Analysis of Mean Plate Temperature of Flat Plates in Ordinary and PVT Setup

Muhsin Ahmad Khan[1], J. P. Kesari[2]

[1, 2] Department of Mechanical Engineering, Delhi Technological University

Abstract: *A comparative study was performed to analyze the behavior of a flat plate setup in a solar PV module. This technology is termed as Solar PVT or Solar hybrid thermal photovoltaic. The behavior of solar PVT module was compared with an ordinary water heating flat plate system. Under ordinary conditions, flat plate in an ordinary setup is able to achieve temperatures of 90100 degrees celcius. Since the amount of heat transfer depends upon the difference in temperatures, mean plate temperature is an important criteria that determines the performance of a solar heat exchanger. Therefore, this study focused on calculating mean plate temperatures of a flat plate in ordinary setup and a PVT setup under the same heat flux. Heat flux was calculated for 6th May, 2021 in New Delhi under clear sky conditions.*

Keywords: Solar Flate Plate collector, Solar PVT, Mean Plate Temperature

1. Introduction

A solar flat plate collector can be thought of as a modified heat exchanger. An ordinary heat exchanger usually involves heat transfer occurring between from fluid to fluid. A solar collector on the other hand involves heat transfer which is significantly affected by radiation. They can be used for domestic and industrial purposes [1]. Solar collectors capture the heat from incident solar radiations which is in turn absorbed by the collector plate. The absorbed heat is then transferred to the fluid to be heated via conduction. Solar collectors can be classified into two general categories: Non - concentrating solar collectors and Concentrating solar collectors. In the nonconcentrating solar type, the collector aperture area (i. e. the area that intercepts the solar radiation) is the same as the absorber area (i. e. the area absorbing the radiation). For temperatures below 100oC, flat - plate collectors of the non - concentrating type are generally used. Solar flat - plate collectors are usually used for small call water and space - heating applications at residential or for small scale businesses. A typical set up consists of an insulated metal box. The box is sealed with glass or plastic sheet because of their transparency, which allows radiation to pass through. The sheet also prevents heat captured from radiation to escape into this atmosphere. One of the drawbacks of this technology is the slow rate of heat transfer. However, advancements in material technology can help in development of materials that can contribute to enhanced conduction and better absorption. Ultimately, accurate prediction of thermal performance is essential to a good collector design [2].

A major disadvantage of solar flat plate collectors is the amount of space these devices occupy. Numerous solutions have been proposed to tackle this issue. One such solution is incorporating flat plate mechanism in a solar PV module. During the regular operation of a solar PV module, solar cells can reach up to a temperature of 50 - 65 degrees Celsius. These high operating temperatures in solar PV panels are known to cause a drop in their efficiencies. It is therefore an implication that this temperature should be monitored closely and regulated if needed so. By incorporating a flat plate system to the backplate of a solar PV model, the overheating situation can be mitigated. This setup is called a solar PVT (photovoltaic thermal) module. This setup enables the generation of electricity and useful heat transfer simultaneously [3]. This paper will however only discuss the viability of the set - up by determining the mean flat plate temperatures in both the models, i.e. ordinary flat collector model and flat plate in solar PV module.

2. Construction and Working

2.1 Flat Plate Collector

A flat plate collector consists of the following parts -
1) Transparent covers - usually glass sheets that are used to seal the metal box. It is usually fitted with a rubber gasket in such a way that is surrounds the glass plate to keep it in place and make a good seal with the frame, though some collectors use silicon caulking.
2) Collector plate - are plates usually made out of materials with high absorptance usually metals such as copper and aluminium and the most important part of the solar water heating system [4]. Sometimes there is a significant loss of energy due to reflective nature of the collector plate. In order to reduce this, the plates are usually painted black in colour. These plates are responsible for absorbing heat which has been trapped by the glass cover. This heat absorbed is then transmitted to the liquid to be heated.
3) Insulation - is the packing placed below the pipes containing the fluid to be heated. The packing is usually made of insulators to avoid heat losses due to convection.
4) Frame - is a crucial component which holds all the other components of the system together. It also prevents heat losses. Materials used for making frame should have low thermal conductivity and a high melting point.

Table 1: Box Specifications

Box Dimensions	1750*650*120
Glazing Thickness	5mm
Collector Thickness	25mm
Insulate Thickness	20mm
Box Thickness	20mm
Plate to Cover SPacing	45mm

2.2 Solar PV Module with Flat Plate Setup

1) Glass - it is glass plate which is provided to allow the sunlight to pass through as well as protect the photovoltaic cells from damaging factors.
2) EVA encapsulate (Ethylene - Vinyl Acetate) - it a polymer that has goof thermal conductivity. In a PV module, the EVA sheet behaves like encapsulate. The main urpose of using EVA sheets is to offer sealing.
3) PV cells - they are the working units of a PV module which convert solar radiations into electricity.
4) EVA encapsulant (Ethylene - Vinyl Acetate)
5) Backsheet - Like the EVA it is also a polymer layer that offers electrical insulation and also protects the solar PV cells.

In this model, the flat plate has been coupled with the backsheet of a solar panel. Following the flat plate. An insulation has been provided to prevent the loss of heat.

Table 2: PVT model specifications

Box Dimensions	352*297*10.31
Thickness of glass	1.5mm
Thickness of encapsulants 1 and 2	0.5mm
Solar cells	0.129mm
Thickness of blacksheet	1.5mm
Collector and Insulate	4.21mm and 1.2mm

Solar Calculations

All calculations have been done according to the equations provided in "Solar Engineering of Thermal Processes by Duffie & Beckman" [5].

1) Declination

$$\delta = 23.45 \times \sin\left(\frac{360(284 + n)}{365}\right)$$

Where, 'n' is the average day of month.

2) Calculation of Zenith Angle

$\cos(\theta_z) = (\cos(\phi)\cos(\delta)\cos(\omega) + \sin(\phi)\sin(\delta)$
Where, ϕ, δ, ω are latitude angle, declination and hour angle respectively.

3) Atmospheric Transmittance

$$\tau_b = a_0 + a_1 + exp(\frac{-k}{cos\theta_z})$$

Where a_0, a_1 & $-k$ are standard values for 23 km visibility. They have been derived from the following equations-
$a_{0*} = 0.4237 - 0.00821(6 - A)^2$
$a_{1*} = 0.5055 + 0.00595(6.5 - A)^2$
$k_* = 0.2711 + 0.01858(2.5 - A)^2$

4) Calculation of Horizontal Radiation

$$Gcnb = Gon\tau b$$
$$G_{cb} = G_{on}\tau_b\cos(\theta_z)$$

Where G_{on}, G_{cb}, & G_{cnb} are the extraterrestrial radiation incident on the plane normal to the radiation on the nth day of the year, horizontal component and beam radiation respectively. Final values are obtained as follows-

Table 3: Heat flux calculations

ω (deg)	ω (RAD)	COS (ω)	COS (θ)	τ	G_{cnb} (W/m^2)	G_{cb} (W/m2)
- 90	- 1.5708	0	0.135214671	0.190370582	255.3992697	34.53372828
- 75	- 1.309	0.258819045	0.353179115	0.398064831	534.0397967	188.611703
- 60	- 1.0472	0.5	0.556289643	0.518093278	695.0687604	386.6595527
- 45	- 0.7854	0.707106781	0.730704607	0.583295692	782.5436676	571.8082633
- 30	- 0.5236	0.866025404	0.864537916	0.619569951	831.208851	718.611568
- 15	- 0.2618	0.965925826	0.948669051	0.638196619	856.1982023	812.2487365
0	0	1	0.977364615	0.643958569	863.9283764	844.3730249
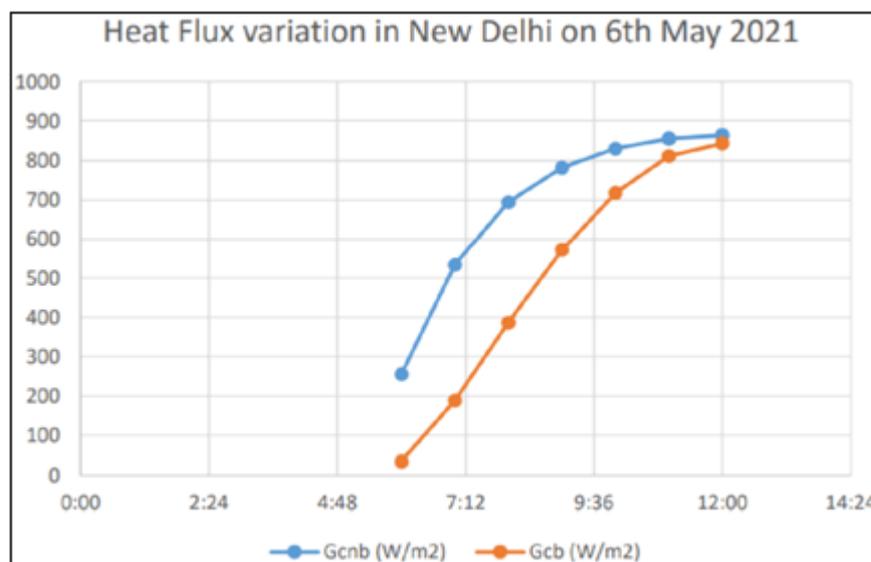
Values were calculated by programming the equations discussed in the previous slides on Microsoft Excel

3. Research Methodology

1) Planning the Analysis - it is the most important part of any analysis. The objective is to model the behavior of a structure under a system of thermal loads. In order to do so, all factors which influence the behavior of the system must be considered.
2) Pre - Processor - preprocessor stage involves specifying the name of the problem and setting up the type of analysis which is going to be used. This is very useful, especially if a number of design iterations are to be completed on the same base model.
3) Creating the model - The model is constructed on the most suitable platform. In this study, the models were developed on ANSYS SpaceClaim. The same units should be applied in all directions, otherwise results will be difficult to interpret.
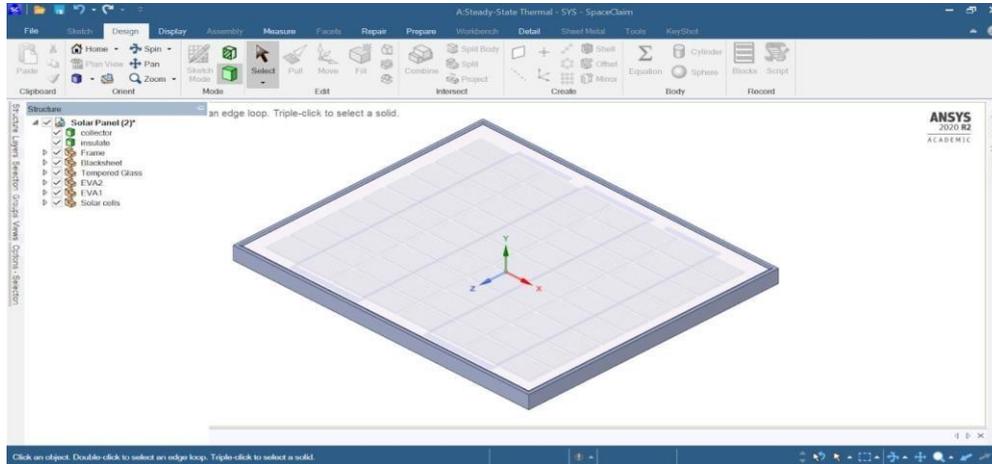

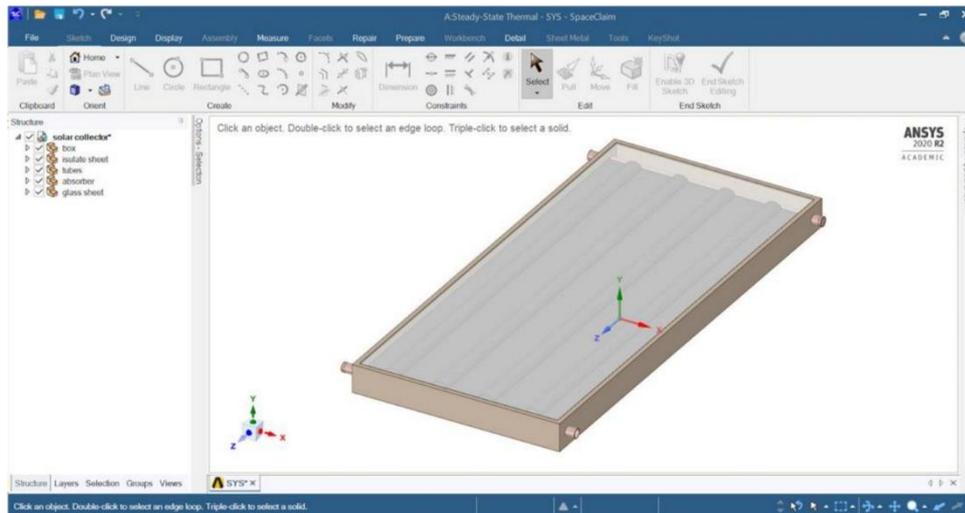**Figure 1:** Model of the Solar PVT Setup

Figure 2: Solid Model of Flat Plate collector modeled on ANSYS SpaceClaim

4) Applying a Mesh - mesh generation is the process of dividing the specimen into number of finite elements. Better results are obtained by using fine mesh. The mesh can be created manually or automatically.
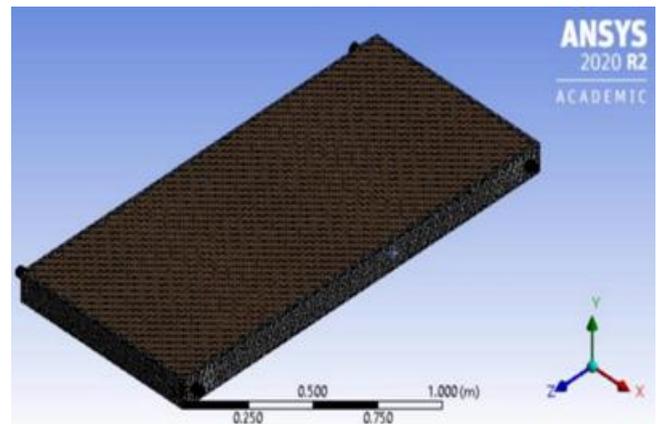

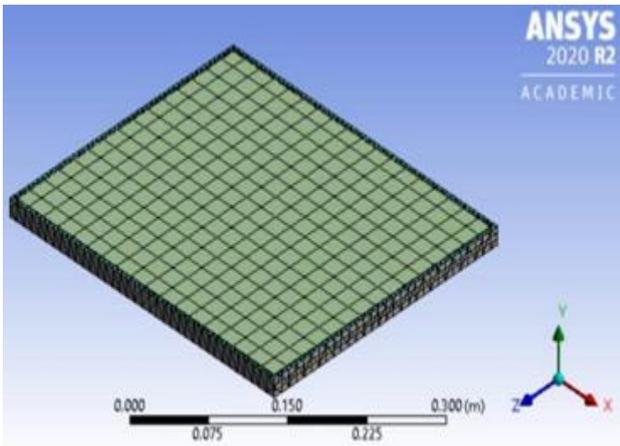**Figure 3:** Meshed model of the ordinary flat plate setup

Figure 4: Meshed model of PVT setup

Table 4: Material assignment for PV setup

Material	K $(\frac{W}{m.K})$	ρ $(\frac{Kg}{m^3})$	C_p $(\frac{J}{kg.K})$
Glass	1.8	3000	500
EVA	0.35	960	2090
PV	148	2330	677
PVF	0.2	1200	1250
Neoprene Rubber	0.19	1230	2200

5) Assigning Material properties - Young's modulus, Poisson's ratio, density etc. will have to be defined. In addition element properties may need to be set. If 2D elements are being used, the thickness property is required.

Table 5: Material assignment for flat plate setup

Material	K $(\frac{W}{m.K})$	ρ $(\frac{Kg}{m^3})$	C_p $(\frac{J}{kg.K})$
Glass	1.8	3000	500
Wood (Frame)	0.12	577	1.76
Steel (Plate)	54	7750	504
Copper (Pipe)	413	8960	1250
Neoprene Rubber (insulation)	0.19	1230	2200

6) Apply Loads. The loading may be in the form of a point load, a pressure or a displacement in a stress (displacement) analysis etc. The loads may be applied to a point, on an edge or a surface or a complete body. In this case, calculated values of heat flux was applied on the models.

7) Applying Boundary Conditions - If you apply a load to the model, then in order to stop it accelerating infinitely through the computer's virtual ether (mathematically known as a zero pivot), at least one constraint or boundary condition must be applied. Structural boundary conditions are usually in the form of zero displacements, specified temperatures or pressures etc. Boundary conditions can either be applied in specific directions or in all directions. They can be placed on nodes, key points, areas or on lines. BC's on lines can be of symmetric or antisymmetric type, one allowing in plane rotations and out of plane translations, the other allowing in plane translations and out of plane rotations for a given line. The applications of correct boundary conditions are critical to the accurate solution of the design problem.
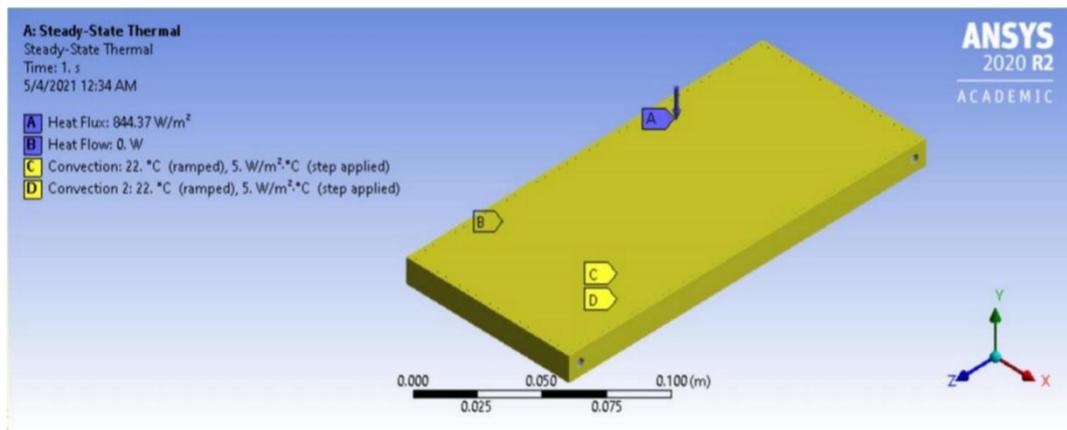

Figure 5: Boundary conditions for ordinary flat plate setup at 12: 00 noon
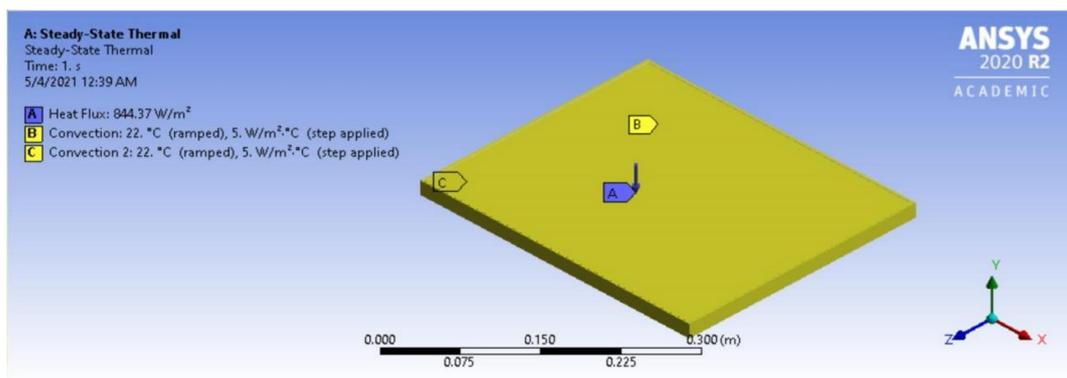

Figure 6: Boundary conditions for PVT model at 12: 00 noon

<Solution - the solver can be logically divided into three main parts, the pre - solver, the mathematical - engine, & the post - solver. The pre - solver reads in the model created by the preprocessor and formulates the mathematical representation of the model. If the model is correct the solver proceeds to form the element - stiffness matrix for the problem & calls the mathematical - engine which calculates the result (displacement, temperatures, pressures, etc.)

The results are returned to the solver & the post - solver is used to calculate strains, stresses, heat fluxes, velocities, etc.

for each node within the component. All these results are sent to a result file, which may be read by the postprocessor.

8) Post - Processor - Here the results of the analysis are read & interpreted. They can be presented in the form of a table, a contour plot, deformed shape of the component or the mode shapes and natural frequencies if frequency analysis is involved.

4. Results
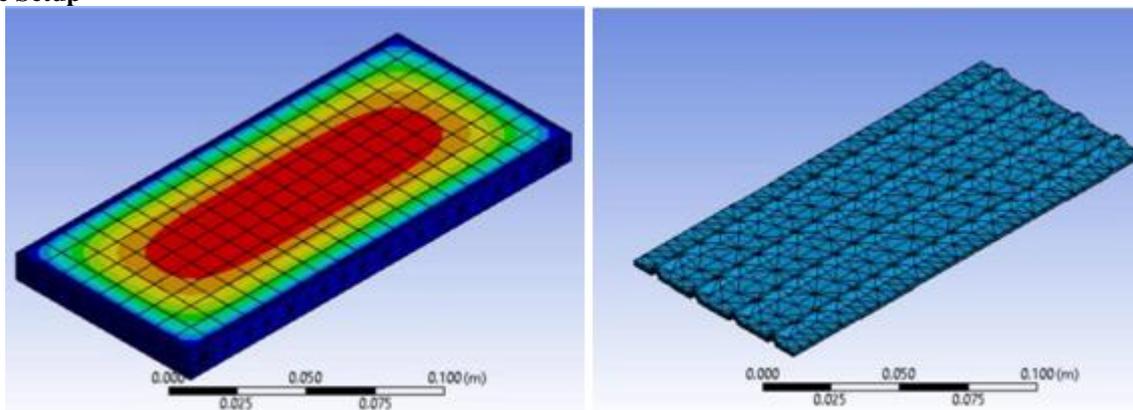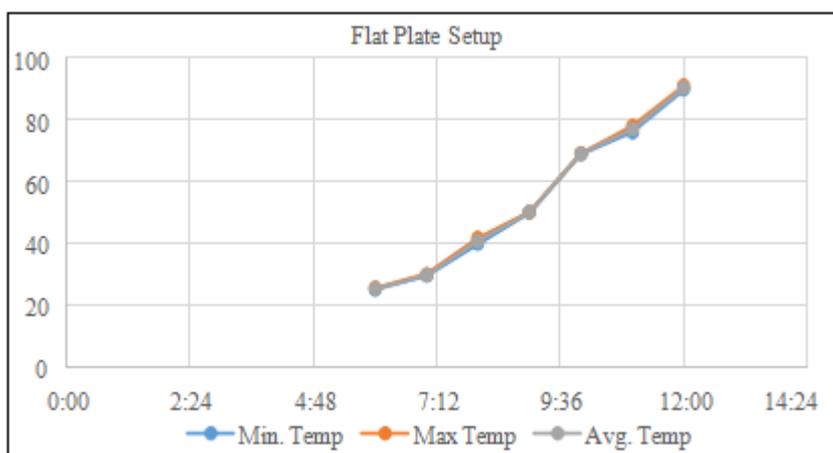
Flat Plate Setup

Figure 6: Thermal contours of the flat plate setup.

The images attached above are the graphics which indicate total temperature at 12: 00 noon. The first image indicates total temperature of the setup which lies between the range of 25.58991.1degrees. The second image shows temperature variation of the collector plate only. The temperature of the plate is about 91 degrees at 12 noon.

Table 6: Mean Plate Temperatures in ordinary setup

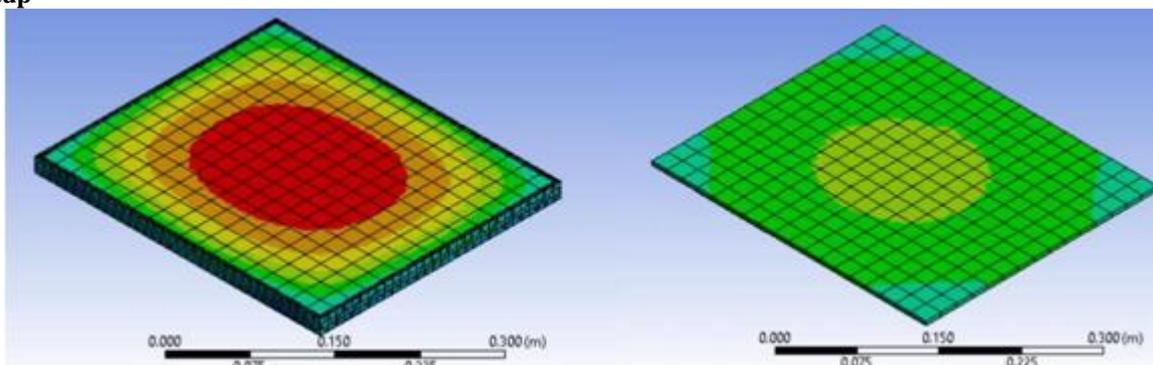| Time	Gcb (W/m2)	Min. Temp.	Max. Temp.	Average
6: 00	34.53372828	25.021	25.589	25.305
7: 00	188.611703	29.498	29.987	29.7425
8: 00	386.6595527	39.825	41.774	40.7995
9: 00	571.8082633	50.024	50.1	50.062
10: 00	718.611568	68.87	69.11	68.99
11: 00	812.2487365	76.064	77.97	77.017
12: 00	844.3730249	89.875	91.1	90.4875

PVT Setup

Figure 7: Temperature contours of PVT setup and flat plate in PVT setup

The images attached along side are the graphics which indicted total temperature at 12: 00 noon. The first image indicates total temperature of the setup which lies between the range of 25.058.253 degrees. The second image shows temperature variation of the collector plate only. The temperature of the plate is about 59 degrees at 12 noon.

Table 7: Mean plate temperature in PVT setup

Time	Gcb (W/m2)	Min. Temp.	Max. Temp.	Average
6: 00	34.53372828	25.063	25.216	25.1395
7: 00	188.611703	27.655	28.025	27.84
8: 00	386.6595527	28.411	29.198	28.8045
9: 00	571.8082633	30.7	31.793	31.2465
10: 00	718.611568	38.59	39.71	39.15
11: 00	812.2487365	49.35	50.13	49.74
12: 00	844.3730249	58.05	58.253	58.1515
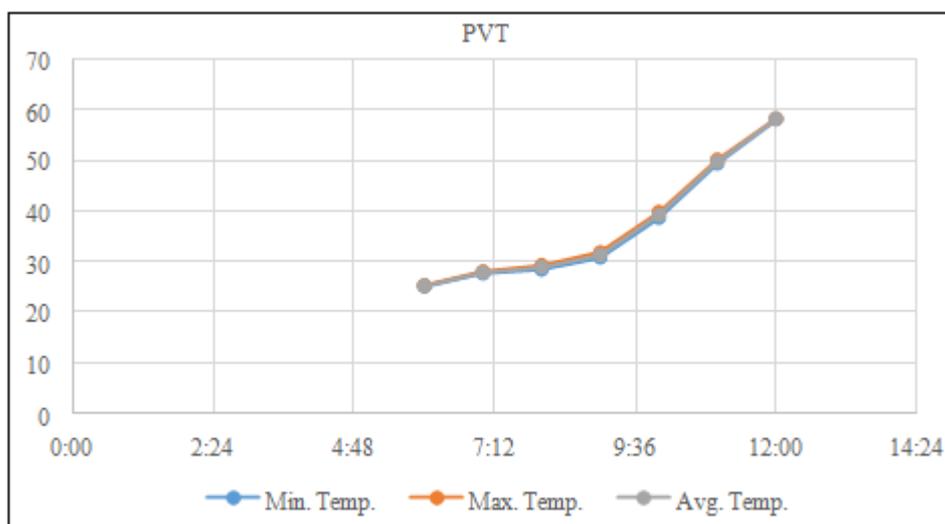
It is clear that flat plate setup in a PV module will not be as effective as heating in the ordinary regular setup. This can be explained by heat loss factors due to conduction and convection. If these losses are countered, PVT might be feasible for day to day applications. Use of nanofluids [6], regular cleaning etc. However, the flat plate setup can still be used for cooling applications and mild heating interactions, which will ensure optimum electrical performance of the operating PV module. In addition, these systems can be incorporated with air heating designs [7].

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