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Computational study on water based hybrid photovoltaic systems with different absorber configurations

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The current study assesses several water-based PVT system thermal absorber configurations. The thermal absorber in PVT system plays a vital role in efficiency evaluation as it lowers PV temperature and collects heat energy. The current study aims to discover and analyze advanced thermal absorber design by comparing well-received spiral circular absorbers and non-cooled PV with proposed semi-circular thermal absorbers with varying flow configurations. The proposed thermal absorber maintains surface contact with PV panels and improves heat transfer thereby yielding better thermal and electrical efficiency. Simulated PVT systems have a constant water flow rate and solar radiation. The CFD-FLUENT software was preferred to evaluate the PVT system in steady-state conditions for the investigation. Under constant ambient and inlet water temperatures of 299 K, the PV temperatures at the surface, water discharge temperature, and pressure drop were measured. It was discovered that a thermal absorber could effectively lower PV surface temperature by cooling. A zigzag thermal absorber was the most efficient since it produced the highest water outlet temperature and lowest PV surface temperature while also slightly raising the pressure drop. In comparison with a non-cooled PV system, a zigzag thermal absorber PVT system yields 11.97% more electrical efficiency, with an addition of 76.75% thermal efficiency. It was also noticed that a conventional spiral circular PVT system provides 13.5% electrical efficiency and 54.8% thermal efficiency while an electrical efficiency of 13.61% and thermal efficiency is 76.75% was obtained from a zigzag thermal absorber PVT system. The zigzag thermal absorber PVT system had a high initial investment of INR 38809.00. It showed a simple payback of 4.63 years, a 28% return on investment with a promising 2.1 Debt Service Coverage Ratio. It is advisable to consider incorporating zigzag semi-circular PVT in the prospective improvements of the PVT system.

Keywords PV cooling, PVT system, Absorber designs, CFD analysis, Parametric performance

Abbreviations

CFD	Computational Fluid Dynamics
DM	Design Modeller
PV	Photovoltaic
PVT	Photovoltaic Thermal
LTB	Lower The Better

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HTB Higher The Better
SPP Simple payback period
DPP Discounted Payback period
IRR Internal rate of return
DSCR Debt Service Coverage Ratio
El Electrical efficiency
Th Thermal efficiency
NPV Net present value
CF Cash flow

List of symbols

Ar PV area (m^2)
C_p Specific heat of water ($kJ.kg^{-1}.K^{-1}$)
V Velocity of air (m/s)

Greek symbols

η Efficiency (%)
η_{th} Thermal efficiency (%)
η_{el} Electrical efficiency (%)
Φ Viscous dissipation
γ Temperature coefficient
η_{net} Overall efficiency (%)
η_{ref} Reference Efficiency (%)
I_{sc} Incident Radiation (W/m^2)
K Thermal conductivity (W/mk)
ϱ Density (kg/m^3)

Subscripts

Mw Mass flow rate (kg/sec)
Tin inlet fluid temperature (°C)
Tout Outlet fluid temperature (°C)
T_{cell} Cell Temperature (°C)
T_{ref} Reference Temperature (°C)
n No of year
N Life period of PV/PVT system

Solar energy, especially photovoltaic systems, is gaining significant importance in renewable energy harvesting devices due to simple construction and direct electricity generation[1]. Nevertheless, only a partial fraction of the radiation is transformed into electrical energy at high solar radiation and PV module temperatures; the outstanding energy is resulted into heat, that reduces the PV module's electrical performance[32,33]. The primary reason observed was that the electron and electron-hole pairing's motion was severely affected at high temperatures that reduce electricity generation[2]. This underperformance is overcome by introducing a thermal absorber and circulation of cooling fluids to reduce module temperature and recover heat energy[29–31]. The combination comprises two units, the PV module to turn out electrical power and the thermal unit to produce heat power simultaneously, known as hybrid or cogeneration or photovoltaic thermal (PVT) system. The noticeable benefits of PVT systems are like co-generation of power, low installation area[3], less payback period, better yield than standalone PV or solar thermal system. These benefits of the PVT system motivated the research and development team for further advancement to minimize installation cost and increase overall performance. Research around the globe has reported many studies regarding the photovoltaic thermal system in the last decade, signifying feasible methodologies to improve overall efficiency. The methodologies adopted are various types of heat transfer cooling medium[4], design and development of PVT system[5] and operating parameters selection[6]. The researchers also focused on the design of thermal absorbers during PVT system development and their investigation studies.In upcoming days it will be an era of solar PV technology and the major problems for the PV's to sustain global market will be the problems related to PV temperature. This problem needs to be address effectively and research is in analogous track from decades. The various effective cooling methodologies were investigated and are summarized below.

Hamid Mortezapour et al.[7] demonstrated copper-based numerical models of different heat exchangers employing a water coolant technique for the PVT system. Thermal distribution and electrical efficiency between tube heat exchangers, square heat exchangers and box heat exchangers are studied using oscillating, spiral and direct configurations with flow rates from 30 l/h to 180 l/h and 600 W/m2, 800 W/m2 and 1000 W/m2 were studied and compared with conventional photovoltaics. The result concluded that spiral flow design was suitable for maintaining consistent temperature distribution and attaining the highest electrical performance, whereas direct flow configuration obtained the highest temperature gradient.

In another study[8], modification in the serpentine flow known as direct serpentine configuration was designed, and photovoltaic thermal performance was evaluate with serpentine flow absorber using analytical treatment. Under the same testing condition, the direct serpentine design improved electrical and thermal efficiencies by 12.51% and 57.66%.

The comparative study between copper-based perpendicular serpentine and oscillatory flow absorber configuration was performed[9]. the theoretical model was developed, and simulation was performed at a range of flow rates and solar radiation incorporating ANSYS FLUENT 16.0 to evaluate thermal, pressure drop characteristics. During the investigation, vertical serpentine flow produced higher thermal efficiency of 56.45% and consumed lower pumping power for operation.

Long et al.[10] examine harp and grid roll bond absorber in domestic copper. It was a water heater-PVT system in Sichuan, Chinese ambience condition via numerical and experimental treatment. An experimental result shows that novel grid channel design poses better thermal and PV efficiencies but also experienced high pressure drop. The overall efficiency of 37% was noted grid channel design with an average pressure drop of 0. 747 Pa that was 3.33 times higher than harp channel design.

Recently, ErkataYandri[11] developed a polymeric thermal absorber of PolyMethyl- methacrylate polymer and observed that the polymer absorber provides better cooling and obtained about 80% thermal efficiency. Recently, heat flux and temperature distribution across various PVT layers by circulating water through copper pipe absorber were demonstrated by AshishSaurabh et al.[12]. The maximum temperature was noted at glass cover and reached to minimum-till tedler as excess heat from tedlar was carried out by water.

Parametric study of radiation value, the water flow rate at constant inlet temperature on PV surface and the water temperature was presented by Misha et al. for Malaysian condition[13]. An ANSYS developed a numerical model for dual oscillating flow copper pipe absorber and validated it against the experimental result. The numerical efficiency was confirmed experimentally where the highest thermal and electrical efficiency of 59.6% and 11.71% were observed for the PVT system at maximum radiation level and water flow of 6LPM.

Abdelkader Morsli et al.[14] designed different shape and sized absorber and pasted below PV Panel to investigate performance of water based PVT system with and without glass cover using MATLAB. The multiple configurations with parallel and spiral flow using round, square and rectangular tube geometry of absorber were investigated to yield electrical and thermal performance. It was observed that parallel tube with rectangular section absorber with glass cover was most effective as it gives total thermal efficiency of 84.20%. It is also important to note that adding glass cover reduces electrical efficiency but it increases thermal efficiency that result in overall thermal efficiency.

The study[15] highlights the importance of effective cooling using cotton wicks integrated with rectangular aluminum fins in improving the performance and efficiency of PV modules in hot climate. The results show that the passive cooling technique reduced the PV module temperature by 31.4% that resulted in enhancement in the electrical efficiency to 8.6%. The active cooling method reduced the PV temperature by 20.8% that enhanced the electrical efficiency by 7.9%.

This study[16] presents an experimental and numerical study on the cooling of a photovoltaic/thermal (PV/T) system using CuO and Fe2O3 nanofluids. This cooling leads to improvements in the electrical efficiency to 10.30% and thermal efficiency to 43.3% compared to the uncooled PV module Furthermore, it was observed that the cooling with nanofluids reduced the exergy destruction and entropy generation, enhancing the overall exergy efficiency by up to 13%.

The literature reveals various combinations of thermal absorber focusing on better thermal and electrical yield. Thermal absorber design is an important part of PVT systems. Based on the designs found in the literature, it is clear that further research is needed to examine the parametric effects on PVT systems. From the literature survey, the following research gap is identified,

- It has been observed that limited studies are available in the PVT system with semicircular thermal absorber design.
- Some researchers have preferred spiral circular absorber design, but the semicircular zigzag and serpentine configuration was not yet studied.
- Many studies have been reported with line contact of thermal absorber with the flipside of the PV surface, whereas in very few studies surface contact with flipside PV surface is presented.
- The comparative study among non-cooled PV, spiral circular absorber, zigzag and serpentine configuration was not yet performed.

Conventionally preferred design is tubular type absorber due to ease of availability, simple in construction. Apart from available absorbers, modification in thermal absorber design can be possible for further performance investigation. Studies of different thermal absorber are addressed numerically in this research which may be very fruitful for the development of effective PVT system and may also lead to a base for experimentation. In the present research work, commercially available low cost polycrystalline photovoltaic cell has been used to investigate thermal and electrical performance by incorporating high thermal conductivity and lightweight Aluminium-based thermal absorber. The computational design on improved thermal absorbers was performed and compared with conventional ones for better performance The present study discusses modified thermal absorber designs along with parametric assessment with views to surface temperature, water outlet temperature, and pressure drop and electro-thermal efficiency. In the present study, comparative analysis among spiral circular thermal absorber (renamed as coil 1), semi circular serpentine absorber (renamed as coil 2) and semi circular zigzag absorber (renamed as coil 3) is performed with computation CFD package. The present study demonstate comparative study to recognize optimum absorber in terms of efficiency and also provide economic analysis for tangible commertialisation.

Methodology

The Navier-Stokes equations are a system of formulas that explain the mass, momentum, and heat transfer processes. Although there isn't a general analytical solution for these partial differential equations, they can be discretized and solved numerically. The steps followed in CFD methodologies for PVT Analysis are shown in Fig. 1.

The following sections include the general equations governing fluid flow and heat transfer processes (Navier-Stokes equations)[17].

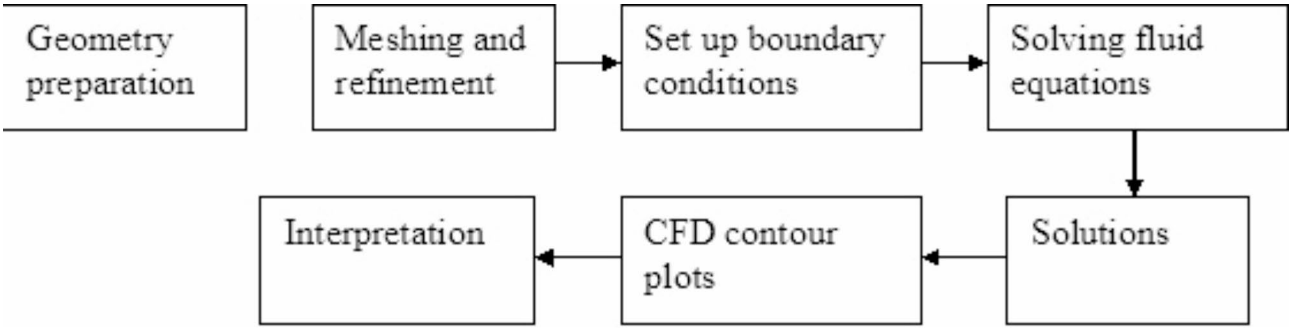


Fig. 1. Steps in CFD methodologies for PVT Analysis.

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = 0 \quad (1)$$

Momentum-X direction

$$\rho \frac{Du}{Dt} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left[2\mu \frac{\partial u}{\partial x} + \lambda \text{ div u}\right] + \frac{\partial}{\partial y}\left[\mu \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right] + \frac{\partial}{\partial z}\left[\mu \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)\right] + S_{Mx} \quad (2)$$

Momentum-Y direction

$$\rho \frac{Dv}{Dt} = -\frac{\partial p}{\partial y} + \frac{\partial}{\partial x}\left[\mu \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right] + \frac{\partial}{\partial y}\left[2\mu \frac{\partial v}{\partial y} + \lambda \text{ div u}\right] + \frac{\partial}{\partial z}\left[\mu \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)\right] + S_{My} \quad (3)$$

Momentum-Z direction

$$\rho \frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + \frac{\partial}{\partial x}\left[\mu \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)\right] + \frac{\partial}{\partial y}\left[\mu \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)\right] + \frac{\partial}{\partial z}\left[2\mu \frac{\partial w}{\partial z} + \lambda \text{ div u}\right] + S_{Mz} \quad (4)$$

$$\rho \frac{Di}{Dt} = -p\, div\, u + div\ (k\, grad\, T) + \Phi + S_i \quad (5)$$

Viscous dissipation (Φ)

$$\Phi = \mu \left\{ 2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right] + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)^2 \right\} + \lambda\ (div\ u)^2 \quad (6)$$

Solid work software is used to create CAD geometry and ANSYS Design is used to de-featuring geometries. The geometry created in CATIA is shown in Fig. 2. After performing de- featuring in ANSYS DM, the final fluid field domain analyzed in the CFD analysis is shown in Fig. 3.

The model created in design modeler is imported into ANSYS WORKBENCH for final analysis. Inflations layers are utilized on all wall surfaces to ensure smooth flow, while a very fine mesh is employed to accurately capture the solution. A body size of 4 mm is the preferred choice for the fluid domain. The Specifications of various layers of PVT system are tabulated in Table 1. The meshing applied to Non Cooled PV system is shown in Fig. 4.

The simulation accuracy was achieved by providing sufficient mesh refinement near the wall surfaces. Among the multiple meshing approaches available, the Sweep mesh approach was applied for most of the regions in the geometry. For this meshing method to succeed, the geometry is converted to regular shaped Bodies. However, it may not be possible to convert all the geometry to regular shaped bodies due to the nature of the geometrical shapes. In such scenarios, the irregular-shaped bodies in the geometry will mesh with the unstructured mesh methods. The complete geometry of the chamber, the layers were meshed with the hexahedral mesh elements. In order to verify the grid-independent solution for this research work, the simulations were carried out using five meshes for the identical boundary conditions. Meshing parameters (number of grid points) in terms of width and height were varied to generate these five mesh configurations for the grid- independent study. The grid independent study is carried out to evaluate optimum model. For this study, five different mesh configurations were selected and for constant solar radiation of 800 W/m^2 were applied on the top of solar PVT system and PV average surface temperature was observed from contour plots. During the study, it was found that in T- mesh and S-mesh, difference in surface temperature was of 0.4 C. Hence, among five models, T mesh was selected for further study. A very good quality of mesh is required for accurate numerical simulation. A mesh is created for the imported CAD model and is evaluated for various grid (mesh) metrics before proceeding for imposing boundary conditions. The result of grid independent study based on surface temperature is tabulated in Table 2.

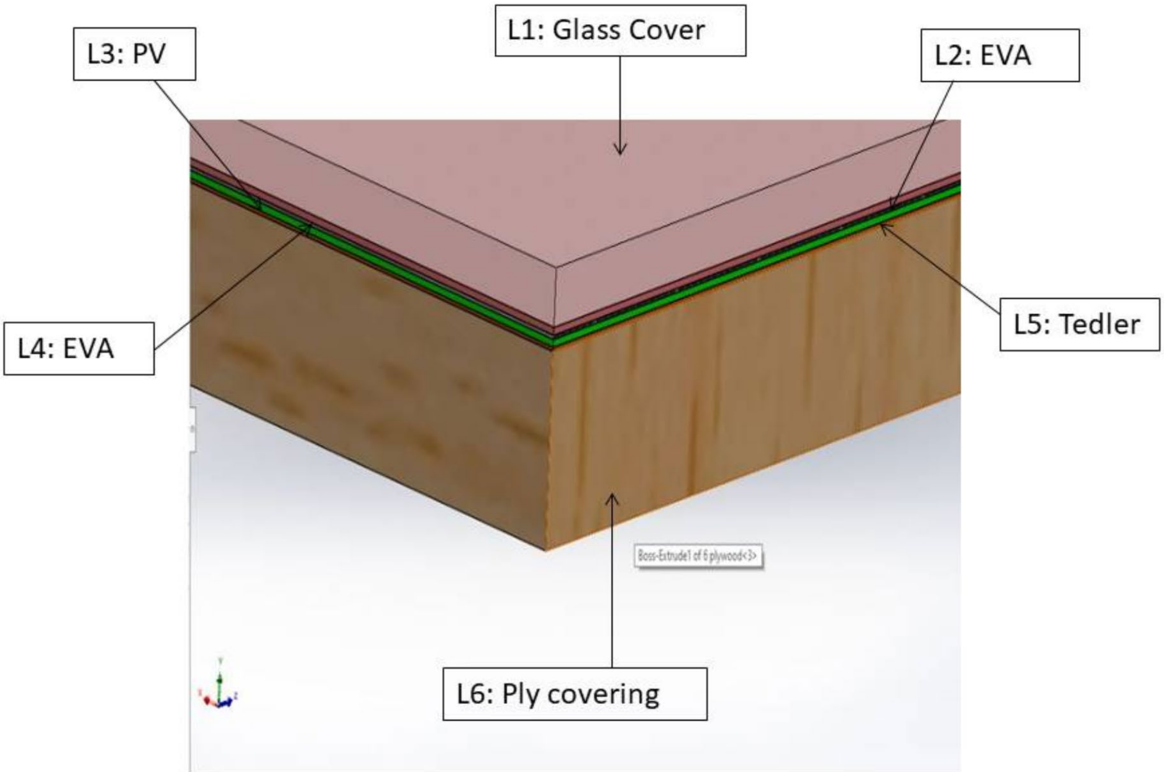


Fig. 2. Chronological Order of PVT System. L1: Glass (pink Color), L2: EVA, L3: PV, L4: EVA, L5: Tedler, L6: Covering.

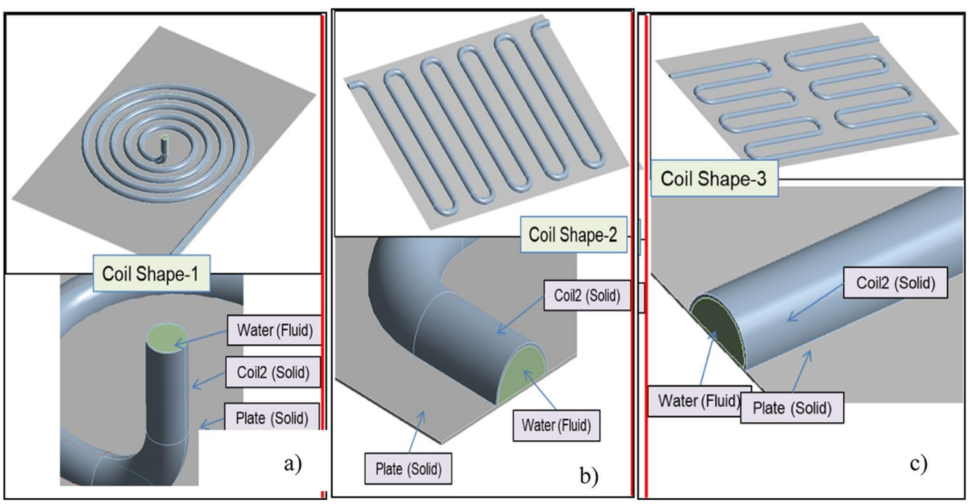


Fig. 3. Different thermal absorber designs Conventional spiral circular thermal absorber (coil 1); (**b**) serpentine semi circular thermal absorber (Coil 2); (**c**) Zigzag semi circular thermal absorber (Coil 3).

Material	Glass cover	Solar film	Si PV	PDF layer	Al Layer	Water fluid	Plywood
Thermal conductivity (W/mk)	2	0.305	151	0.15	202	0.61	0.15
Density (kg/m^3)	2455	945	335	1190	2719	1000	558
Specific heat (J/kg-K)	575	2085	712	1255	871	4182	2550
Thickness (mm)	3	0.4	0.2	0.2	1		10

Table 1. Specifications of various layers of PVT system.

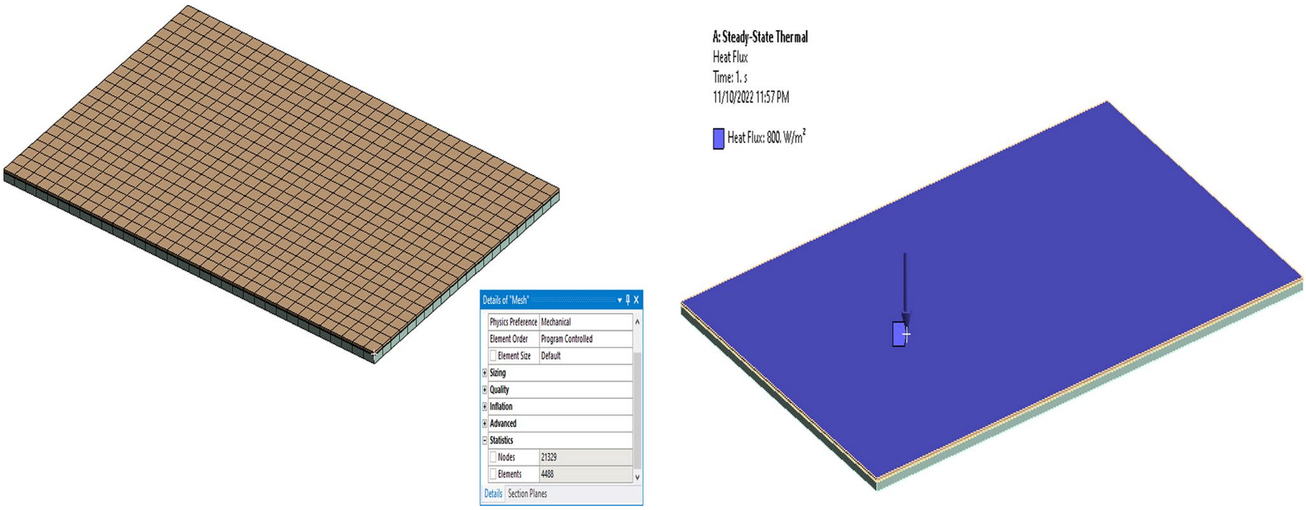


Fig. 4. Meshing of Non Cooled PV system.

Mesh	Solar radiation (W/m^2)	Surface Temperature (°C)	Deviation (°C)
P- Mesh		85.8	-
Q- Mesh		83.3	2.5
R- Mesh	800	81.5	1.8
S- Mesh		80.6	0.9
T- Mesh		80.2	0.4

Table 2. Grid independent study based on surface temperature.

Sr No	Type of absorber PVT	Node	Element
1	Conventional circular PVT	243,446	664,126
2	Serpentine semi circular PVT	214,350	570,610
3	Zigzag semi circular PVT	210,199	549,603

Table 3. Nodes and elements of different PVT system.

For all the cases, automatic mesh is generated by default settings then sizing is applied to the internal surface and the method for sizing is selected as no. of divisions, after this each type is given no. of divisions on internal surface as per geometry. Next step is applying face meshing to the front and back face for improving mesh quality. Table 3 represents nodes and elements count for all PVT system.The Fig. 5 shows Mesh distribution of spiral circular thermal absorber for all layer with enlarge view.

Once all these is done orthogonality and skewness graph is checked and if found satisfactory simulation is performed otherwise no. of divisions on internal face are increased to improve mesh quality. For all the cases it is taken care that the grid generated must have the recommended value of skewness and orthogonality so that the accuracy of result seems to be extremely good and anyone can easily rely to proceed for experimentation based on simulation results. In mesh refinement, orthogonality was found more than 0.90 for all types of PVT system while skewness was found less than 0.28. The meshing of all thermal absorber PVT system was performed and

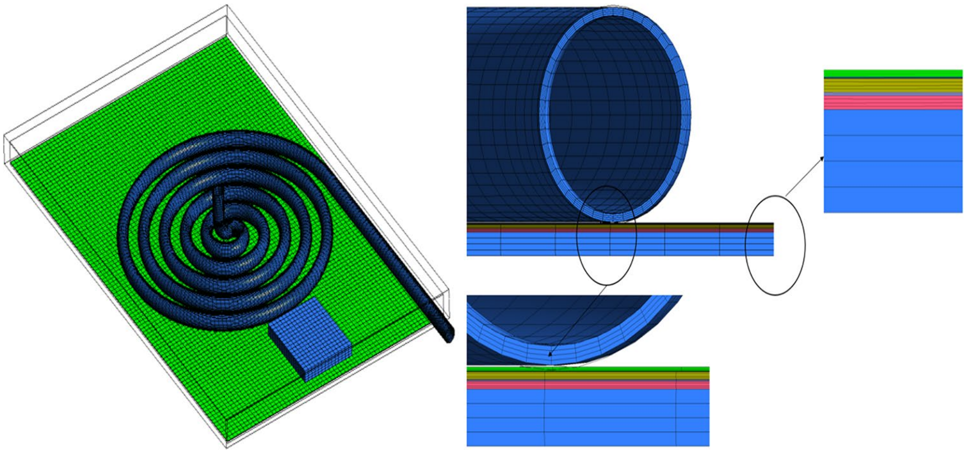


Fig. 5. Mesh distribution of spiral circular thermal absorber with enlarge view.

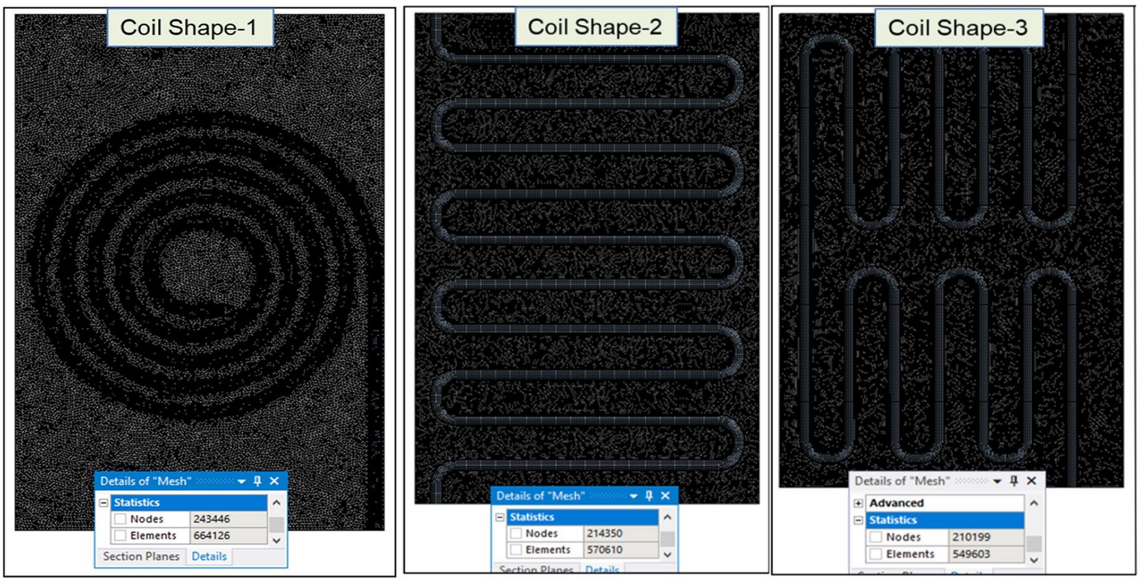


Fig. 6. Meshing of thermal absorber PVT system.

Boundary condition	Unit	Value
Water flow rate	kg/sec	0.05
Solar radiation –Heat flux	W/m^2	800
Atmospheric temperature	K	299.00
Water inflow temperature	K	299.00

Table 4. Details of boundary conditions applied to PVT model.

shown in Fig. 6. The next step in analysis includes applying boundary conditions on the model. The boundary conditions applied for simulation were as given in Table 4.

After solving the problem using a CFD solver, analysis needs to be carried out in graphs, plots, and contours performed in post-processing for all the cases. The contour option is selected to study contours of temperature distribution on the top surface outlet water temperature.Additional features of extreme and average temperature variations are acquired from the contour plot for the micro study purpose. As discussed in the introduction, the electrical performance of a photovoltaic module depends on its instantaneous temperature and is given by[18],

$$\eta_{el} = \eta_{ref}\left[1 - \gamma\ (T_{cell} - T_{ref})\right] \tag{7}$$

Sr No	Component and description	Cost (INR)
1	Polycrystalline PV module (100 W), battery and inverter	19,936
2	Supporting structure	3540
3	Electrical accessories	2400
4	Transport and installation charges	1500
	Salvage value	0
	GST	1369
	Total	28,745/-

Table 5. Average component cost of the conventional PV system.

Sr No	Component and description	Cost (INR)
1	Polycrystalline PV module (100 W), battery and inverter	19,936
2	A. Sprial circular Thermal Absorber	3200
	B. Semi circular Thermal Absorber	4200
3	Insulation	875
4	Water storage Tank	2100
5	Centrifugal Pump	3800
6	Electrical accessories and piping	950
7	Supporting structure	2850
8	Transport and installation charges	2250
	Salvage value	0
	GST	1778
	Total for conventional Sprial circular Thermal Absorber	37,739/-
	Total for serpentine and zigzag Semi circular Thermal Absorber	38,809/-

Table 6. Average component cost of the W-PVT system.

The above equation evaluates electrical efficiency from T_{cell} since η_{ref}, T_{ref} and γ are the constant values. T_{cell} is PV surface temperature simulated by the model and averaged among ten central locations. γ is the temperature coefficient having a value of 0.0045 /°C, and Tref is the reference temperature of PV panel, i.e. 25 °C, η_{ref} is standard reference efficiency mentioned by the manufacturer, i.e. 14.9%. Thermal gain can be evaluated by predicted water outlet temperature by a simulated model.

$$\eta_{\,th} = \frac{m_w C_p \int_{tin}^{tout} dT}{I_{sc} \int dA_r} \tag{8}$$

$$\eta_{\,th} = \frac{m_w C_p \left(T_{in} - T_{out}\right)}{I_{sc} A_r} \tag{9}$$

$$\eta_{\,net} = \eta_{\,el} + \eta_{\,th} \tag{10}$$

It is important to evaluate economic feasibility of proposed system to asses investment and possible returns. For the proposed system; simple payback period, discountedpayback period, internal rate of return and Debt Service Coverage Ratio were evaluated to understand gives financial potential.

The market survey in the Indian market was performed to estimate the cost of components, manufacturing, and installation of simple PV and PVT systems and tabulated in Tables 5 and 6. According to the market availability and the cost analysis, economic analysis for a single prototype unit are prepared and presented in the result and discussion section. During market analysis, it was found that manufacturing cost of conventional Sprial circular Thermal Absorber was lesser that Semi circular Thermal Absorber. It was also observed that cost of zigzag and wavy Semi circular Thermal Absorber was nearly same.

The simple payback period (SPP) is popular decision making tool that give time period taken by new project to get invested amount back. It is considered as screening tool for an investment. Mathematically it is expressed as

$$SPP = \frac{initial\ invested\ amount}{annual\ returCash\ flow\ per\ year} \tag{11}$$

SPP has disadvantage that it does not consider time value of money. Hence discounted payback period (DPP) is evaluated.

$$DPP = \frac{-\ln\left(1 - \left(\frac{invested\ amount * Discounted\ Rate}{Cash\ flow\ per\ year}\right)\right)}{\ln(1 +\ Discounted\ Rate)} \tag{12}$$

The internal rate of return indicates the potential profitability of the project[19] and given by

$$0 = CF_0 + \frac{CF_1}{(1+IRR)} + \frac{CF_2}{(1+IRR)^2} + \frac{CF_3}{(1+IRR)^3} + \ldots + \frac{CF_n}{(1+IRR)^n} \tag{13}$$

$$0 = NPV = \sum\nolimits_{n=0}^{N} \frac{CF_n}{(1+IRR)^n} \tag{14}$$

The Debt Service Coverage Ratio (DSCR) measures an individual project capability to meet their recurring, maintenance and annual debt payments[20].

$$Debt\ Service\ Coverage\ Ratio = \frac{Net\ Operating\ Income}{Debt\ Service} \tag{15}$$

Result and discussion

Due to the non-linear nature of the equation, iterative approach is required, andit is said to converge if the solution is close to an exact solution. The governing equation residual graph from the CFD simulation was as shown in Fig. 7.

Contour plot for surface temperature

The contour plot for surface temperature of Non-cooled PV system was shown in Fig. 8. As shown in plot, red color distribution was observed due to uniform high temperature over all regions. The average surface temperature of Non-cooled PV system was observed to be 78.2 ℃ that leads to a decrease in electrical efficiency.

It was observed from Fig. 8, that solar radiation increases surface temperature. The uniform red contour indicarte high temperature of 80.2 °C. Beyond manufacturers specified temperature surface temperature of PV is inversely proportional to output voltage generation. It resulted in reduction in electrical power generated from the PV system. As shown in Fig. 9(a), (b) and (c), under 800 w/m^2 radiations, maximum surface temperature is exhibited by non cooled PV system followed by conventional spiral circular absorber and semi circular serpentine absorber PVT system. The lowest average surface temperature is shown by zigzag semi circular absorber PVT. It is due to the fact that zigzag absorber maintained superior surface contact with back side of PV system compare to other PVT system. Additionally zigzag flow enhanced turbulence that able to extract maximum heat there by reducing surface temperature. The least PV temperature of 44.2 °C was noted for zigzag thermal absorber that is 4.33% and 10.70% lower than serpentine semi circular and conventional circular absorbers.

Contour plot PVT water outlet temperature

The degree of heat absorption by water is the deciding factor for the degree of cooling and water outlet temperature.As discussed in the above paragraph, the highest heat was absorbed by zigzag semi circular absorber PVT, hence exhibited the highest thermal energy gain. The Fig. 10(a), (b) and (c) shows contour plot for water outlet temperature of PVT systems. The outlet water temperature is displayed on the contour plots of zigzag semi circular absorber PVT shows 45.7 °C that is 4.16% higher than serpentine semi circular PVT and 17.9% higher than conventional circular absorber PVT system.

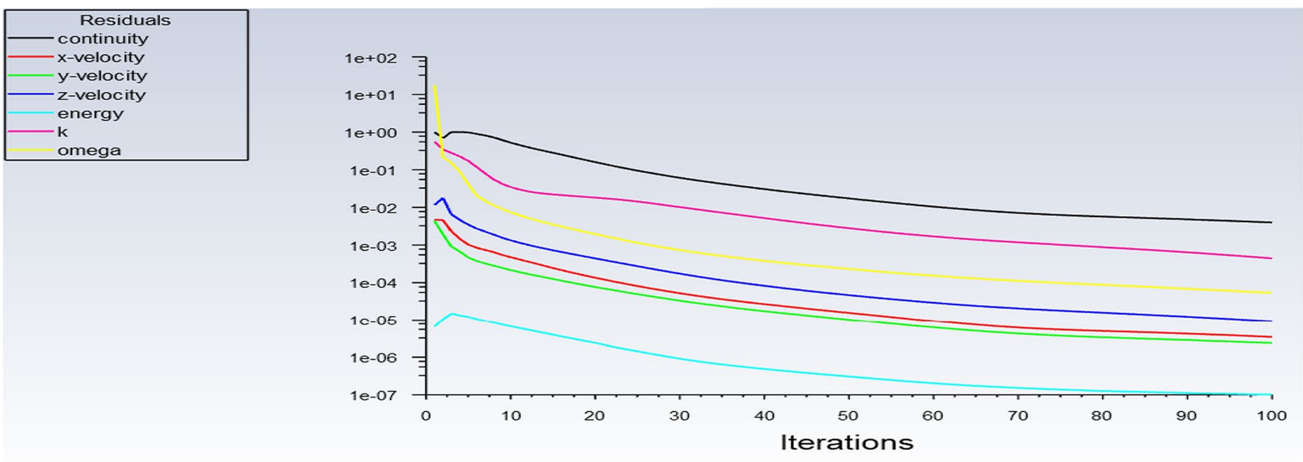


Fig. 7. Governing equation residual graph from the CFD simulation.

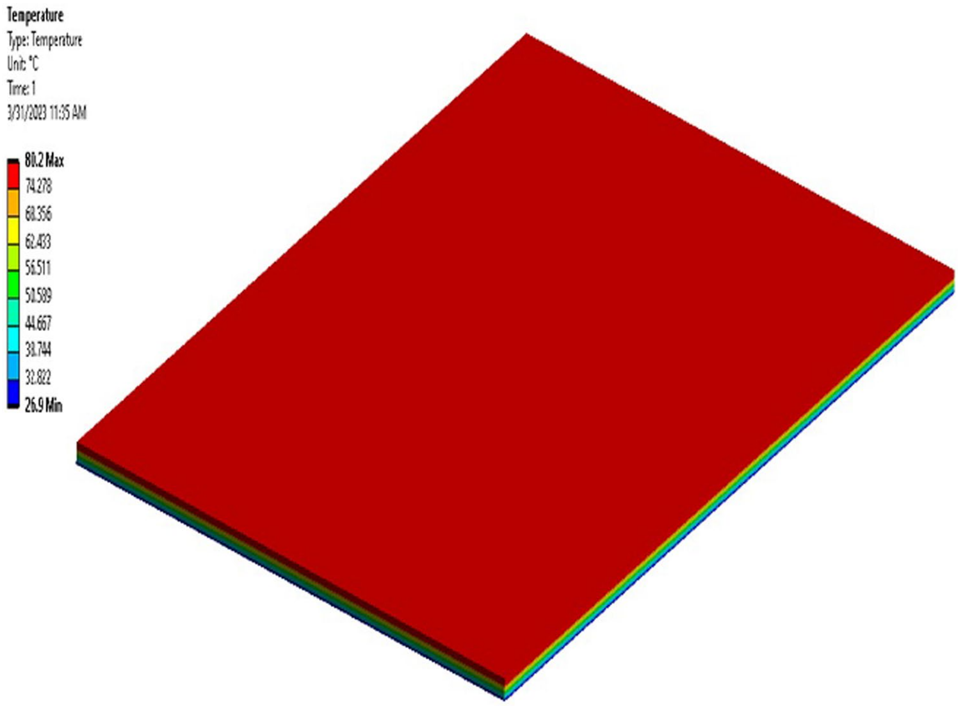


Fig. 8. Contour plot for surface temperature of Non-cooled PV system.

Contour plot for pressure drop

The absorber geometry, flow configuration and direction affects pressure distribution and any change in the configuration creates pressure drop. The more complex absorber configurations can lead to higher pressure drop and this higher pressure drop increases pumping power required to run PVT system hence pressure distribution study was perform. As observed in contour plot Fig. 11(a), (b), and (c), pressure drop of 76. 60 Pawas observed for serpentine semicircular PVT system while highest pressure drop of 221 Pa was observed in case of conventional spiral circular PVT system the zigzag semi circular PVT system shown pressure drop of 89.8 Pa. It is important to mention that though zigzag semi circular PVT performed better in PV temperature and water outlet temperature, it shown higher pressure drop that will increase pumping power[34,35].

The Eqs. (7), (8), (9) and (10) were used to assess electro-thermal and overall yield of PV and PVT systems and plotted along with the comparison graph as in the Fig. 12. The lowest power obtained from the non-cooled PV system is due to the high temperature and without cooling and noted as 11.8%. Electrical efficiency of 13.25%, 13.47%, 13.61% and thermal efficiency of 54.8%, 69.3%, and 76.75% were obtained from conventional spiral circular PVT, serpentine semi-circular PVT and zigzagsemi-circular PVT respectively. The electro-thermal performance favors zigzagsemi-circular PVT due to maximum efficiency. The present study result were tabulated in Table 7 and compared with literature for PVT system.

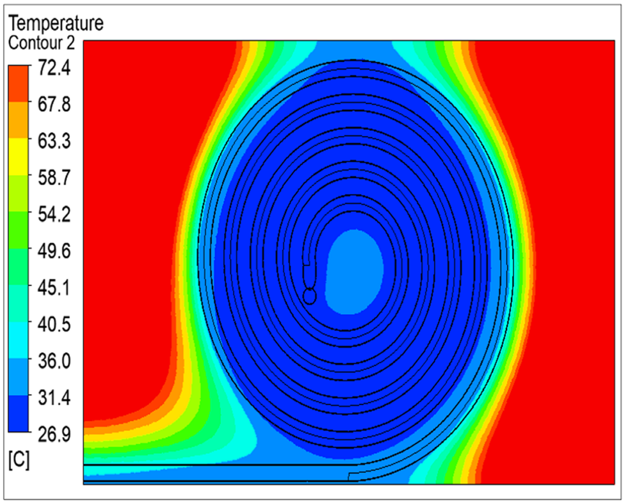
The solar PV system has high initial and low operating costs, while the solar water heater has low initial and high operating costs. Therefore, the cost-benefit investigation is carried out for a simple PV system, and the newly designed solar PVT system comprises the generation of heat and power. For annual revenue calculation, power produced by the PV and PVT system were considered.

In economic analysis, simple payback period and discounted payback period are primary calculation that work as economic screening tools. IRR is deciding tool to whether the project is likely to be accepted or rejected. The positive IRR shows project is accepted to provide a good return on investment values, while the negative IRR indicates complicated cash flow that makes the project uneconomical. The DSCR is evaluated by calculating annual recovery expenses, interest and principal payments. The lower DSCR indicates the project has risk and may possess financial difficulties, while a higher ratio implies the project is creditworthy and commercially economical. The Eqs. (11), (12), (13), (14) and (15) were used to calculated economic term and and tabulated in Table 8.

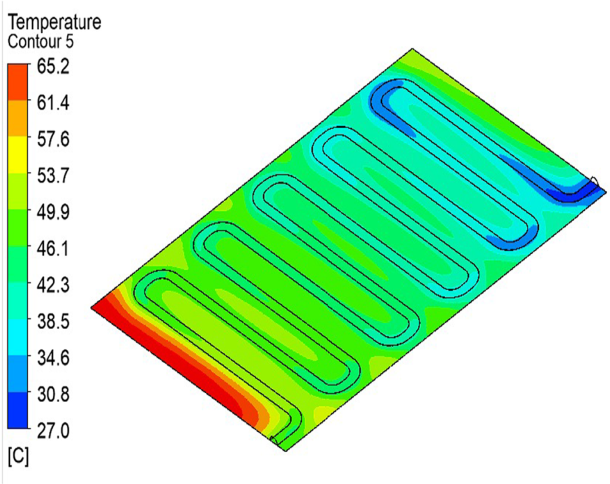
Conclusion

The current study was focused on study of varuious absorber deisgn for PV and PVT systems CFD-FLUENT packageand parameters such as surface temperature, water outlet temperature and pressure drop etc. we observed and below are te key findings to conclude.

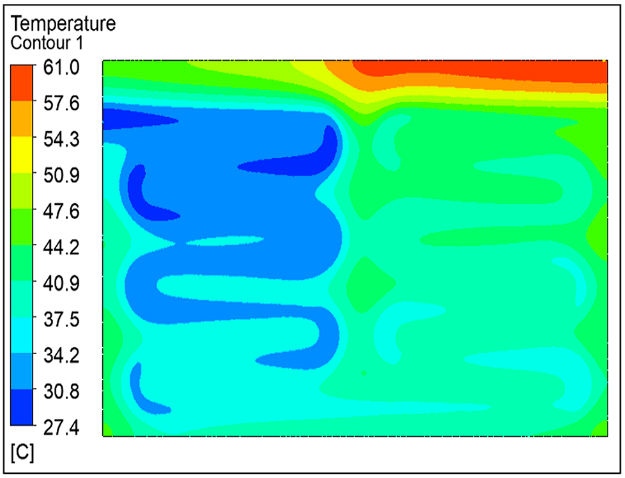
- The Computational results forecasts that the lowest average PV temperature of 44.2 °C for zigzag thermal absorber that is 4.33% and 10.70% lower than serpentine semi circular and conventional circular absorbers.



(a)



(b)



(c)

Fig. 9. (**a**) Contour plot for surface temperature of Conventional Sprial circular PVT system. (**b**) Contour plot for surface temperature of Serpentine Semi circular PVT system. (**c**) Contour plot for surface temperature of Zigzag Semi circular PVT system.

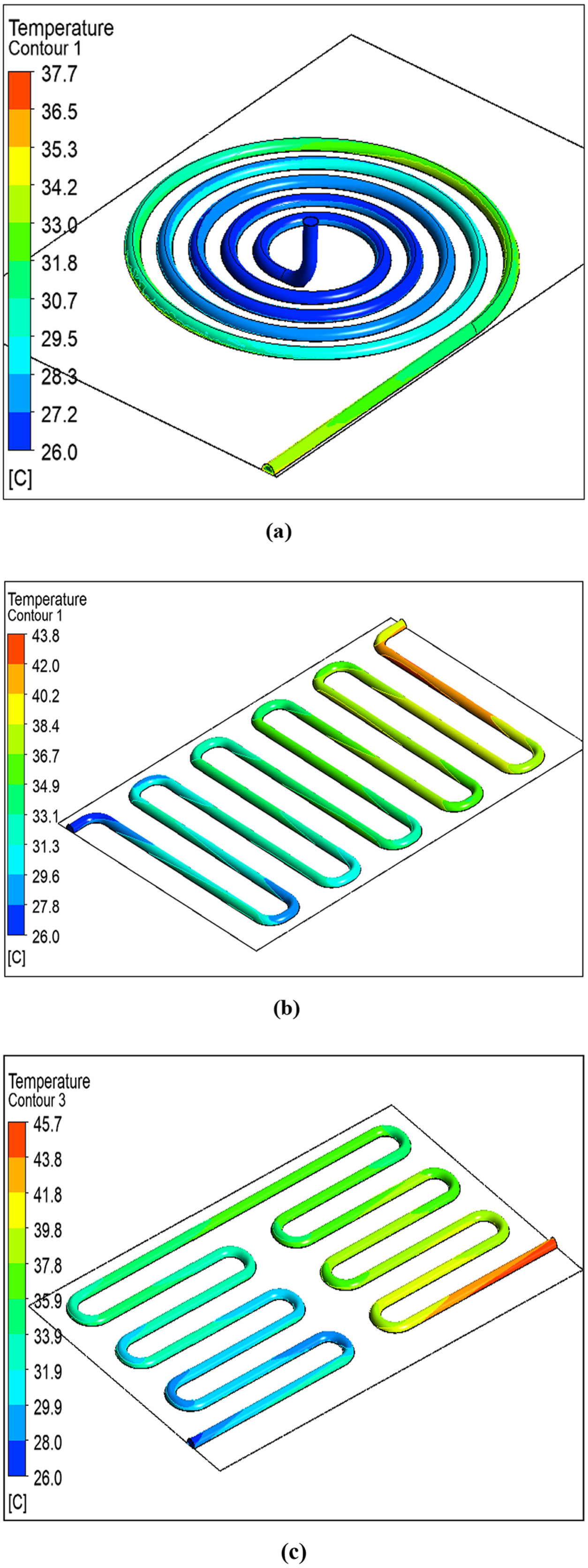
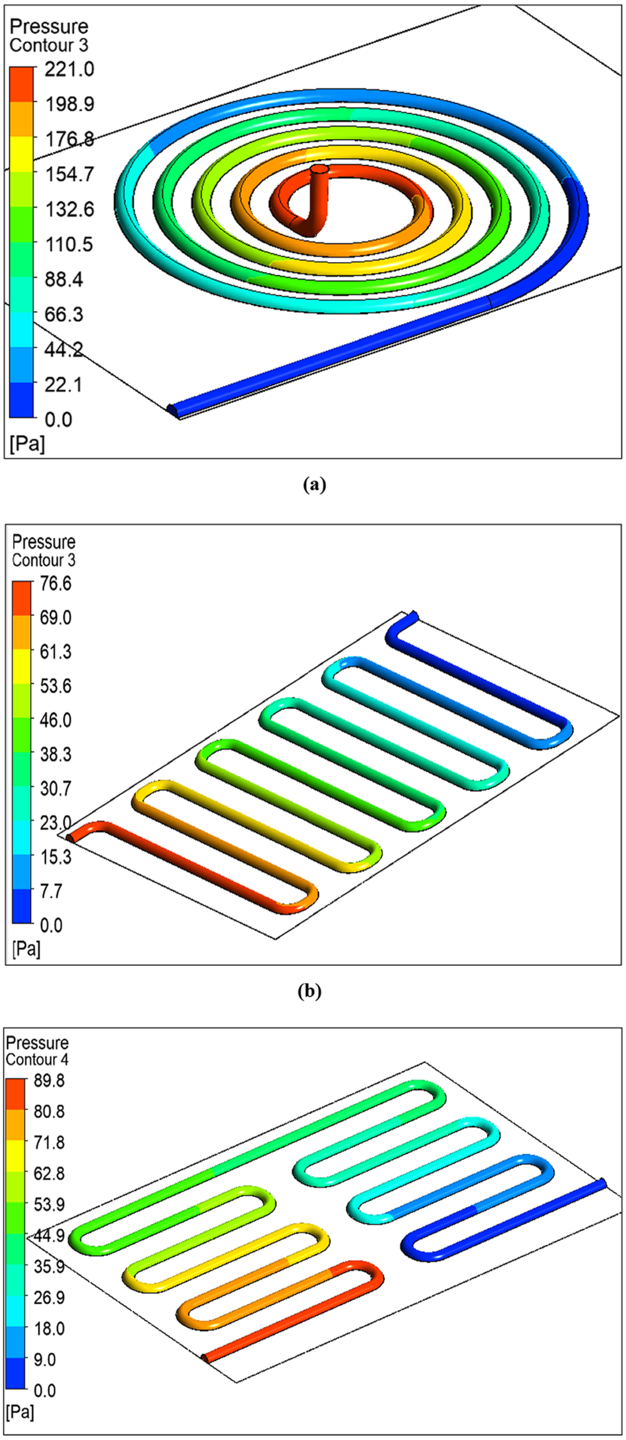


Fig. 10. (**a**) Contour plot for water outlet temperature of Conventional Sprial circular PVT system. (**b**) Contour plot for water outlet temperature of Serpentine Semi circular PVT system. (**c**) Contour plot for water outlet temperature of Zigzag Semi circular PVT system.



(c)

Fig. 11. (**a**) Contour plot for pressure drop of Conventional Sprial circular PVT system. (**b**) Contour plot for pressure drop of Serpentine Semi circular PVT system. (**c**) Contour plot for pressure drop of Zigzag Semi circular PVT system.

- For average water outlet temperature, highest water outlet temperature of 45.7 °C is observed for zigzag semi circular PVT while is limited to 43.8 °C and 37.5 °C for semi circular and conventional circular absorbers. However the zigzag thermal absorber showed a slightly higher pressure drop of 89.8 Pas while it was 76.6 Pas for semi circular serpentine and 221.1 Pas for conventional circular thermal absorber.
- The surface contact between absorber and PV panel increased heat transfer effectively and hence zigzag thermal absorber based PVT system demonstrates a maximum average electrical efficiency of 13.61% and a thermal efficiency of 76.75%. The economic analysis was also performed evaluate financial feasibility of the

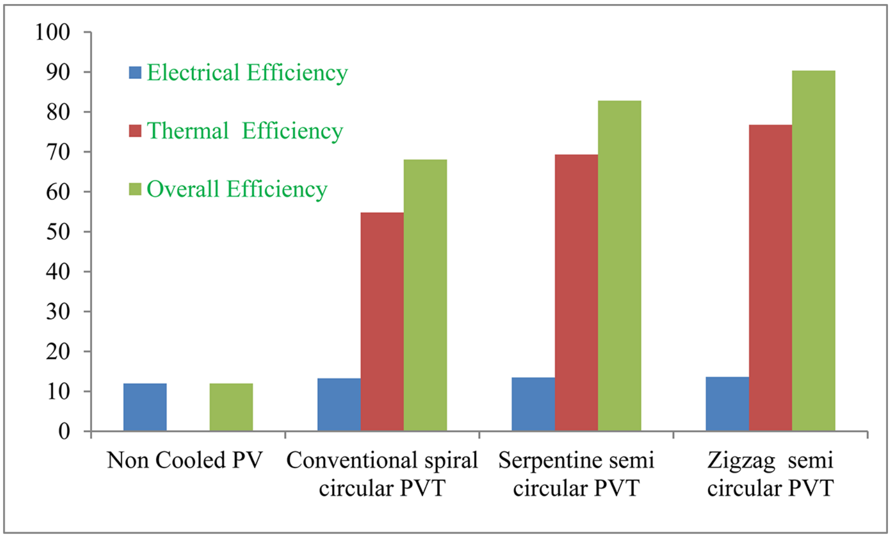


Fig. 12. Efficiency assessment of different configurations of the thermal absorber-PVT collector.

					Radiation	Flow	El	Th
Authors	**Year**	**Absorber**	**Flow type**	**Investigation tool**	**W/m^2**	**Kg/s**	**(%)**	
Abdullh et al.[21]	2020	Circular	Oscillating	Theoretical Model	500–1000	0.033-0.1	11.5	58.64
Rejeb et al.[22]	2020	Sheet-Tube	Chhanel	Mathematical Model	800		15.4	73
Barbu et al.[23]	2021	Roll Bond	Direct	Numerical Model	0–700	0.05	12.1	61.2
Rosli et al.[24]	2022	Tubular	Spiral	ANSYS CFD	800 – 1000	0.011	14.2	85.8
Prasetyo et al.[25]	2023	Finned	Direct	Solid-works	1000	0.05	11.3	69.3
Zohri et al.[26]	2024	Rectangular Absorber	Serpentine	ANSYS CFD	500–1000	0.0010.009	11.9	64.3
Alktranee et al.[27]	2023	Tubular	Serpentine	Experimental	0-950	0.016	12.4	45.8
Alktranee et al.[28]	2024	Tubular	Serpentine	ANSYS CFD	912	-	12.8	46.72
Present Study	2024	Semi Circular	Zigzag Flow	ANSYS CFD	800	0.05	13.6	76.7

Table 7. Comparative analysis with recent works for PVT system.

	Decision criteria	Non cooled PV	Convention sprial circular PVT	Serpentine semi circular PVT	Zigzag semi circular PVT
Simple Payback Period	LTB	6.95	5.14	4.91	4.63
Discounted payback period (10%)	LTB	8.20	6.10	5.84	5.54
Internal rate of return	HTB	17	23	26	28
Debt Service Coverage Ratio	≥ 1.5	1.5	2.01	2.05	2.1

Table 8. Summary of economic analysis of PV and PVT systems. The technical and economic analysis shows that PVT system particularly Zigzag Semi circular PVT shown better techno-economic yield and has potential of commercialization. The system can be employed in hospitals, hotels and industies in large scale to fullfil demand of hot water and backup electicity in more efficient and sustainable manner.

proposed absorber system and it was found that zigzag thermal absorber based PVT system showed lowest payback period of 4.63 years with highest rate of return of 28%.

- Zigzag thermal absorber based PVT recommended for manufacturing and further experimental work.This work can be further extended by varying mass flow rates and radiation in enlarge scale at various locations of globe to optimize zigzag thermal absorber PVT under experimental setting for real time performance.

Data availability
The datasets used and/or analysed during the current study will be made available from the corresponding author on reasonable request.'

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Declarations

Competing interests
The authors declare no competing interests.

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