Effect of dusting and aging on the performance of partially PV covered flat plate air collector

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ABSTRACT

In this communication, an effort has been made to observe the effect of dusting (reduced transmittivity) and aging (reduced absorptivity of absorbing plate) on the performance of partially PV covered flat plate air collector. Thermal modelling has been done for the partially PV coveredflat plate air collector and parameter like outlet air temperature, electrical efficiency, thermal energy and cell temperature have been calculated with the help of MATLAB program. Further, effect of dusting and agingon thermal energy, electrical energy, and overall thermal energy have been evaluated. Variation in thermal energy, electrical energy and overall thermal energy with respect to dusting effect (transmittivity changes from 1 to 0.5) found to be 2.19-1.08, 0.19-0.10 and 2.69-1.35 kWh/dayi.e. 50.57, 47.33 and 49.97% reduction in comparison to maximum values respectively for a typical day of May.

Keywords: Flat plate air collector, dusting effect, aging effect, thermal energy

I INTRODUCTION

PVT collectors are hybrid systems which are built for best use of the solar energy to generate not only electricity but also heat from a single module. High transparent low emissivity silver coating based study has been done specifically to optimize the application in PVT collectors. It was found that the newly established low-e coating decreases heat losses from the collector about to 82%, while the electrical efficiency reduces by only 3%. However glazed PVT collectors reach higher temperature levels, but it has no significant market portion because of comparatively high thermal losses in comparison to standard solar thermal collectors with spectrally selective absorber coatings. Low-emissivity coatings were used to decrease radiative losses [1]. A solar air heater combined with PV module has been designed, fabricated and its performance was studied. Thermal model has been established based on the energy balance equations. Electrical and thermal efficiency of the solar air heater found to be 8.4% and 42% respectively [2]. Tiwari et al. [3] developed a novel hybrid PVT greenhouse solar drying system. Thermal modelling with experimental validation was done and values of overall thermal energy found to be 2.03 kWh experimentally. The Performance analysis of glazed PVT air collector has been done and found that there is a substantial reduction in annualized uniform cost caused by earning carbon credit [4]. Relative study of the climate condition of Srinagar was done on different type of PVT air collector namely, conventional hybrid PVT, glazed and unglazed hybrid PVT tiles air collectors [5].The solar air heater was designed, fabricated and assessed. The maximum temperature of the room found to be 45.5 ^{0}C and 41.75 ^{0}C which were more than 12.25 ^{0}C and 8.5 ^{0}C from ambient under forced and natural circulation respectively [6]. The authors reviewed PVT solar collectors for air heating. It is concluded that the PVT air heater may in the future be feasible for preheating air for numerous uses, containing space heating and solar drying. Further, it was found that the combined PVT collectors provide more energy per unit collector area than distinct PV and thermal solar systems [7].

The objective of present paper is to analyse the effect of dusting (reduced transmittivity) and aging (reduced absorptivity of absorbing plate) on the performance of partially PV covered flat plate air collector. This paper helps to researchers how the maintenance and cleaning is important for solar thermal systems.

II EXPERIMENTAL SETUP

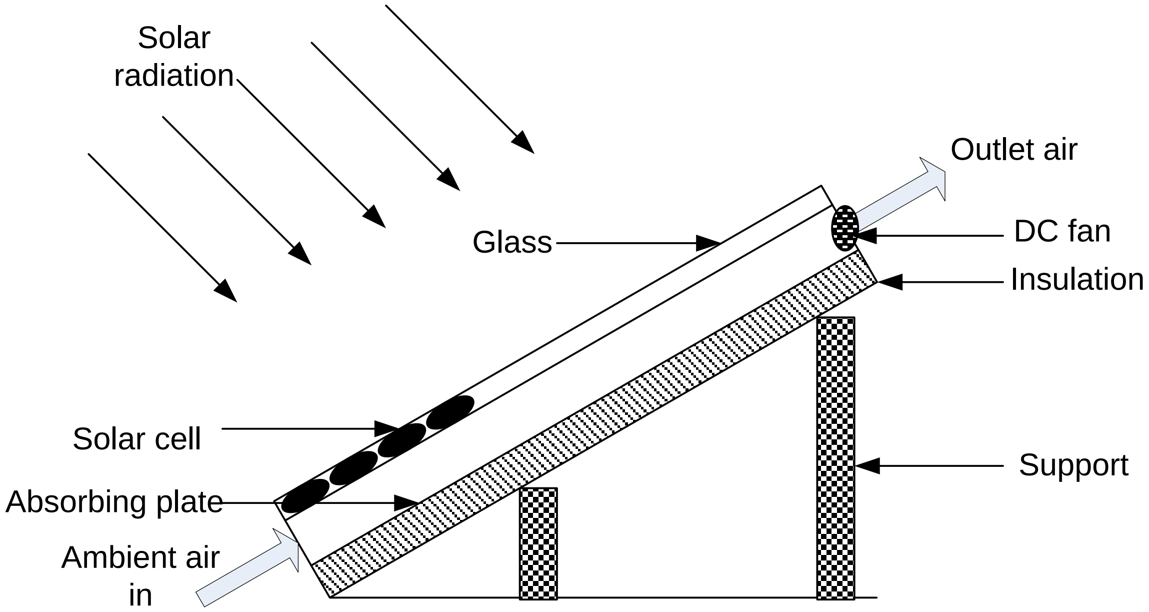

Fig. 1 Partially PV covered flat plate air collector

Figure 1 shows partially covered flat plate air collector. The experimental setup consist of flat plate air collector and a DC fan. Flat plate collector divided into two section namely, photovoltaic thermal (PVT) air collector and conventional air collector. Present system is self-sustainable due to PV.

2.1 Thermal Modelling

The following assumptions has made to develop the mathematical model of thermal modelling,
Energy balance equation for partial part of PVT air collector

Energy balance equation for PV [8],

$$\alpha_c \tau_g \beta_c I_t A_m = U_{tca}(T_c - T_a) A_m + U_{bcf}(T_c - T_f) A_m + \tau_g \beta_c \eta_c I_t A_m \qquad (1)$$

Temperature dependent solar cell efficiency can be written as [9]

$$\eta_c = \eta_o (1 - \beta_o (T_c - T_o)) \qquad (3)$$

Energy balance equation for absorbing plate [8],

$$\alpha_p (1 - \beta_c) \tau_g{}^2 I_t bdx = h_{pf}(T_p - T_f) bdx + U_{bpa}(T_p - T_a) bdx \qquad (3)$$

Energy balance equation for working fluid (air),

$$\dot{M}_f C_f \frac{dT_f}{dx} dx = [U_{bcf}(T_c - T_f) + h_{pf}(T_p - T_f)] bdx \qquad (4)$$

Energy balance equation for conventional (glazed part) air collector

Energy balance equation for blackened surface [8]

$$\alpha \tau_g I_t bdx = [U_{bpa}(T_p - T_a) + h_{pf}(T_p - T_f)] bdx \qquad (5)$$

Energy balance equation for flowing fluid [8],

$$\dot{M}_f C_f \frac{dT_f}{dx} dx + U_{tfa}(T_f - T_a) bdx = [h_{pf}(T_p - T_f)] bdx \qquad (6)$$

From equations (1), (3), (4)

$$\frac{dT_f}{dx} + \left(\frac{bU_{Lm}}{\dot{M}_f C_f}\right) T_f = \left(\frac{b}{\dot{M}_f C_f}\right) [(\alpha \tau)_{meff} I_t + T_a U_{Lm}] \qquad (7)$$

Where,

$$U_{Lm} = U_{tfa} + U_{bfa}, h_{p1} = \frac{U_{bcf}}{U_{tca} + U_{bcf}}, h_{p2} = \frac{h_{pf}}{h_{pf} + U_{bpa}}$$

$$U_{tfa} = \frac{U_{tca}}{U_{tca} + U_{bcf}}, U_{bfa} = \frac{U_{bpa}}{h_{pf} + U_{bpa}}, (\alpha\tau)_{meff} = h_{p1}(\alpha_c \tau_g \beta_c - \eta_m) + h_{p2}\alpha_p (1-\beta_c)\tau_g{}^2$$

For solution of equation (7), it can be compared with equations (8), (9)

$$\frac{dT}{dt} + aT = f(t) \tag{8}$$

$$T = \frac{f(t)}{a}(1 - e^{-at}) + T_{cro}e^{-at} \tag{9}$$

Solution of the equation (7) is,

$$T_{fom1} = [\frac{(\alpha\tau)_{meff} I_t}{U_{Lm}} + T_a][1 - \exp(-\frac{bU_{Lm}L_m}{\dot{M}_f C_f})] + T_{fi}\exp(-\frac{bU_{Lm}L_m}{\dot{M}_f C_f}) \tag{10}$$

(at initial condition x=0, T_f=$T_{fi}$and x=L_m, T_f=T_{fom1})

From equations (5) and (6)

$$\frac{dT_f}{dx} + (\frac{bU_{Lc}}{\dot{M}_f C_f})T_f = (\frac{bU_{Lc}}{\dot{M}_f C_f})[\frac{(\alpha\tau)_{ceff} I_t}{U_{Lc}} + T_a] \tag{11}$$

Where,

$$h_{p2} = \frac{h_{pf}}{U_{bpa} + h_{pf}}, U_{pfa} = \frac{U_{bpa}h_{pf}}{U_{bpa} + h_{pf}}, U_{Lc} = U_{pfa} + U_{tfa}$$

$$(\alpha\tau)_{c,eff} = h_{p2}(\alpha_p \tau_g)$$

Solution of equation (11) can be written by comparing equations (12), (13)

$$T_{fo} = [\frac{(\alpha\tau)_{ceff} I_t}{U_{Lc}} + T_a][1 - \exp(-\frac{U_{Lc}A_c}{\dot{M}_f C_f})] + T_{foi}\exp(-\frac{U_{Lc}A_c}{\dot{M}_f C_f}) \tag{12}$$

And,

$$T_{foi} = T_{fom1} = [\frac{(\alpha\tau)_{meff} I_t}{U_{Lm}} + T_a][1 - \exp(-\frac{bU_{Lm}L_m}{\dot{M}_f C_f})] + T_{fi}\exp(-\frac{bU_{Lm}L_m}{\dot{M}_f C_f}) \qquad (13)$$

From equations (12) and (13)

$$T_{fo} = \frac{I_t}{\dot{M}_f C_f}[AF_R(\alpha\tau)]_1 + \frac{T_a}{\dot{M}_f C_f}[AF_R U_L]_1 + T_{fi}[1 - \frac{[AF_R U_L]_1}{\dot{M}_f C_f}] \qquad (14)$$

The efficiency of PV module can be describe as

$$\eta_m = \tau_g \beta_c \eta_c \qquad (15)$$

Electrical energy available through PV module can be describe as

$$\dot{E} = \eta_m A_m I(t) \qquad (16)$$

Thermal energy gain from N PVT air collector can be written as

$$\dot{Q}_{th} = \dot{M}_f C_f (T_{f0} - T_a) \qquad (17)$$

Overall (equivalent) thermal energy gain can be calculated as

$$\dot{Q}_{th,ov} = \dot{Q}_{th} + (\dot{E} / 0.38) \qquad (18)$$

III RESULT AND DISCUSSION

Figure 2 representsthe hourly variation of solar intensity and ambient temperature. Figure 3 indicates the hourly variation of outlet air temperature with varying transmissivity of glass. It is clear from the graph that as the transmissivity decreases, the outlet air temperature also decreases. It is seen that after installation of solar air collectors, it is not properly maintained. In maintenance only glass cleaning is required. The analysis clearly shows that if transmissivity decreases due to dust deposition on glass from 1 to 0.5, the maximum outlet air temperature reduces from 75.88 to 57.64 ^{0}C i.e. nearly 25%.

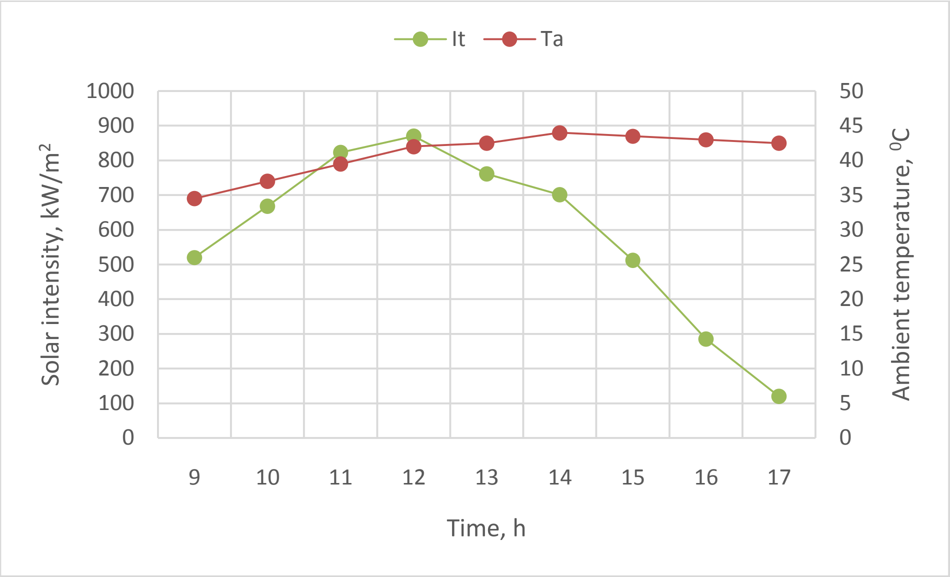

Fig. 2 Hourly variation of solar intensity and ambient temperature

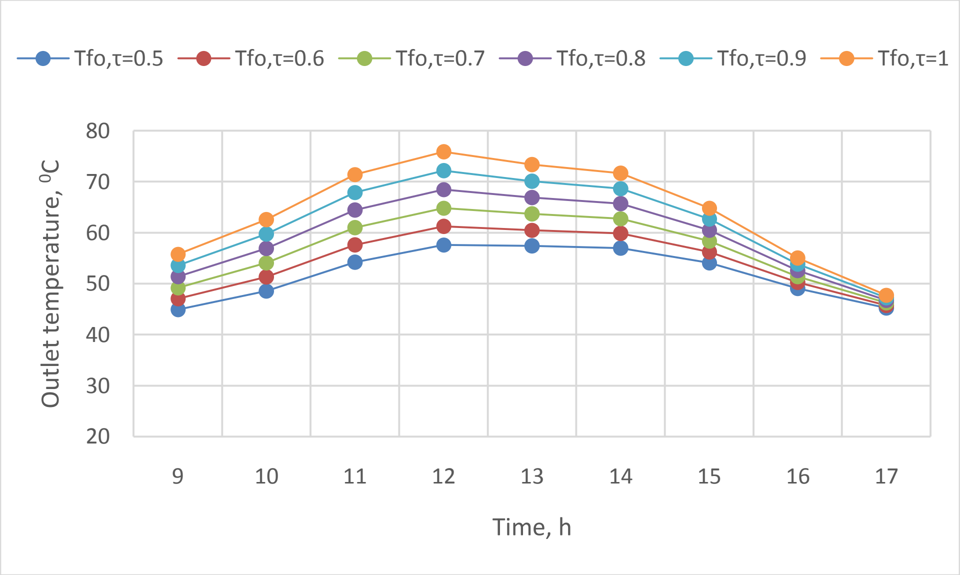

Fig. 3Hourly variation of outlet air temperature with varying transmissivity of glass

Figure 4 shows hourly variation of solar cell efficiency with varying transmissivity of glass. This graph gives interesting results. The efficiency of solar cell decreases with increasing transmissivity. It means by regular cleaning, efficiency of solar cell decreases due to increment of solar cell temperature. Figure 5 shows variation of electrical energy with varying transmissivity of glass in a particular day. It is clear from the graph although the efficiency of solar cell decreases with increase transmissivity of glass but electrical gain is increases due to more availability of solar radiation to the PV module. So, cleaning of flat plate always beneficial in term of electrical gain.

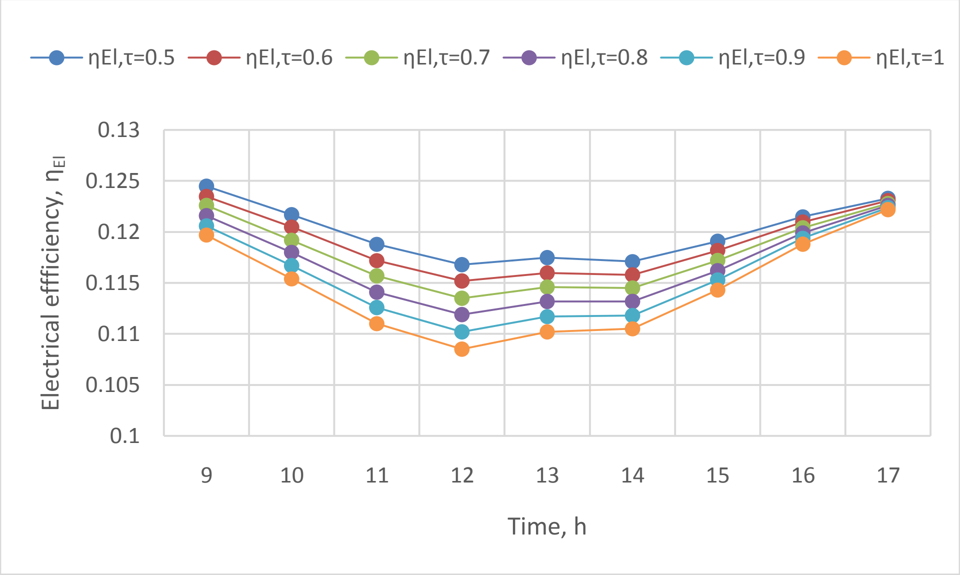

Fig. 4 Hourly variation of solar cell efficiency with varying transmissivity of glass

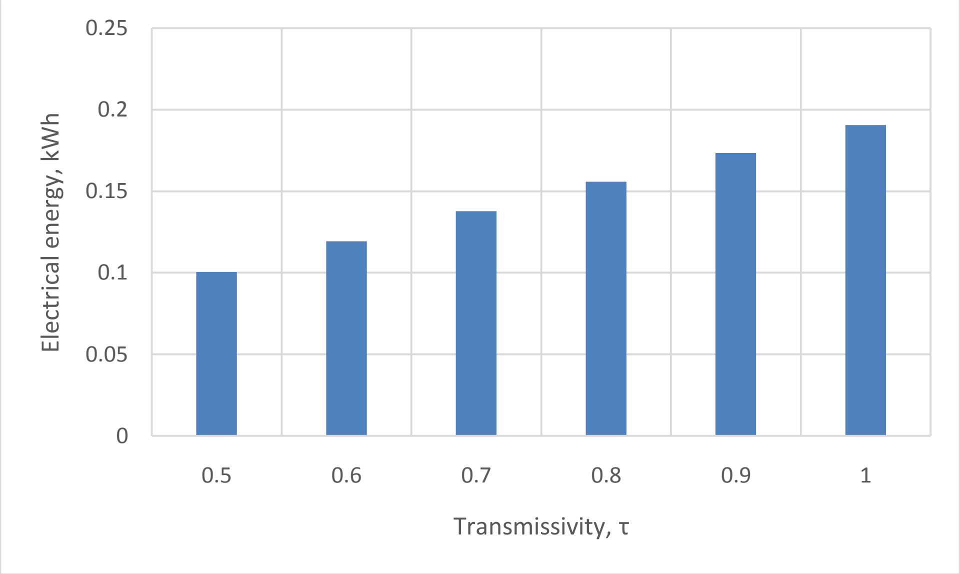

Fig. 5Variation of electrical energy with varying transmissivity of glass in a particular day

Figure 6 shows variation of thermal energy (Q_{th}) and equivalent (overall) thermal energy ($Q_{th,ov}$) with varying transmissivity of glass in a particular day. It is clear from the graph that the transmissivity of glass play vital role in the performance of the flat plate solar air collector. As the transmissivity of glass decreases from 1 to 0.5, the overall energy decreases 2.69 to 1.34 kWh/day i.e. 49.97% decrement compared to maximum output. Figure 7 shows hourly variation of outlet air temperature with varying absorptivity of heat absorbing plate. In normal condition, blackboard paint is used to increase the absorptivity of the absorbing plate but over a time period it can be faded then absorptivity decreases. It is clear from the graph if absorptivity decreases (1 to 0.5), maximum outlet air temperature also decreases (79.68 to 60.90 ^{0}C).

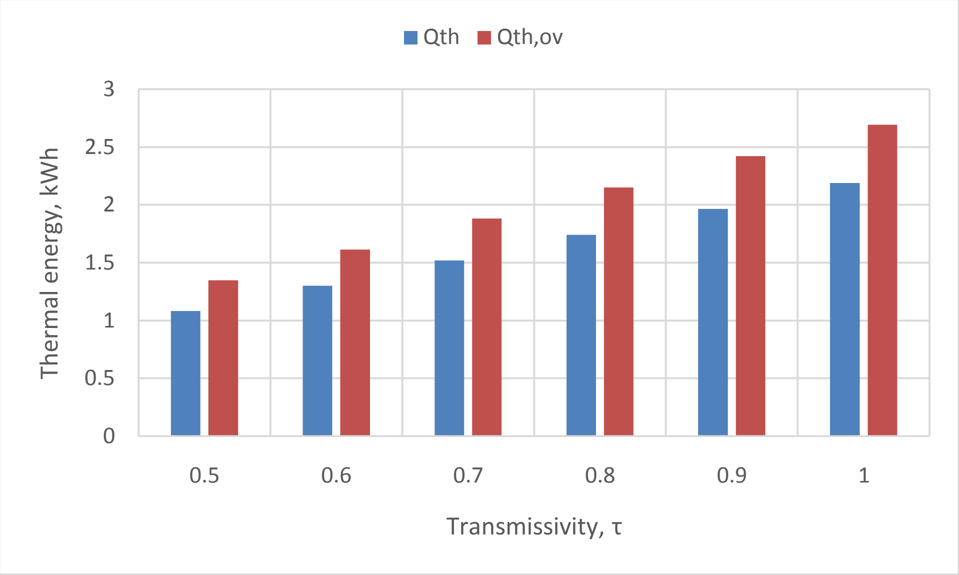

Fig. 6 Variation of thermal energy (Q_{th}) and equivalent (overall) thermal energy ($Q_{th,ov}$) with varying transmissivity of glass in a particular day

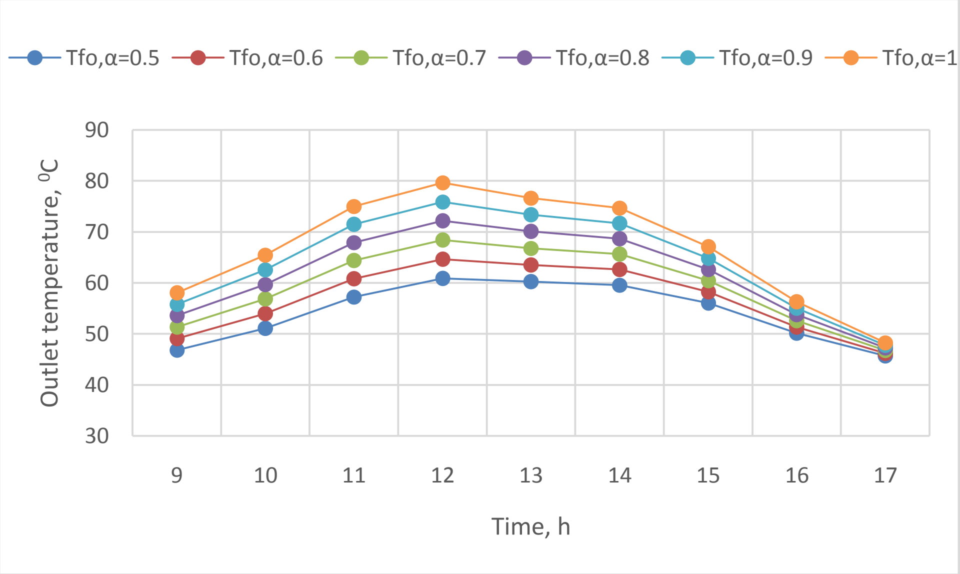

Fig. 7 Hourly variation of outlet air temperature with varying absorptivity of absorbing plate

Figure 8 shows the variation of thermal energy (Q_{th}) and overall thermal energy ($Q_{th,ov}$) with varying absorptivity of glass in a particular day. It is seen from the graph if absorptivity of absorbing plate decrease from 1 to 0.5, the thermal energy and overall thermal energy decreased by 47.13 and 38.65 % respectively. It is also found with analysis that decrease in absorptivity of absorbing plate has very low impact on electrical energy production from PVT air collector.

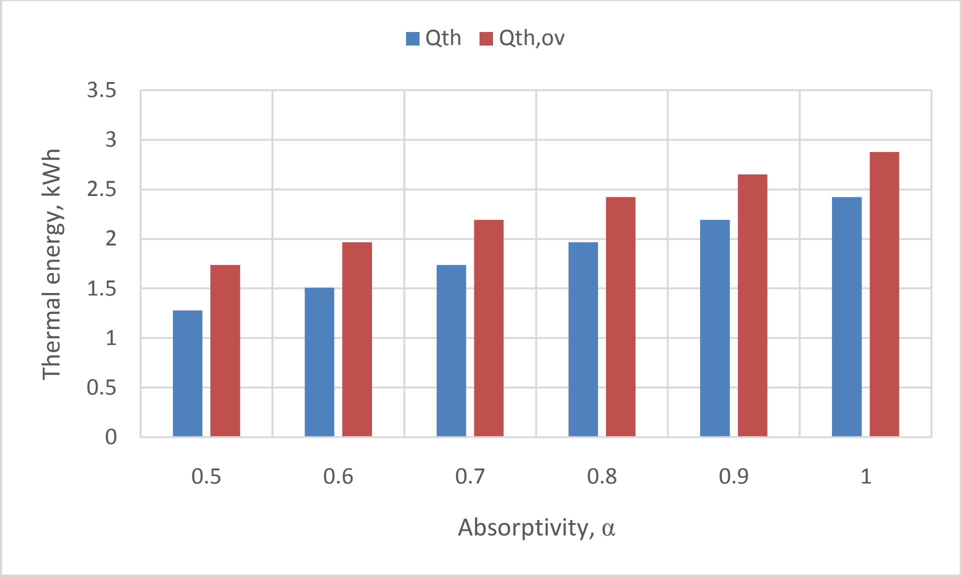

Fig. 8 Variation of thermal energy (Q_{th}) and overall thermal energy ($Q_{th,ov}$) with varying absorptivity of glass in a particular day

IV CONCLUSIONS

The following conclusions made on the basis of present study

- Although the efficiency of solar cell decreases with increase transmissivity of glass but electrical gain is increases. So, cleaning of flat plate always beneficial in term of electrical gain.
- As the transmissivity of glass decreases from 1 to 0.5, the overall energy decreases 2.69 to 1.34 kWh/day i.e. 49.97% decrement compared to maximum output.
- If absorptivity of absorbing plate decrease from 1 to 0.5, the thermal energy and overall thermal energy decreased by 47.13 and 38.65 % respectively.
- Finally, it can be concluded that the maintenance and regular cleaning is very essential for PVT solar air collector. It can be seen without maintenance and regular cleaning leads to huge loss in term of electrical and thermal energy output.

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Nomenclature

A_c	Area of the crop surface (m^2)
A_{cf}	Opening area of fan (m^2)
A_{c1}	Cross-sectional area of duct of air collector (m^2)
A_m	Area of the PV module (m^2)
A_w	Area of side walls of dryer (m^2)
A_t	Area of the tray (m^2)
C_f	Specific heat of air (J/kg K)
C_{cr}	Specific heat of crop (J/kg K)
d	Diameter of DC fan (m)
E_{el}	Electrical energy (kWh)
hi	Heat transfer coefficient inside PVT air collector and solar drying system (W/m^{2}K)
h_{crr}	Total heat transfer coefficient from crop surface to drying chamber (W/m^{2}K)

h_{crc}	Convective heat transfer coefficient from crop surface to drying chamber (W/m^{2}K)
h_{crew}or h_{ew}	Evaporative heat transfer coefficient from crop surface to drying chamber (W/m^{2}K)
h_o	Heat transfer coefficient from top of module to ambient air (W/m^{2}K)
h_{pf}	Heat transfer coefficient from absorbing plate to working fluid (W/m^{2}K)
I_t	Solar intensity (W/m^2)
I_w	Total solar intensity on the walls of drying chamber (W/m^2)
K_g	Thermal conductivity of glazing (W/mK)
L_g	Thickness of the glass (m)
$\dot{M}_f$	Mass flow rate of working fluid (air) (kg/s)
M_{cr}	Mass of crop (kg)
P_{Tr}	Partial pressure at green house chamber temperature (N/m^2)
P_{Tcr}	Partial pressure at crop temperature (N/m^2)
T_a	Ambient temperature (^{0}C)
T_o	Cell temperature for optimum cell efficiency
T_c	Cell temperature (^{0}C)
T_{cr}	Crop temperature (^{0}C)
T_{cro}	Initial crop temperature (^{0}C)
T_r	Drying chamber temperature (^{0}C)
T_{foN}	Air temperature at outlet of Nth PVT air collector (^{0}C)
U_{bcf}	Heat transfer coefficient from bottom of module to working fluid (W/m^{2}K)
U_{tca}	Heat transfer coefficient from top of module to ambient air (W/m^{2}K)
U_{bpa}	Heat transfer coefficient from bottom of absorbing plate to ambient air (W/m^{2}K)
Q_{th}	Thermal energy (kWh)
$Q_{eq,th}$	Equivalent thermal energy (kWh)
$Q_{th,ex}$	Thermal exergy (kWh)
α_c	Absorptivity of solar cell
α_{cr}	Absorptivity of crop
β_0	Temperature dependent efficiency factor
β_c	Packing factor of module
γ	Relative humidity
η_0	Standard efficiency at standard condition
η_c	Solar cell efficiency
η_m	Module efficiency
η_{th}	Thermal efficiency
η_{el}	Electrical efficiency

$\eta_{eq,th}$	Equivalent thermal efficiency
η_{ex}	Exergy efficiency
$\eta_{eq,ex}$	Equivalent exergy efficiency
v	Wind velocity in ambient (m/s)
v_1	Air velocity in duct of air collector (m/s)
v_2	Air velocity from fan (m/s)
v_3	Air velocity in drying chamber (m/s)
τ_g	Transmittivity of glass