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Experimental Analysis of Glazed Solar Photovoltaic Thermal Air Collector

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Abstract: ***With the rapid depletion of fossil fuels, opportunities for renewable energy including solar energy are endless. The efficiency of photovoltaic cells to convert the solar energy into electricity drops with the rise in temperature due to increased resistance. Thus improving the Efficiency by lowering the Thermal Resistance and allowing the cooling fluid (Air/Water) to flow through Solar Photovoltaic Thermal (PVT) system is an attractive option. Climate condition based performance of any PVT system varies location wise and cannot be generalized. A Photovoltaic Thermal Collector is a Solar Collector that combines a Photovoltaic module with a Solar Thermal Collector, and which produces Electricity and Heat at the same time. Depending on the medium used for collecting Thermal energy, there are two types of PVT collectors: Air based and Water based. The integration of PV module and this decreases the Efficiency of PVT collectors, it is necessary to extract the heat in the form of hot or warm air from the PV module and thus decrease its temperature. The warm air extracted from the PVT collector can be utilized as a heat source for the building. In this study, an Air based Photovoltaic Thermal Air Collector with a Mono Crystalline Photovoltaic Module was designed for the Climatic Conditions of Bangalore, India and its Electrical and Thermal performance was analysed with the experimental results. The Climatic data of Bangalore for a period of 1 year (2016-2017) has been obtained from Indian Meteorological Department (IMD), Pune, India. Based on the Climatic data, the Experiment has been carried and the results indicated that the Thermal and Electrical Efficiencies of Photovoltaic Thermal Air Collector from the month of January to December were, on average 43% and 11% respectively. Graphs are drawn to evaluate the various effects of Temperature and Solar Radiation on tilted surfaces. Monthly and Hourly based graphs are drawn to evaluate the Temperatures and Solar Radiation. Monthly Analysis graph of Efficiencies is also drawn to evaluate Thermal, Electrical and Overall Efficiencies. The values calculated are put and shown as Tables in Appendix.***

Keywords: Air Based Photovoltaic Thermal Air Collector, Beam Radiation, Diffuse Radiation, Incident Solar Radiation, Electrical Efficiency, Thermal Efficiency, Overall Efficiency and Solar Energy.

1. Introduction

Since the industrial revolution in eighteenth century, energy has been one of the greatest challenges facing mankind. Fossil fuels such as coal, petroleum, and natural gas have been the main energy resources for everything vital for human society (transportation, electricity, lightning, heating of buildings, cooking, etc.). However, fossil fuel resources are being rapidly depleted by excess exploration, and once they run out they can't be replenished. Furthermore, fossil fuels are expensive to retrieve from the earth and to use them, and these fuels create massive pollution in the environment.

The promising alternative energy source is the sun, the most abundant energy resource available for human society. The total energy of solar radiation reaching the earth per year is approximately 5.46 x 1024 J. To have an idea of how much the sun energy is, it is enough to know that in the years 2005-2010, the annualglobal energy consumption was about 5 x 1020 J, Chen, (2011). That means 0.01 % of the annual solar energy reaching the earth can satisfy the energy needs of the entire world.

The major component of any solar system is the solar collector. Traditionally, devices intended for using solar energy fall into two main classes depending on the method of its conversion: either heat or electricity, like thermal collectors and photovoltaic modules respectively.

However, studies have been made to incorporate both the methods of energy conversion, the solar energy conversion in to electricity and heat with a single device called *hybrid photovoltaic thermal collector*. In this way, heat and power are produced simultaneously with a single device that can comply with both heat and electricity demands.

1.1 Photovoltaic Solar Thermal Collector

A photovoltaic-thermal solar collector is a module in which the photovoltaic module is not only producing electricity but also operates as a thermal absorber. In this way, heat and power are produced simultaneously with a single device that can comply with both heat and electricity demands. In fact, PV cells utilize only a fraction of the incident solar radiation to produce electricity and the remainder is turned mainly into heat, raising the temperature of PV as a result and decreasing the efficiency of the module. The photovoltaic-thermal technology recovers part of this heat and uses it for practical applications. The simultaneous cooling of the PV module maintains electrical efficiency at satisfactory level and thus the PVT collector offers a better way of utilizing solar energy with higher overall efficiency.

A typical hybrid PVT system is composed by a solar thermal collector in which a PV laminate is used as a thermal absorber. Different configurations of PVT collector can be created changing the cells density (packing factor) or the photovoltaic technology in order to balance electricity and thermal energy output of the system.

A classification of PVT systems based on various heat transfer techniques (water, air, bi-fluid, etc.) and integration of PVT systems in different possible infrastructures is presented in Fig. 1.6. The PVT systems can again be classified depending on various system parameters like absorber plate design and fluid flow systems like natural circulation, forced circulation, single pass, double pass and number of channels and so on.

Glazed Photovoltaic Thermal Collectorsare characterized by the presence of an air gap betweenthe transparent frontal cover and the absorber, which allows reducing heat losses. Anyway, the glass cover causes optical losses that reduce electrical efficiency, for the concurrent rise of cell temperature, but it improves the thermal performance of the PVT collector. This leads to a better global energy conversion per surface unit

Joshi and Tiwari (1) made a detailed analysis of energy and exergy efficiencies of a hybrid photovoltaic thermal (PV/T) air collector. They performed experiments for four climatic conditions of Srinagar, India and observed that an instantaneous energy and exergy efficiencies of a PV/T air heater varies between 55-65 and 12-15%

Jakhrani et al. (2) in their paper have experimented and estimated incident solar radiation on tilted surface by different emperical models. They have taken three isentropic and anisotropic sky models of Kuching, Sarawak, Malaysia and finally concluded Liu and Jordan method could be useful for prediction of solar energy irradiation on tilted surfaces.

LippinPauly et al. (3) has performed Numerical simulation for solar hybrid photovoltaic thermal air collector. The numerical simulation was done in commercial software ANSYS FLUENT 14.5.0. The results show a very good agreement between experimental and simulated result for outlet air temperature and PV cell temperature. In order to increase overall performance a novel design has been proposed which gives 20% enhancement in overall performance.

Kim et al. (4) have done experimental performance of a photo voltaic thermal air collector and the results indicated that the thermal and electrical efficiencies of PVT collector were on average 22% and about 15% respectively.

Debbarma et al. (5) has performed energy and exergy analysis of solar photovoltaic/ thermal hybrid air collector system. Inlet and outlet temperature of air, thermal, electrical and overall efficiencies of the system are measured under the meteriological conditions of Bhopal, M.P, India. It is found that the overall efficiency varies between 30-60% and the maximum exergy efficiency is 9.72%.

Singh et al. (6) have done analysis of different types of hybrid photovoltaic thermal air collectors. They have concluded that overall annual thermal energy, energy gain and exergy efficiency of unglazed PVT tiles air collector have been improved by 32%, 55.9% and 53% over conventional PVT air collector and carbon emission reduction of unglazed and glazed hybrid PVT tiles air collectors is 62.3% and 27.7%.

Sarma et al. (7) have done analysis on laminar convective heat transfer with twisted tape inserted in a tube. The eddy diffusivity expression of van Driest is modified to the case of the internal flows in a tube with twisted tapes. The present theoretical results are rendered in the form of correlation equation.

Sukhatme and Nayak (8) in their book gave explanations regarding the principles of thermal collectors and storage. They have clearly explained about the solar energy applications. They have also described about the classification of solar collectors with detailed explanation and application.

Tiwari and Dubey (9) in their book explained about the fundamentals of photovoltaic modules and their applications. They have also clearly described about the thermal modeling of Hybrid Photovoltaic Thermal systems.

Robert Hastings (10) in his book analyzed about the solar air systems. He has explained about the design of various air systems and applications of air systems. He had clearly mentioned about the functioning of air systems, Classification of Air systems, Advantages and Disadvantages of Air systems.

Sarma et al. (11) in their paper have done the Evaluation of Momentum and Thermal Eddy Diffusivities for Turbulent Flow in Tubes. The prediction of Nusselt numbers from the eddy diffusivity expression agree with Dittus Bolter heat transfer correlation. Thus the efficiency of the model is established for different correlations with a modification in the correction factor for mixing length.

Goh Li Jin et al. (12) in their paper have done evaluation of single pass photovoltaic thermal air collector with rectangle tunnel absorber. It describes that photovoltaic thermal collector with tunnel shows better performance in cooling, electrical and thermal efficiency. At mass flow rate of 0.0754 kg/sec, electrical efficiency can achieve 10.06% and thermal efficiency was 75.16%.

Nashine and Kishore (13) in their paper have done the Thermal Analysis of a Compound Parabolic Collector. In this thesis the performance analysis of a compound parabolic collector is evaluated. The performance evaluation of the system shows potential of improving the thermal efficiency upto 75%. From the obtained results, graphs are drawn to assess the performance of the compound parabolic collector.

Khelifa et al. (14) in their paper have done an energetic study of hybrid solar PV/T collectors. They have described that hybrid solar thermal (PV/T) offer an attractive option because the absorbed solar radiation is converted into heat and electricity. To stabilize the operating temperature, the simple solution is to cool the cell even though it requires a refrigeration system, power consumption, with which overall performance also low.

Vokas et al. (15) in their paper have studied the simulation of the hybrid photovoltaic/thermal air systems on building facades. A simulation method of using photovoltaic/thermal air system on the façade of a building complemented by conventional system is developed, aiming at covering the needs for warm water usage as well as the indoor central heating and air conditioning of the building.

Shaneb et al. (16) in their paper described about the performance evaluation of solar photovoltaic thermal air collector based on energy and exergy analysis. A computer simulation program has been developed and the results indicate that an increase of 52, 52.4 and 68.25% in the total system efficiency has been achieved from the corrugated duct, double pass design and finned duct respectively.

Revathi (17) estimated the Performance Evaluation of Solar Photovoltaic Thermal Air Collector. The experiment has been carried and the results indicated that the thermal and electrical efficiencies of photovoltaic thermal air collector were 43% and 11%.

2. Description and Working of Solar Photovoltaic Thermal Air Collector

A Solar Photovoltaic Thermal (PVT) Air Collector is a Solar Collector that combines a Photovoltaic module with a Solar Thermal and which produces Electricity and Heat simultaneously. A Photovoltaic Thermal (PVT) Air Collector takes Air as medium for collecting Thermal Energy.

The performance of a PVT air collector depends on climatic, operating and design parameters including ambient temperature, solar radiation intensity, wind speed, solar cell temperature, back surface temperature, inlet and outlet temperature , inlet air velocity, length and width of PVT air collector.

Air as a fluid can be flown either above or below the PV module; one can get hot air in addition to enhanced electrical output. Hot air has also many applications such as solar crop drying and space heating.

The working principle of PVT Air Collectors can be explained as follows: There is an air duct with a proper channel below the PV module. There is an overall heat transfer from the solar cell of the PV module which flows air through tedlar, which is used to heat the flowing air with a mass flow rate and specific heat of air. Once the temperature of the flowing air is increased, there is also a rate of overall heat loss from flowing air toambient air through bottom insulation. Hence it is important to mention that there is an indirect gain of thermal energy to the flowing air.

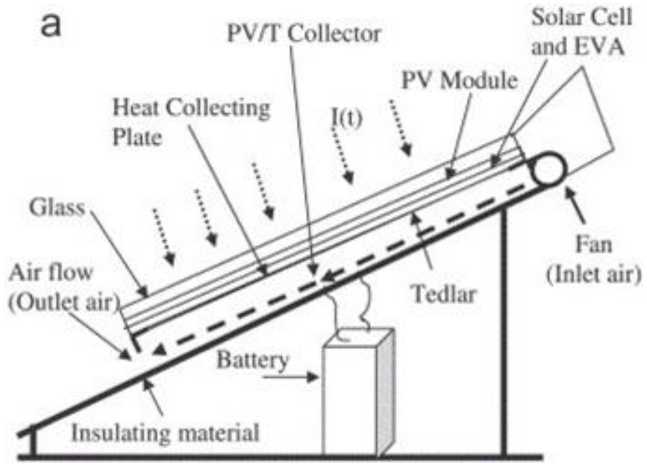

Figure 1: Schematic diagram of PV/T system when air is used as a medium to collect thermal insulation

Fig 1 shows the Schematic Diagram of a PV/T air collector. Air has been considered as the medium for transport of thermal energy. Two PV modules with an effective area of 0.61 m^2 each are connected in series. The module has been mounted on a wooden structure with the air duct below the module known as Tedlar. In other words Tedlar is an Insulating and Non- Corrosive material used beneath the Solar Cell for better support to PV module. There is a provision for Inlet and Outlet Air flow through the duct. The PV module with a wooden structure is placed on a steel frame. The design parameters of Hybrid Photovoltaic Thermal System is given in Table 1.

The Outlet temperature, Back Surface Temperature, Cell Temperature are calculated by Energy Balance Equations of Photovoltaic Thermal System.

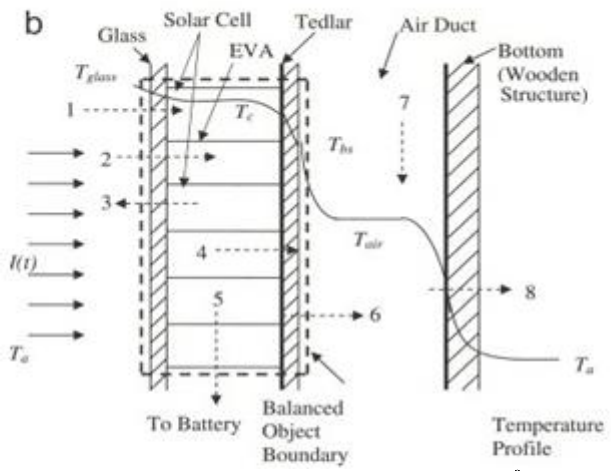

Figure 2: Cross sectional view (rotated at 90^0 from horizontal) of hybrid PV/T air collector with temperature profile

A rectangular block with length “L” and width “b” is considered and direction of flow of air is from the top of the rectangle with a mass of air m_a. If we consider an element in the midpoint it has a length of “dx” which shows the flow pattern of air below the tedlar.

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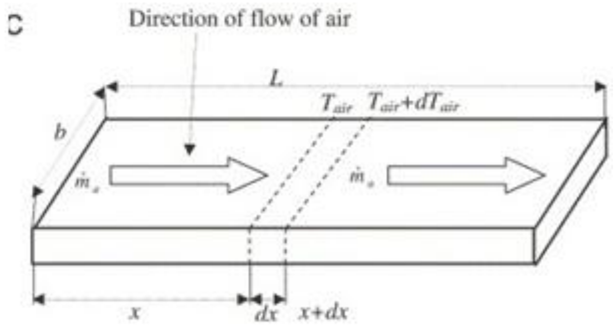

Figure 3: An elemental length "dx" shows flow pattern of air below tedlar

Components of Solar Photovoltaic Thermal Air Collector

The components of PV/T air collectors are as follows:
- Glass cover
- PV module
- Solar cell and EVA (Ethyl Vinyl Acetate)
- Absorber plate (Heat Collecting plate)
- Tedlar with PV/T collector
- Insulating materials
- Battery
- Fan for inlet air

Glass Cover

Double glazing, or double-pane, consist of two glass panels fixed together through a structural framework of thermal spacers, generally attached with a layer of butyl and desiccant with silicon sealing is used in this experiment.

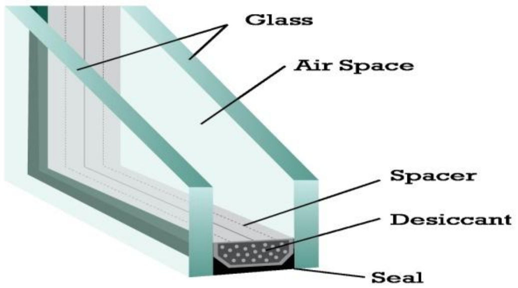

Figure 4: Double glazed glass made with butyl and desiccant with silicon sealing

Photovoltaic Module

For both thermal and electrical reasons, mono-crystalline silicon cell PV module has been chosen. In particular, *Siemens SP75* PV modules are used. Length and width of PV module is 1.2m and 0.51m and with an effective area of about 0.61 m^2.

Solar Cell (Photovoltaic Cell)

For this hybrid collector, a single string of 60 cells are connected from bottom to top in series.

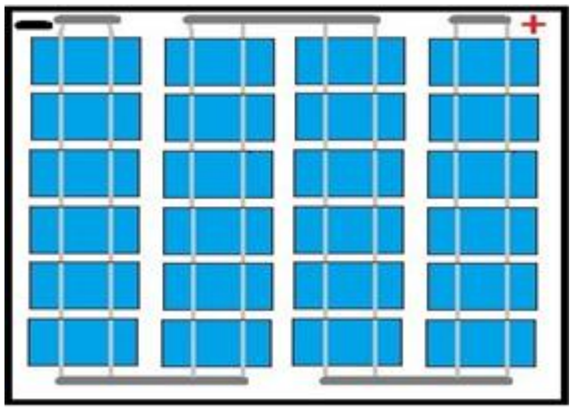

Figure 5: A single string of 60 cells connected in series

EVA (Ethyl Vinyl Acetate) Lamination

Ethylene vinyl acetate is encapsulate most largely adoptedin photovoltaic modules. Some researches demonstrated that this method is also feasible for hybrid collectors. PV cells are poised between two layer of EVA, with cover glass on top and metal absorber on bottom. Lamination is carried out at high temperature and pressure to allow the polymerization reaction of EVA.

Absorber Plate

The design of the aluminium roll-bond absorber plate is adopted for thishybrid collector.

Figure 6: Roll Bond Absorber Plate

Tedlar with Photovoltaic Thermal Collector

Tedlar is an insulating and non-corrosive material used beneath the solar cell for better support to PV module. Tedlar is made by poly vinyl fluoride (PVF) a polymer material usually used for PV/T collectors.

Insulating Material

PUR (Polyurethane) insulating material is used in this collector due to its properties: very low thermal conductivity, low absorption of liquids, low vapour permeability.

3. Analysis of Solar Photovoltaic Thermal Air Collector

The Energy Analysis is performed. To determine Temperature of Components of Photovoltaic Thermal, an Energy Balance Equation should be written for each component. The following Assumptions are considered in order to write Energy Balance:
1) The System is in the Quasi-Steady State Condition.
2) One-dimensional Heat Conduction is considered.

3) The Temperature variation along the Thickness of Component is neglected.
4) The Air Flow through Air Duct is in forced mode.
5) The Transmissivity of Ethylene-Vinyl Acryl ate material (EVA) is nearly 100%.
6) The heat capacity of the components except for theair, are neglected.

Equations of Solar Irradiation

Declination Angle:

$$\delta = 23.45\, Sin\left(\frac{365(284+n)}{365}\right) \quad ......1$$

δ= Declination angle (degrees)
n= Day of the year i.e. n=1 for Jan 31st and n=365 for Dec 1st

Hour Angle:

$$\omega_s = Cos^{-1}(-tan\varphi tan\delta) \quad ....2$$

Φ= Latitude (degrees)
ω_s= Hour angle (degrees)
δ= Declination angle (degrees)

Extra Terrestrial Solar Radiation:

$$H_o = \frac{24\times 3600}{\pi} G_{sc}\left[1+0.33Cos\left(\frac{360n}{365}\right)\right]$$
$$[Cos\varphi\, Cos\delta\, Sin\omega_s + Sin\varphi\, Sin\delta\, \omega_s] \quad ......3$$

H_o= Extra Terrestrial solar radiation
G_{sc}= Solar constant = 1367 W/m^2

Incident Solar Radiation on Tilted Surface:

$$H_T = H_{T,b} + H_{T,r} + H_{T,d} \quad .....4$$

H_T = Monthly total incident solar radiation on tilted surface
$H_{T,b}$= Beam radiation on tilted surface
$H_{T,r}$ = Ground reflected radiation
$H_{T,d}$ = Diffuse radiation on tilted surface

Beam Radiation on Tilted Surface:

$$H_{T,b} = H_b R_b \quad ......5$$

$$H_b = (H - H_d)R_b \quad ......6$$

H_b = Beam radiation on horizontal surface
R_b = Ratio of mean beam radiation on tilted surface to horizontal surface

$$R_b = \frac{Cos(\varphi-\beta)Cos\delta\, Sin\omega_s^1 + \left(\frac{\pi}{180}\right)\omega_s^1\, Sin\,(\varphi-\beta)Sin\delta}{Cos\varphi\, Cos\delta\, Sin\omega_s + \left(\frac{\pi}{180}\right)\omega_s\, Sin\varphi\, Sin\delta} \quad ...7$$

ω_s^1 =Sunset angle on tilted surface

Sunset Angle on Tilted Surface

$$\omega_s^1 = min\begin{Bmatrix} Cos^{-1}(-tan\varphi\, tan\delta) \\ Cos^{-1}(-tan\,(\varphi-\beta)tan\delta) \end{Bmatrix} \quad ......8$$

Diffuse Radiation on Tilted Surface:

$$H_{T,d} = H_d\left[\frac{1+Cos\beta}{2}\right] \quad ......9$$

H_d = Diffuse radiation on horizontal surface

Ground Reflected Radiation on Tilted Surface:

$$H_{T,r} = H\,\rho_g\left(\frac{1-Cos\beta}{2}\right) \quad ......10$$

H = Monthly mean daily global radiation
ρ_g = Albedo factor = 0.2

Temperature Analysis of Photovoltaic Thermal Air Collector:

Cell Temperature:

$$T_c = 30 + 0.0175(H_T\text{-}300) + 1.14(T_a - 25) \quad ....11$$

T_a= Ambient temperature

Bottom Loss Coefficient:

$$U_b = \frac{k_{ins}}{\delta_{ins}} \quad ......12$$

k_{ins} = Thermal conductivity of insulation = 0.035 W/mk
δ_{ins} = Thickness of insulation = 0.05 m

Wind Convective Factor:

$$h_w = 2.8 + 3V_w \quad ......13$$

H_w= Wind convective factor
V_w = Velocity of air = 1 m/s

Conductive Heat Transfer through Tedlar:

$$U_T = \frac{k_t}{\delta_t} \quad ......14$$

k_t = Thermal conductivity of tedlar
δ_t = Thickness of tedlar

Overall Heat Transfer Coefficient between Solar Cell to Ambient Through Glass Cover:

$$U_t = \left[\frac{L_G}{k_G} + \frac{1}{h_o}\right]^{-1} \quad ......15$$

$$h_o = 5.7 + 3.8V_w$$

L_G = Length of glass cover
k_G = Thermal conductivity of glass cover
h_o = Wind transfer coefficient of glass cover

Penalty Factor Due To Glass of a Photovoltaic Module:

$$h_{p_1} = \frac{U_T}{U_t + U_T} \quad ......16$$

U_T = Conductive heat transfer through tedlar
U_t = Overall heat transfer coefficient between solar cell to ambient through glass cover

Overall Heat Transfer Coefficient from Glass to Tedlar through Solar Cell:

$$U_{tT} = \frac{U_T U_t}{U_T + U_t} \quad ......17$$

Penalty Factor Due To Tedlar of a Photovoltaic Module:

$$h_{p_2} = \frac{h_i}{U_{tT} + h_i} \quad ......18$$

$$h_i = 2.8 + 3V_w$$

h_i = Wind transfer coeeficient of tedlar

Overall Heat Transfer Coefficient from Glass to Ambient:

$$U_{t_{air}} = \left[\frac{1}{U_{tT}} + \frac{1}{h_t}\right]^{-1} \quad ......19$$

h_t = Convective heat transfer coefficient from tedlar back surface to working fluid

Overall Heat Transfer Coefficient from Solar Cell to Ambient Through Top and Back Surface Of Insulation:

$$U_L = U_{tair} + U_b \qquad ......20$$

U_b = Bottom loss coefficient

Back Surface Temperature:

$$T_{bs} = \frac{T_c(U_T + U_t) - (\alpha\tau)_{eff}\, I(t) - U_t T_a}{U_T} \qquad ......21$$

Convective Heat Transfer Coefficient Can be calculated by Back Surface Temperature

$$h_t = \frac{T_{bs}(U_{tT} + h_i) - h_{p_1}(\alpha\tau)_{eff} I(t) - U_t T_a}{T_f} \qquad ......22$$

Plate Temperature

$$T_p = \frac{(\alpha\tau)_{eff} I(t) + h_{p_1}(\alpha\tau)_{eff} I(t) + U_L T_a + h_{p,f} T_f}{U_L + h_{p,f}} \qquad ...23$$

$h_{p,f}$ = Heat transfer coefficient from plate to air cavities i.e. flowing fluid

$$h_{p,f} = Nu \times \frac{k}{d_e}$$

By Dittus Bolter Equation

$$Nu = 0.023 \times (Re)^{0.8} \times (Pr)^{0.4}$$

$$R_e = \frac{Vd_e}{\vartheta},\ d_e = \frac{4A_{ch}}{P}$$

Glass Temperature:

$$T_g = T_a + h_W^{0.42}\left[0.621\,\varepsilon_p + \frac{T_p}{505} - 0.27\right](T_p - T_a) \cdots\cdots 24$$

ε_p = Emissivity of plate = 0.95

Convection Heat Transfer Coefficient:

a) Free Convection heat transfer between PV panels and Glass covers

$$h_c^1 = \frac{k}{s}\{1 + 1.44[1 - R](1 - R(Sin\ 1.8\theta)^{1.6}) + [0.66416R^{1/3} - 1] \qquad .....25$$

$$R = \frac{1708}{R_{a_s}\ Cos\theta};\ R_{a_s} = \frac{L^3\, g\ Sin\theta\ \beta\ \Delta T}{\vartheta . \alpha}$$

ΔT = Temperature difference between PV panel and glass temperature

b) Natural Convection heat transfer coefficient between air flow and PV panels or tedlar

$$h_c = \frac{k}{d_e}(0.0965 R_{a_s}{}^{0.29}) \ ......26$$

Radiation Heat Transfer Coefficient

(a) Radiative heat transfer coefficient between glass cover and sky

$$h_{r,g-s} = \sigma\, \varepsilon_g \frac{T_g^4 - T_s^4}{T_g - T_a} \qquad ......27$$

$$T_{sky} = 0.0552 T_a^{1.5}$$

Efficiencies of Photovoltaic Thermal Air Collector

Electrical Efficiency

$$\eta_{el} = \eta_{ref}\left(1 - \beta_{ref}(T_c - T_{ref})\right) \quad ......28$$

η_{ref} = Panel efficiency at reference temperature T_{ref} = 0.125
β_{ref} = Temperature coefficient of solar cell efficiency= 0.006 K^{-1}
T_{ref}= Reference temperature = 25^0C

Thermal Efficiency

$$\eta_{th} = \frac{Q_u}{A_{pvt} H_T} \qquad ......29$$

$$Q_u = m C_p (T_{out} - T_{in})$$

Q_u = Rate of useful energy transfer
m = mass flow rate of air
C_P= Specific heat capacity
A_{pvt}= Area of the PV module
T_{out} = Outlet temperature
T_{in} = Inlet temperature

Overall Efficiency:

$$\eta_{ov} = \eta_{th} + \eta_{el} \qquad ......30$$

η_{th} = Thermal efficiency
η_{el}= Electrical efficiency

4. Results and Discussions

The Temperatures of a Photovoltaic Thermal Air Collector for the Climatic Conditions of Bangalore are obtained from energy balance equations (Chapter-4)

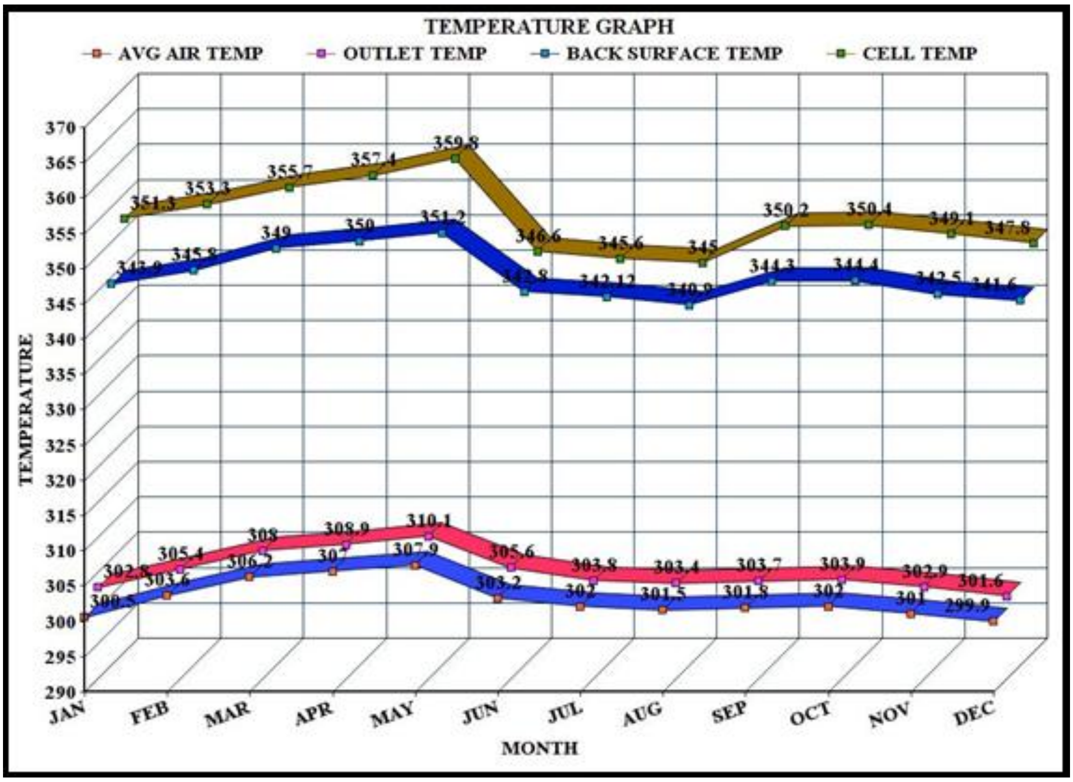

Figure 7: Monthly Analysis of Temperature's for Climatic Conditions of Bangalore from Jan to Dec

The above fig 7 describes about the Monthly Variation of Average Air Temperature, Outlet Temperature, Back Surface Temperature and Cell Temperature for a typical day from January to December for the Climatic Conditions of Bangalore.

The Monthly Temperature Analysis shows that the results obtained in the month of May is maximum (309.3K for Average Air Temperature, 310.1K for Outlet Temperature,351.2K for Back Surface Temperature and 359.8K for Cell Temperature respectively) and is minimum in the Month of December (299.9K, 301.6K, 340.6K, 344.8K respectively).

The Average Air Temperature is slightly lower than Outlet Air Temperature. The Cell Temperature and Back Surface Temperature are significantly higher than Outlet Air Temperature. The Outlet Air Temperature can be further increased by reducing flow velocity of air in duct.

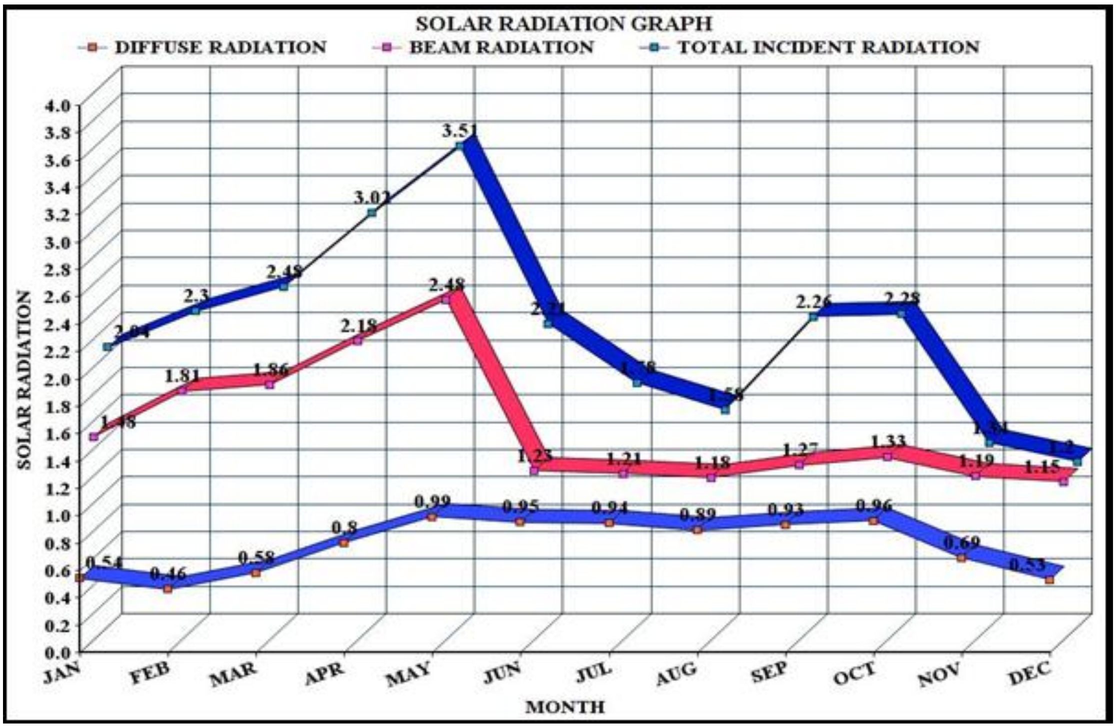

Figure 8: Monthly Analysis of Solar Radiation for the Climatic Conditions of Bangalore from Jan to Dec

The above figure 8 describes the variation of Solar Radiation for the Climatic Conditions of Bangalore from the month of January to December. The Solar Radiation is generally measured in MJ/m^2 or W/m^2

The figure gives the values of Beam Radiation, Diffuse Radiation and Total Incident Solar Radiation on a Tilted Surface. The Total Incident Solar Radiation is calculated by Liu Jordan Method (Chapter-4)

The zig-zag graph shows that there is a maximum Solar Radiation in the month of May ($0.98 MJ/m^2$, $2.58 MJ/m^2$ and $3.51 MJ/m^2$ respectively) and a minimum Solar Radiation is observed in the month of December (0.53, 1.15, 1.2 MJ/m^2 respectively)

The Diffuse Radiation is less than the Beam Radiation on a Tilted Surface and the Total Incident Solar Radiation is higher than beam and Diffuse Radiation. The Beam and Diffuse Radiation varies with latitude and climatic conditions of the region.

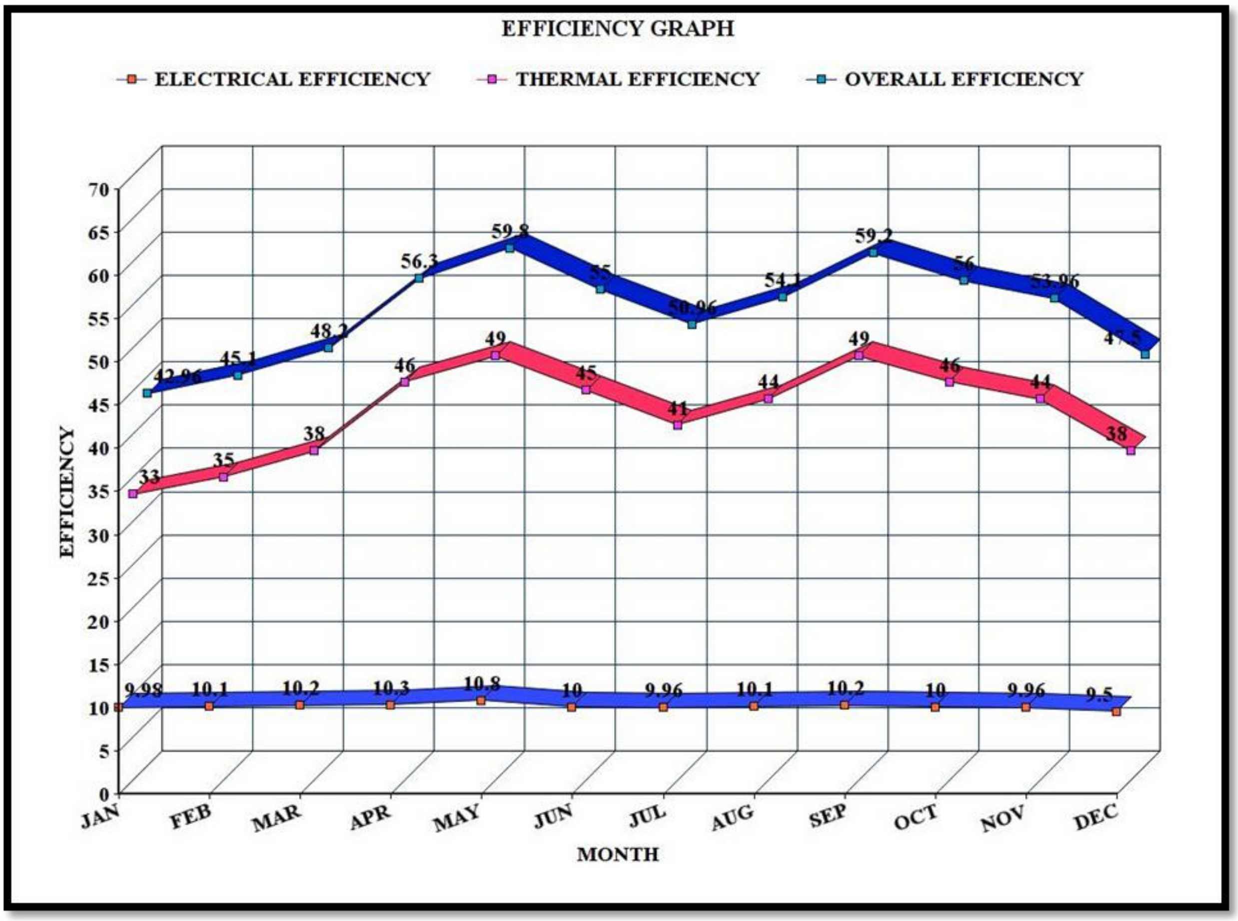

Figure 9: Monthly Analysis of Efficiencies for the Climatic Conditions of Bangalore from the Month of Jan to Dec

The above figure 9 shows the variation of Electrical, Thermal and Overall Efficiencies of a Photovoltaic Thermal Air Collector for the Climatic Conditions of Bangalore.

The Electrical Efficiency varies between 9%-11% and the Thermal Efficiency varies between 30%-50%. There is a variation of Overall Efficiency from 40%-60% respectively.

By previous calculations and analysis it is clearly shown that the Maximum Efficiency is obtained in the month of May and Minimum Efficiency is obtained in the month of December.

Due to Glass Cover there is a slight decrease in the Electrical Efficiency but placement of Glass Cover increases the Thermal Efficiency of the system.

The values obtained above are calculated for a particular day from morning 9 AM to evening 5 PM for the climatic conditions of Bangalore from the month of Jan to Dec.

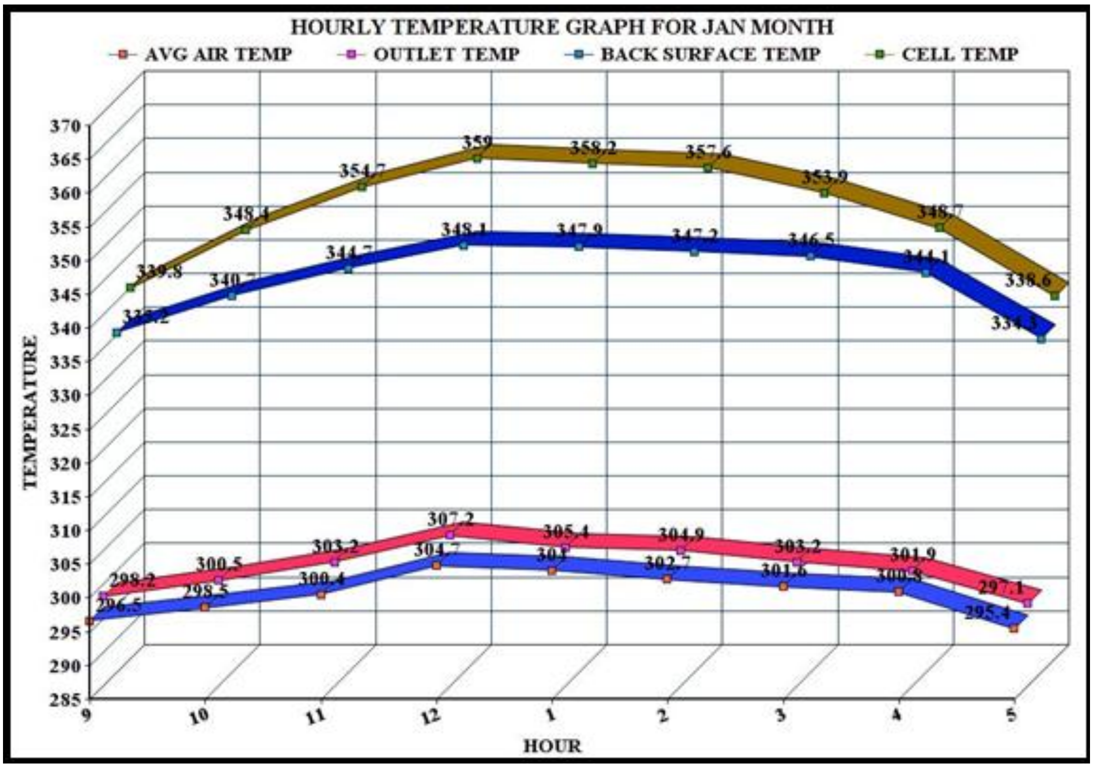

Figure 10: Hourly Analysis of Temperatures from 9 Am to 5 Pm for the Month of January for Bangalore

The above figure 10 gives the Hourly Variation of Average Air Temperature, Outlet Temperature, Back Surface Temperature and Cell Temperature from 9 AM to 5 PM on a typical day in the month of January.

It is clearly seen that the Maximum Temperature values are obtained at 12 PM and Minimum Temperature values are obtained at 5 PM.

The Maximum Temperatures obtained at 12 PM are 304.7K for Average Air Temperature, 307.2K for Outlet Temperature, 348.1K for Back Surface and 359K for Cell Temperature respectively.

The Minimum Temperatures obtained at 5 PM are 295.4K, 297.1K, 334.3K and 338.9K respectively.

The Hourly Analysis of Beam Radiation, Diffuse Radiation and Total Incident Radiation is calculated from 9 AM to 5 PM on a typical day for the Climatic Conditions of Bangalore.

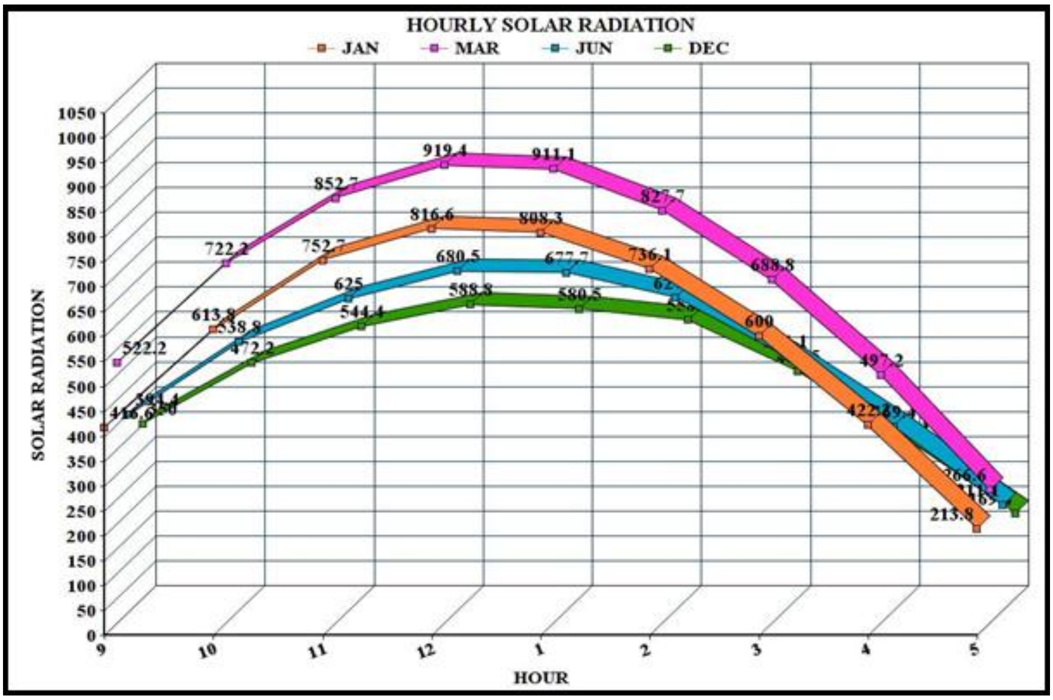

Figure 11: Hourly Analysis of Total Incident Radiation from 9 Am To 5 Pm for the Months of Jan, Mar, June and Dec.

The above figure 6.5 shows the Hourly Analysis of Total Incident Radiation from 9 AM to 5 PM on a typical day for the months of January, March, June and December for Climatic Conditions of Bangalore.

The Total Incident Radiation varies from a Minimum value of 211.1 W/m^2 at 5 PM to a Maximum value of 816.6 W/m^2 at 12 PM for the month of January. It varies from a Minimum value of 266.6 W/m^2 at 5PM to a Maximum value of 919.4 W/m^2 at 12 PM for the month of March where as for the month of June and December the Maximum values obtained at 12 PM are 588.8 W/m^2 and 680.5 W/m^2 respectively. The Minimum values obtained at 5 PM for the months of June and December is 213.8 W/m^2 and 169.4 W/m^2 respectively.

The Solar Radiation for the month of March is higher than the obtained values for the month of January, June and December. The similar calculations were carried out for each month and the results are shown in appendix.

5. Conclusions

The following conclusions are obtained from the Performance Evaluation of Solar Photovoltaic Thermal Air Collector:

1) The Thermal Efficiency of Solar Photovoltaic Thermal Air Collector for the month of January is recorded as 33% and that of May is 49%. The Thermal Efficiency in the month of December is recorded as 38%. There is a substantial amount of increase in Thermal Efficiency from January to May and there is a decrease from the month of June to December. The Maximum Thermal Efficiency occurs in the month of May as it has more clear days when compared to other months. Hence, the Thermal Efficiency of Solar Photovoltaic Thermal Air Collector varies between 30%-50% respectively.
2) The Electrical Efficiency of Solar Photovoltaic Thermal Air Collector also increases from the month of January till May and decreases from the month of June to December. The Electrical Efficiency for the month of January is 9.98% and for the month of May is 10.8%. For the month of December it is 9.5% which is the minimum of all months. Due to Temperature raising of Photovoltaic Cells and Glass Cover effect the Electrical Efficiency is low which varies between 9%-11% respectively.
3) The Overall Efficiency of Solar Photovoltaic Air Collector depends on the Thermal Efficiency and Electrical Efficiency. The Overall Efficiency also increases from January to May. The Overall Efficiency for the month of May is 59.8% which is the maximum value attained. The minimum Overall Efficiency is 42.98% for the month of January. Hence, the Overall Efficiency varies between 40%-60% respectively.
4) It is observed that there is a significant increase in Outlet Air Temperature which gives additional thermal energy for both winter and summer climatic conditions. The Average Air Temperature is slightly lower than Outlet Air Temperature. The Cell Temperature and Back Surface Temperature are significantly higher than Outlet Temperature due to flow velocity of air in the duct.
5) By increasing Cell Temperature, the Outlet Air and Back Surface Temperature of the module increases.
6) The Thermal Efficiency is more impressive than the Electrical Efficiency in calculating Overall Efficiency. The greenhouse effect is effective on increasing the temperature of Solar Cell.
7) With locating Glass Cover, the PV contact with the environment is cut and rate of heat transfer from the top surface of PV decreases but the Thermal Efficiency increases with Glass Cover as the glass cover reduces the convective and radiative losses and transmits the Incident Solar Radiation to the absorber plate with minimum loss thus increasing the Thermal Efficiency.

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