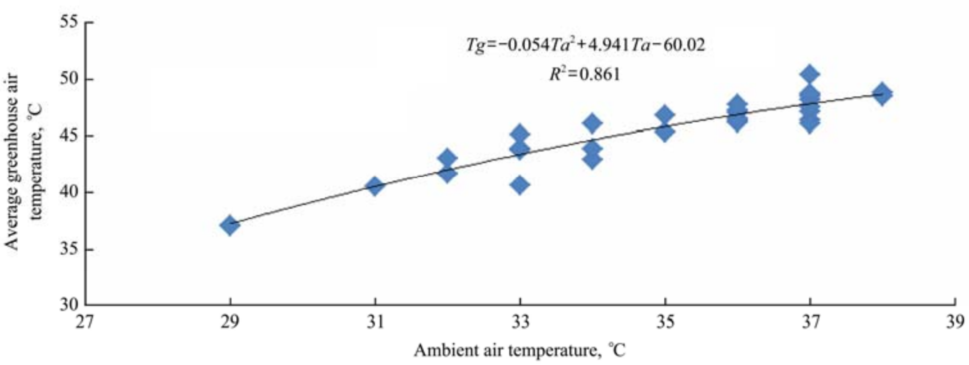

Figure 5 The correlation between greenhouse and ambient air temperature during May month

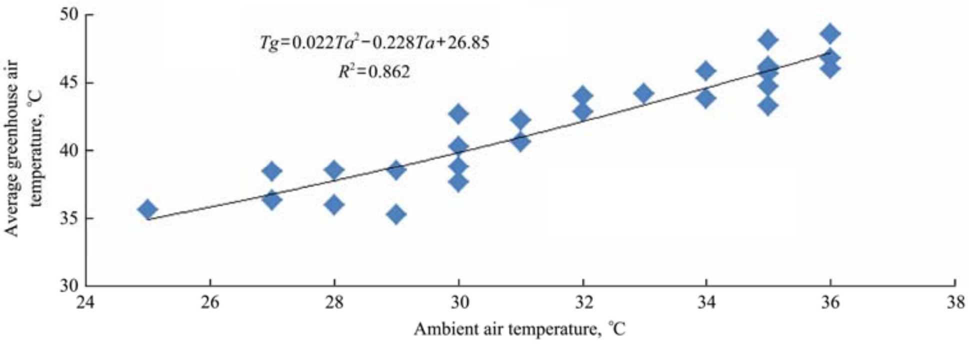

Figure 6 The correlation between greenhouse and ambient air temperature during December month

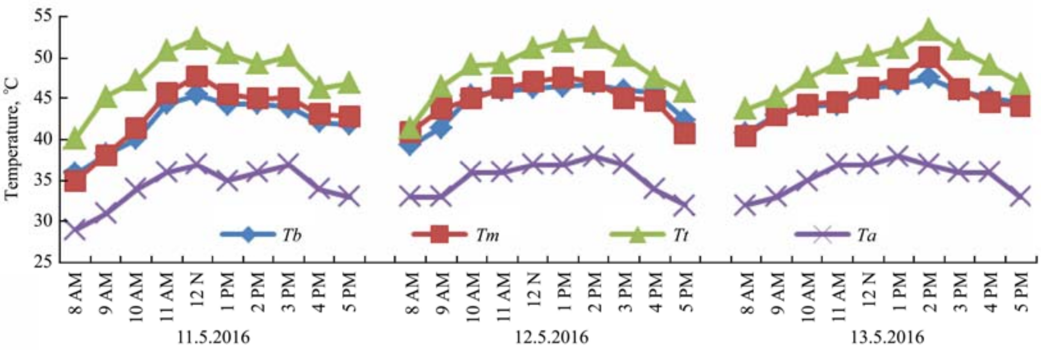

Figure 7 Variation of greenhouse air temperatures at different locations and ambient temperature with respect to time during the month of May

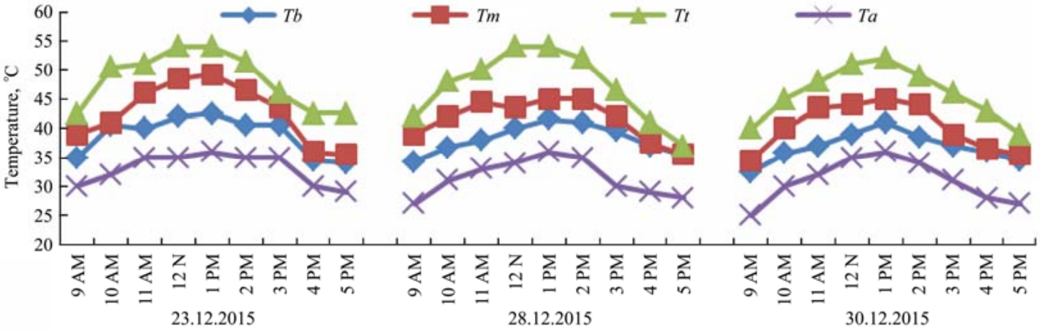

Figure 8 Variation of greenhouse air temperatures at different locations and ambient temperature with respect to time during the month of December

An average air temperature rose at the top layer (*Tt*) over ambient temperature (*Ta*) was found to be 8.5°C-16.5°C (26%-45%). There has not great variation in temperature been observed among middle (*Tm*) and bottom (*Tb*) portions of the dryer (Figure 7). The lower portion temperature was found to be 6.8°C-11.8°C (18%-38%) higher than ambient temperature during May. The average air temperature rose at the top layer over ambient temperature was found to be 9°C-21°C (31%-59%) in December whereas in bottom layer 5°C-10°C (14°C-32°C) rose was observed (Figure 8). Similar results were also reported Rathore and Panwar, 2011; Seveda, 2012; Dulawat and Rathore, 2012; and Singh et al., 2007).

3.2 Variation of greenhouse air relative humidity

Variation in relative humidity during day time was studied and shown in Figure 9 and Figure 10. It was observed that the relative humidity decreased with time in the solar greenhouse dryer and in ambient conditions during the first half of the day. This was due to increase in temperature inside and outside the greenhouse dryer; hence it increased the water holding capacity of the air in the greenhouse dryer. During the latter half of the day, the relative humidity was increased as the temperature in both the cases was decreased. Furthermore, the relative humidity of air inside the greenhouse dryer was less than that of ambient air at any point of time since the temperature inside the solar greenhouse dryer was higher than the ambient air at any point in time.

An average relative humidity of the solar greenhouse dryer (*Hg*) varied in the range of 22%-36.6% and 29.5%-42.67% during the month of May and December respectively. It was also observed that the average relative humidity of the greenhouse dryer was 26%-47% and 23%-40% lower than the ambient relative humidity (*Ha*) during the same period.

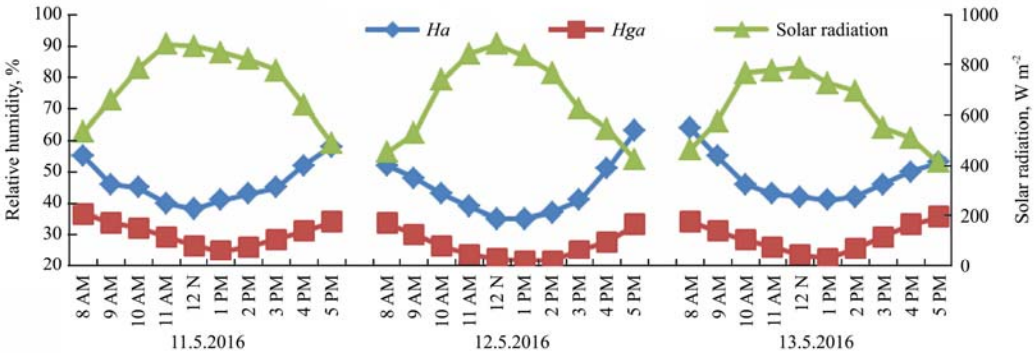

Figure 9 Variation in average greenhouse air relative humidity, ambient temperature and solar radiation with respect to time during the month of May

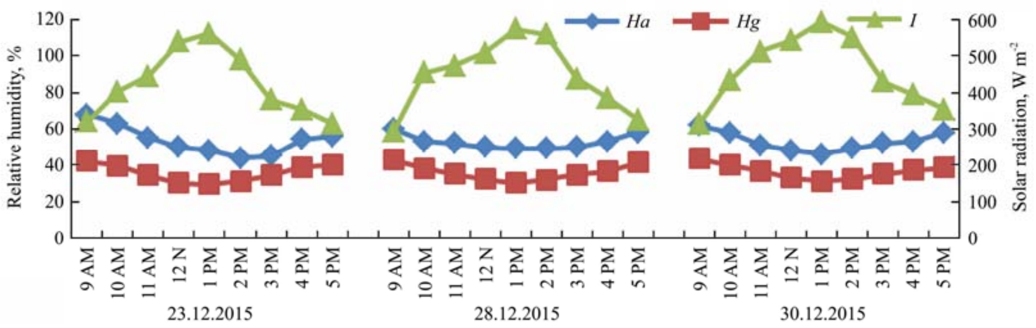

Figure 10 Variation in average greenhouse air relative humidity, ambient temperature and solar radiation with respect to time during the month of December

There has great variation in ambient and greenhouse air relative humidity under forced ventilated condition. The second order polynomial relationship established between the greenhouse air relative humidity (*Hg*) as a function of ambient air relative humidity (*Ha*) (Figure 11 and Figure 12) with the Equation (3) and Equation (4) given below.

$$Hg = -0.016Ha^2 + 2.093Ha - 32.00, \quad R^2 = 0.755 \qquad (3)$$

$$Hg = -0.011Ha^2 + 1.929Ha - 32.55, \quad R^2 = 0.744 \qquad (4)$$

Variation of greenhouse air relative humidity at different locations within the greenhouse was studied and shown in the Figure 13 and Figure 14. It was observed that there was considerable variation among the different locations of the greenhouse dryer. It was also found that the relative humidity at upper layer was always lower than corresponding to the lower layer. This was due to relatively less temperature in the lower layer due to shading effect of the corresponding upper tray. However, the relative humidity profile followed a similar cyclic pattern at all three layers along the length of the day.

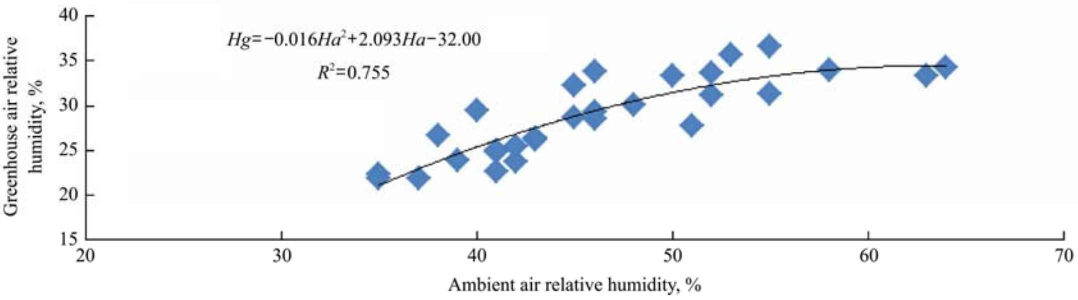

Figure 11 The correlation between greenhouse relative humidity and ambient air relative humidity during May

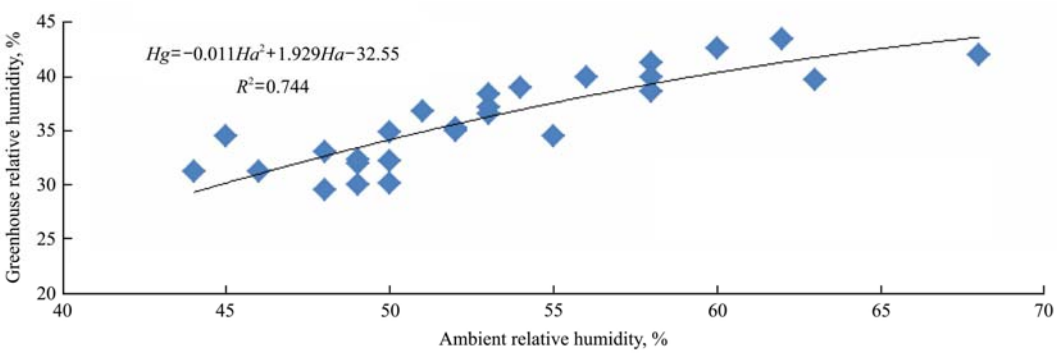

Figure 12 The correlation between greenhouse relative humidity and ambient air relative humidity during December

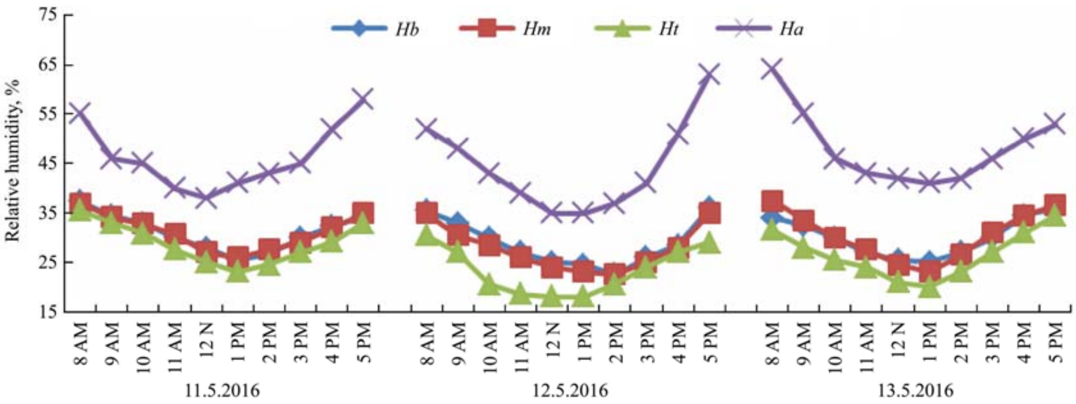

Figure 13 Greenhouse air relative humidity at different locations under no-load condition with forced ventilation during May

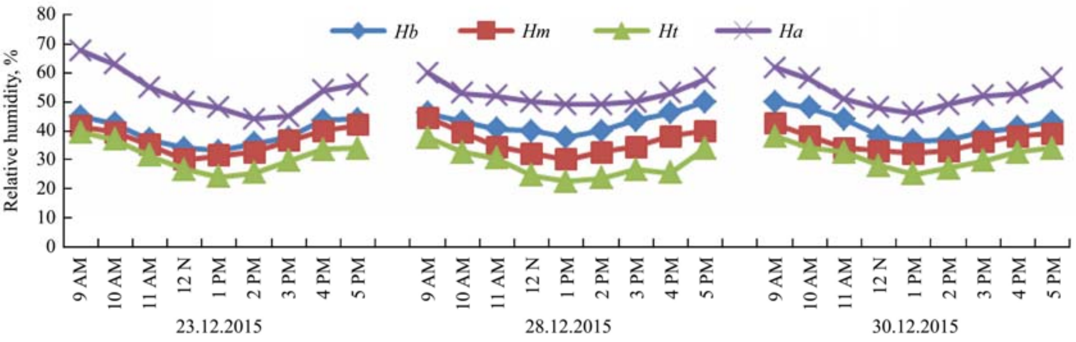

Figure 14 Greenhouse air relative humidity at different locations under no-load condition with forced ventilation during December

Among the three locations, the average relative humidity depression at the top layer (*Ht*) over ambient relative humidity (*Ha*) was found to be 13%-34% (28%-54%) and 16%-29% (34%-54%) during the month of May and December respectively. Lower layer relative humidity (*Hb*) was found to be 10%-30% (25%-47%) and 7%-20% (13%-34%) lower than ambient relative humidity during May and December months respectively. Low relative humidity is more favorable for drying due to the increase of the evaporating capacity of the air. These results are in accordance with the results reported(Kumar et al., 2013; Rathore and Panwar, 2011; Kadam et al., 2011; Kouhila et al., 2002; Lahsasni et al., 2004; and Shahi et al., 2009).

3.3 Variation of greenhouse air flow rate

The ventilation rate (*Qa*) depends on the intensity of solar radiation (*I*). Figure 15 and Figure 16 shows the variation of exhaust air volume and solar radiation during the month of May and December. The airflow rate increased sharply in the early part of the day, then becomes fairly constant and then drops sharply in the afternoon. The pattern of changes in air flow rate follows the pattern of the changes in solar radiation since the air flow is regulated by PV powered DC fans. Variation of the air flow rate helped to regulate the drying air temperature. During high solar radiation period, more energy was received by solar greenhouse dryer which increased the greenhouse dryer temperature, but it was compensated by the increase of air flow rate. During low solar radiation period, less energy was received by the solar greenhouse dryer and the air flow rate was low. This resulted in a minimum variation of drying air temperature throughout the drying period.

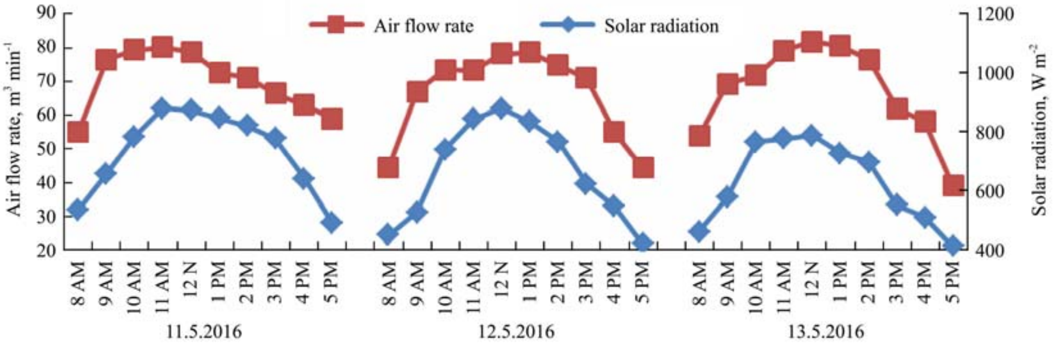

Figure 15 Exhaust air flow rate from the greenhouse under no-load condition with forced ventilation during May month

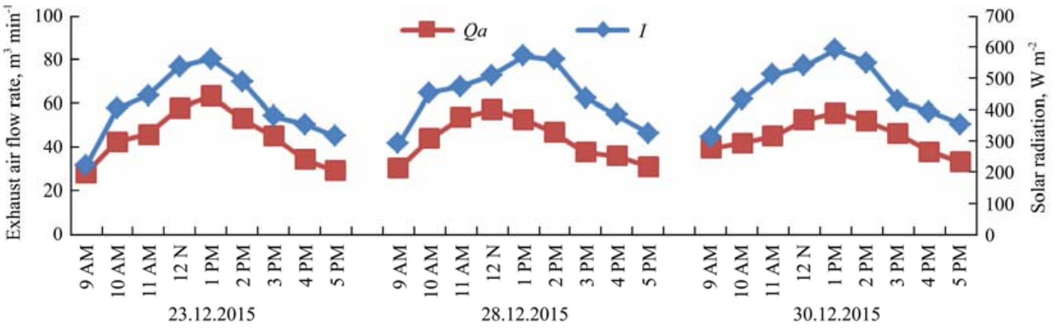

Figure 16 Exhaust air flow rate from the greenhouse under no-load condition with forced ventilation during December month

Exhaust air flow rate (*Qa*) varied in the range of 81.95-38.93 m^3 min^{-1} and 28-63 m^3 min^{-1} during the month of May and December respectively (Figure 15 and Figure 16). The relationship between air flow rate and solar radiation was studied and shown in the Figure 17 and Figure 18. The polynomial relationship was established between the solar radiation and air flow rate is shown in Equation 5 and Equation 6 for the month of May and December respectively. These results are in alliance with the results reported (Kumar et al., 2013; Shahi et al., 2009; Shahi et al., 2011).

$$Q = 4\text{E-}07I^3 - 0.001I^2 + 0.846I - 167.3, \quad R^2 = 0.863 \tag{5}$$

$$Q = 4\text{E-}06I^2 + 0.084I + 6.297, \quad R^2 = 0.791 \tag{6}$$

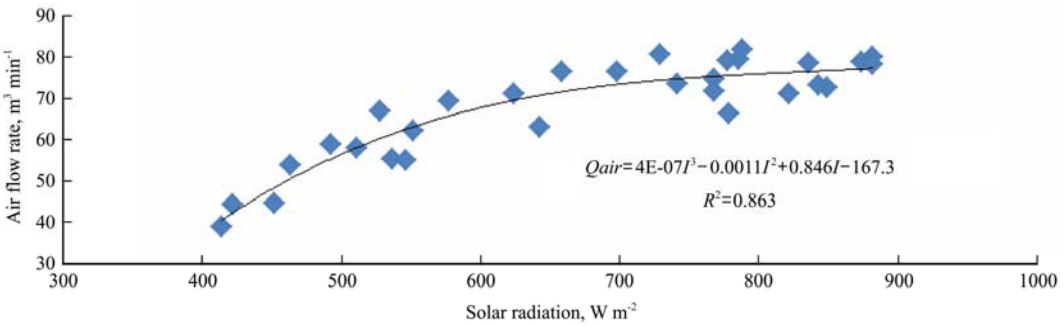

Figure 17 Correlation between exhaust air flow rate and solar radiation during month of May

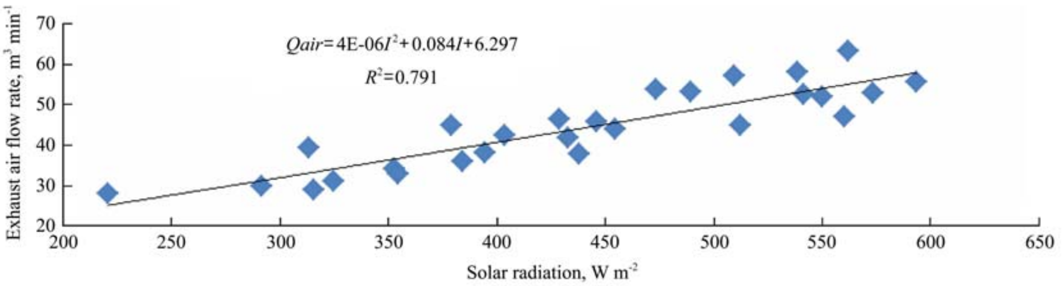

Figure 18 The correlation between exhaust air flow rate and solar radiation during December

4 Conclusions

Performance evaluation of PV ventilated hybrid greenhouse dryer under no-load condition revealed that the average greenhouse air temperature was 7.6°C-13.4°C (26.4%-35%) and 6.3°C-13.2°C (22%-43%) higher than the ambient temperature under forced ventilated condition during May and December respectively. An average relative humidity of the greenhouse dryer was 26%-47% and 23%-40% lower than the ambient relative humidity during the same period. The increase in greenhouse air temperature, decrease in relative humidity would increase the water holding capacity of the greenhouse dryer air, hence drying time would be less as compared with open sun drying.

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