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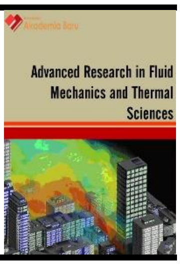

A Review: Parameters Affecting the PVT Collector Performance on the Thermal, Electrical, and Overall Efficiency of PVT System

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ABSTRACT

PVT solar systems are recently emerging solar technology that allows the simultaneous conversion of solar energy into both electricity and heat. The aim of these systems PVT is to improve the electrical efficiency with the cooling system by reducing the temperature of the cell. The performance of PV is reduced with the increase in temperature and use under the advice the absorber collector takes in the excess heat underneath the PV and transfers the heat through the working fluid such as water. The harvested heat is used for low-temperature applications such as domestic hot water supply, water preheating, and space heating. In this paper, the effects of the major control parameters on the thermal and electrical performance of PVT collectors are compiled and reviewed. Figures and tables are provided to give an overall picture of how PVT performance could be improved in terms of these parameters. Although investigators understand the effects of different parameters, the improvement of PVT performance by optimizing these parameters has not been fully realized.

Keywords:
PVT collector; Climatic-design-operational parameters Thermal efficiency; Electrical efficiency; Overall efficiency

1. Introduction

The effects of the major control parameters on the thermal/electrical performance of PVT collectors are compiled and reviewed by Moradi *et al.,* [1, 2]. Both air-and water-cooled PVT collectors have enjoyed the growing attention in recent years. Investigators have reported that PVT research data within a wide range of control parameters**.** In the mid-1970s, PV technology was directed towards the PVT system, where the problem of PV power degradation at high temperatures for PV panels began to draw attention due to its high potential for energy production. Solar technology consists of solar collectors and PV solar technology as shown in Figure 1.

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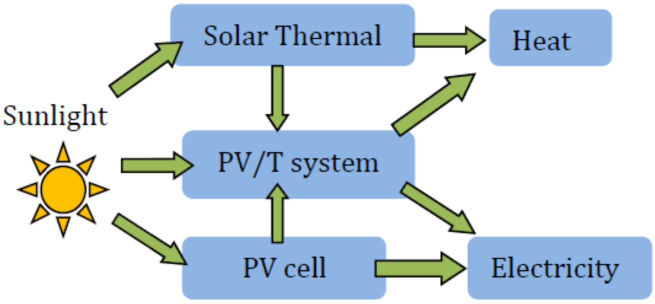


Fig. 1. Solar conversion technology tree

Hybrid PVT systems were proposed and revised by Martin Wolf [3]**.** Many designs have been considered to improve photoelectric performance and for that purpose, PVT collectors have been proposed. A good thermal conductivity between a heat absorption unit and a PV module can improve electrical and thermal efficiency. PVT technology has been developed in recent decades. According to a survey, each type of PVT system has its advantages, disadvantages, and applications, as shown in Table 1. Much research is needed to consistently improve their performance [4, 5]. The covered PVT has to compromise with electrical efficiency due to temperature rise while the other without cover suffers from lower thermal efficiency but has better electrical efficiency [6, 7].The development of a mathematical model by Touaibi *et al.,* [8] has been studied in order to optimize the absorption cooling machine by using the Lagrange multiplier method to the thermal model.

2. Factors Affecting the PVT Collector Performance

The following sections summarize the factors and related parameters that affect the performance of PVT (thermal and electrical) to discuss and evaluate the factors and improve electrical efficiency, as shown in Figure 2.

2.1 Climatic Parameters

Climatic parameters in this section are included

i. Solar radiation
ii. Relative humidity
iii. Wind speed
iv. Ambient temperature
v. Accumulated dust

Several research and development studies have been carried out to determine the effect of solar radiation on the performance of the PVT system. This section provides a summary of the following specific papers.

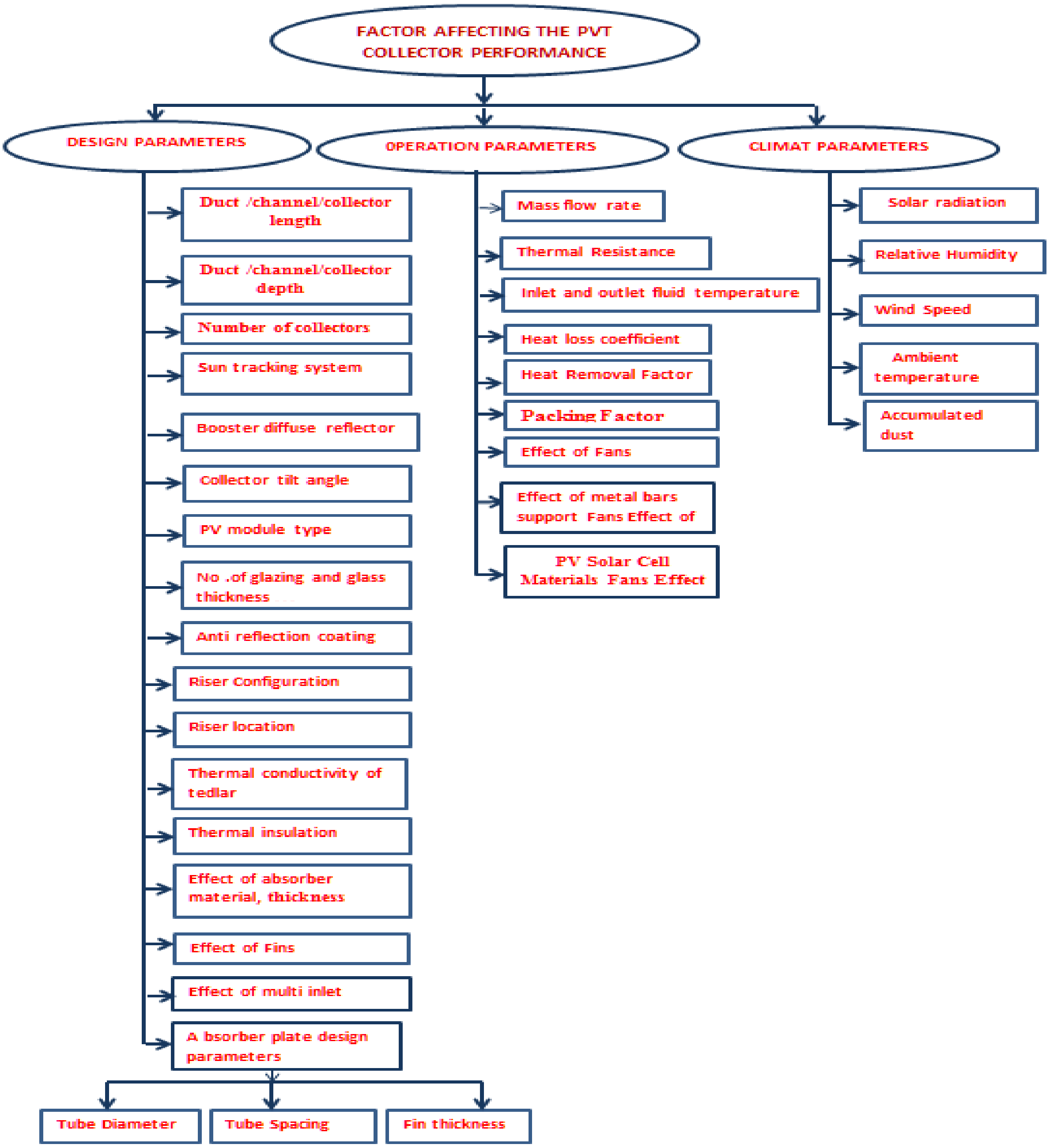


Fig. 2. Factors affecting the performance of the PVT collector

2.1.1 Solar radiation

Hamrouni *et al.,* [9] simulated the effects of solar radiation from (100-1000)W/m^2 in photovoltaic properties and produced the maximum power of the photovoltaic power generator at a constant temperature of 25 ° C, as shown in Figure 3. As a result, the short circuit current "I_{sc}" increases linearly as solar radiation increases, and the maximum power of the generator increases with increasing solar radiation.

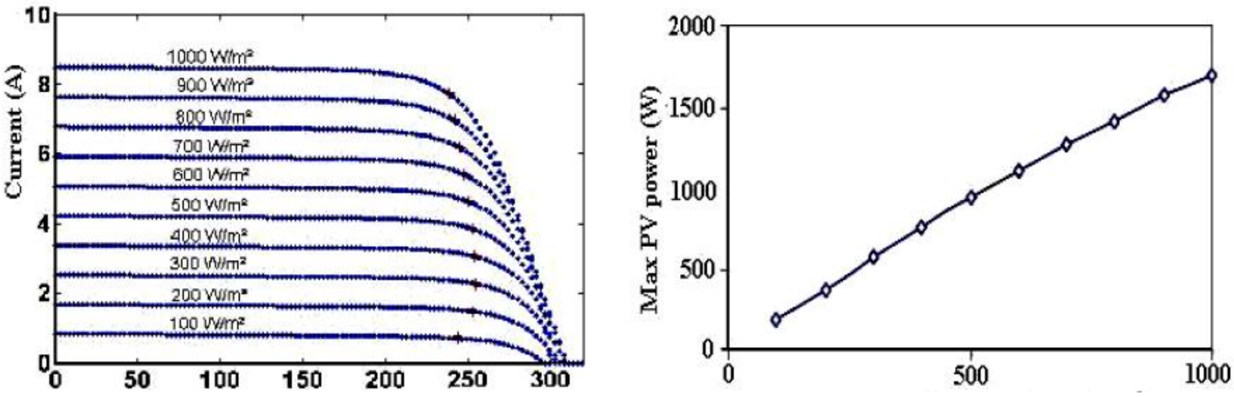


Fig. 3. The effect of solar radiation on PV and the maximum energy generated at a constant temperature of 25 °C [9]

They were studied by Imroz Sohel *et al.,* [10] on the effect of solar radiation at electrical efficiency. The increase in solar radiation at 100-1000 W / m ^{2} shows that efficiency increases by 11-11.6 % as shown in Figure 4.

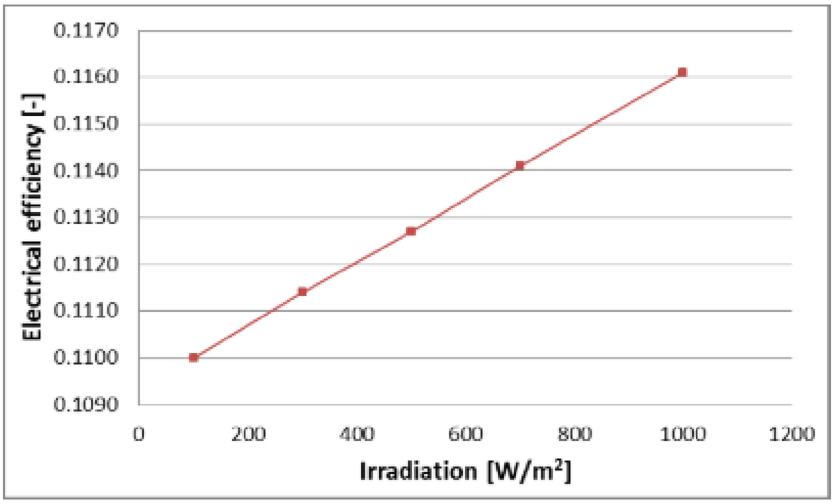


Fig. 4. Effect of solar radiation on electrical efficiency [10]

2.1.2 Relative humidity

The influence of relative humidity on photovoltaic efficiency was studied in Calabar by Njok *et al.,* [11]. They measured humidity during the day. The measured relative humidity decreased from 6:85% to 3:75%. The results showed that PV conversion efficiency increases with weekly relative humidity reduction, resulting in a relative humidity range of 70 to 75% as shown in Figure 5.

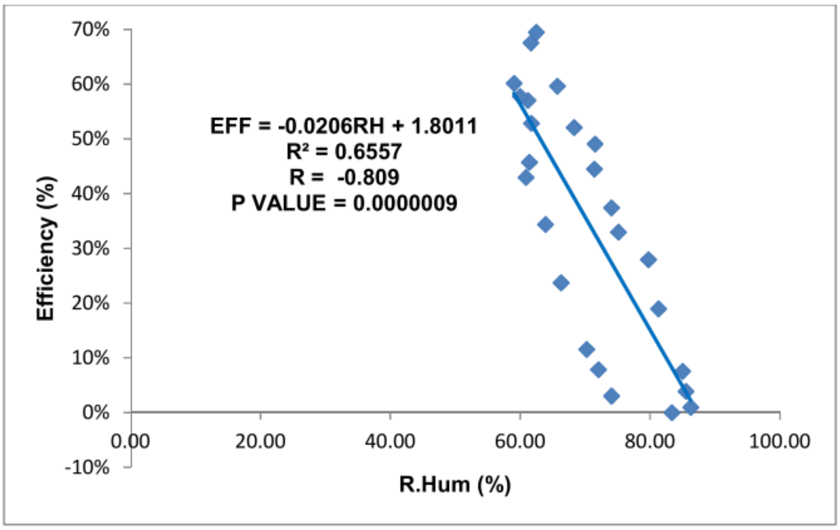
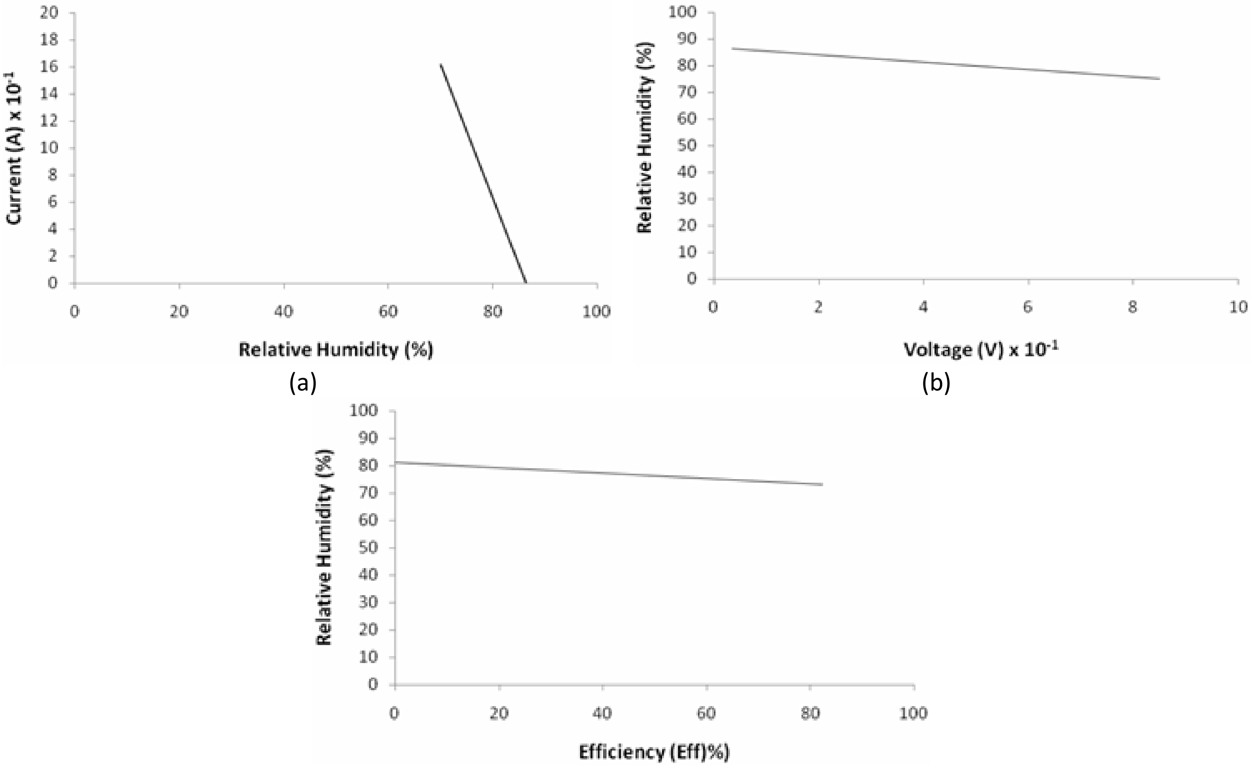


Fig. 5. Effect of relative humidity on efficiency [11]

Another study was conducted by Omubo-Pepple *et al.,* [12] and investigated the relative humidity effect on current output, output voltage, and photoelectric efficiency of the module, as shown in Figure 6(a), (b), and (c).



(a)

(b)

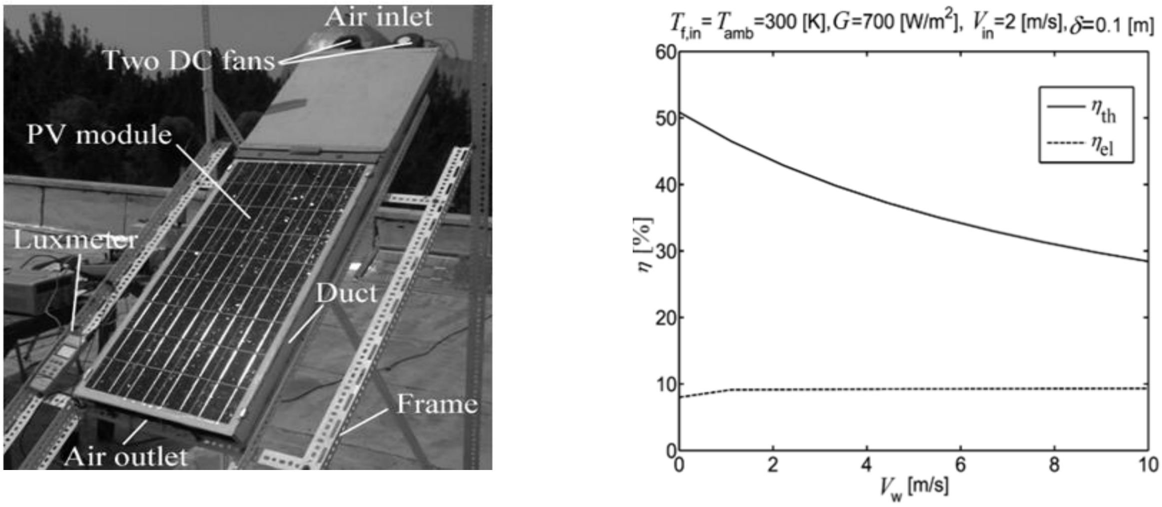
(c)

Fig. 6. Effect of relative humidity on (a) current (b) voltage and (c) efficiency [12]

2.1.3 Wind speed

Experimental work for typical PVT air collectors was created by Adeli *et al.,* [13] to measure energy performance. Figure 7(a) and (b) show wind speed effect on electricity and thermal efficiency.

The result shows that the higher the wind speed (0-10) m / s, the thermal efficiency is reduced from 51% to 29%, which increases efficiency from 8 to 9.5%. In another study.



(a)

(b)

Fig. 7. (a) Image of the experimental setup of hybrid air PVT collector and (b) Thermal and electrical efficiency with respect to wind speed [13]

In another study, Yang and Athenian [14] examined the impact of wind speed on the thermal efficiency of the PVT collector. Figure 8 explains the thermal efficiency against mass flow rate at different wind speeds, where thermal efficiency decreases as wind speeds increase at every wind speed. Based on the results of both studies, wind speed has proved to have a significant impact on reducing thermal efficiency.

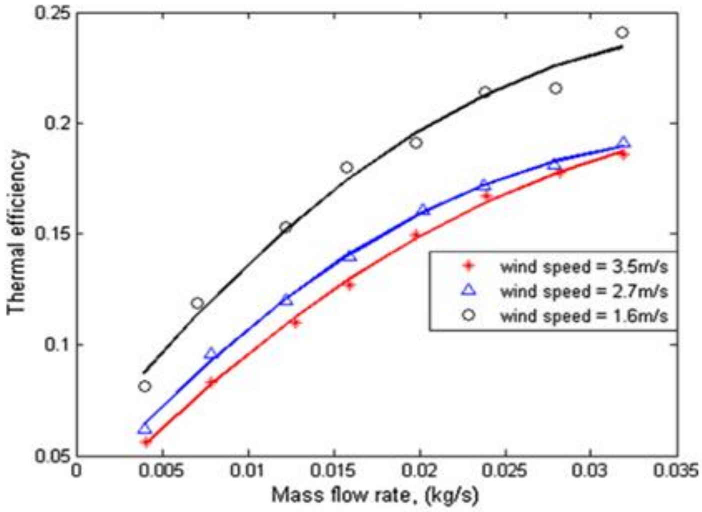


Fig. 8. Thermal efficiency of the PVT system with various wind speed [14]

2.1.4 Ambient temperature

In a similar study, Koech *et al.,* [15], where they analyzed the effects of different ambient temperatures on the performance of PVT based air systems. The results are shown in Figure 9, in which the higher the ambient temperature, the less efficient the electrical and thermal systems.

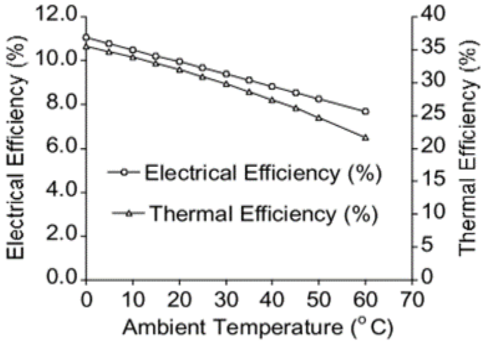


Fig. 9. Effect of ambient temperature on electrical and thermal efficiencies [15]

2.1.5 Accumulated dust

Elminir *et al.,* [16] assessed the transmittance of the glass after each thunderstorm in the surrounding area at intervals of about seven months. Figure 10 shows that the lack of permeability is due to the dust accumulated on the glass surface. This means that with increased sediments, the transmittance increases but decreases gradually until the upper limit is reached. As a result, the effect of dust accumulation disappears. The results showed that the density of dust deposition increased from 0 to 15.84 g / m^2 with a slope angle of 4.48 g / m^2, and improved transmittance at 90 ° is about 12.38-52.54%.

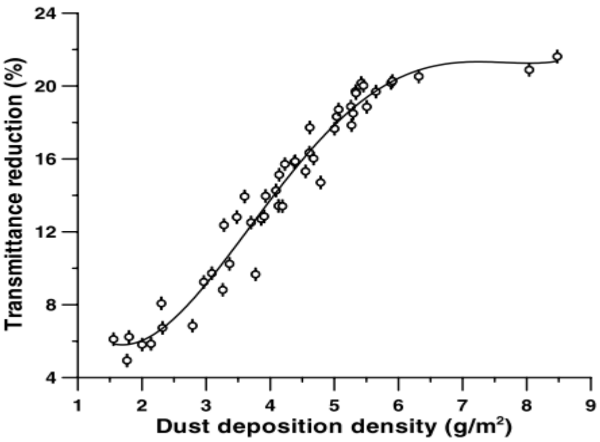
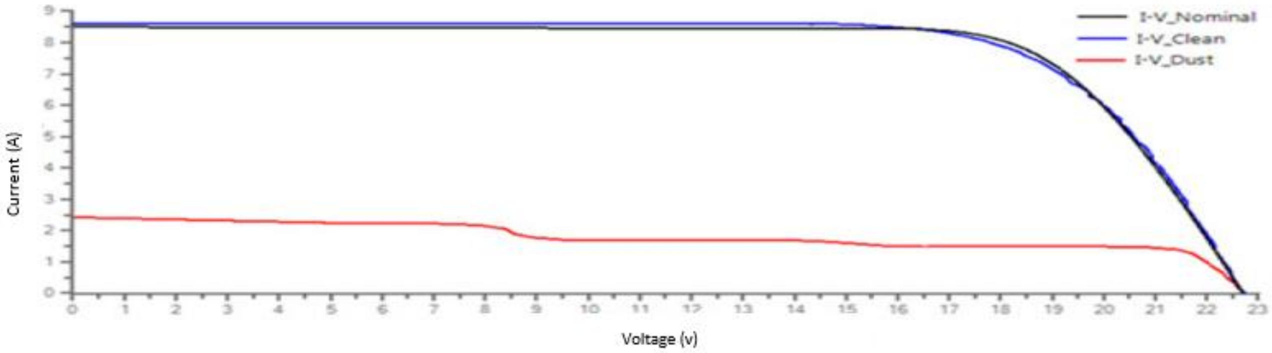
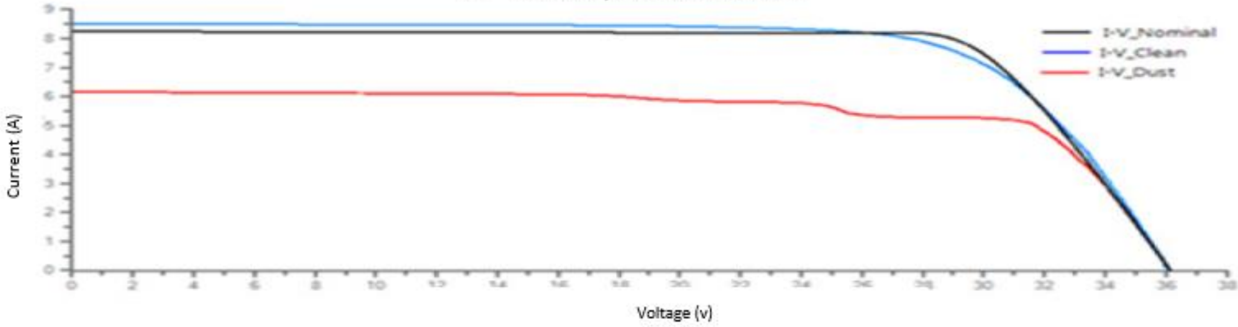


Fig. 10. Reduce transmittance as a function of dust adhesion density [16]

Ndiaye *et al.,* [17] studied the effects of dust on the performance of monocrystalline and crystalline PV modules and stressed that maximum energy, maximum current, short circuit current, and refill factor are the performance characteristics most affected by accumulated dust on Photoelectric Surface. Figure 11 and Figure 12 compares the properties of I-V and P-V for both models in clean and dusty conditions after one year of exposure. As a result, the maximum loss of production was found in the range of 18 to 78%, and the current maximum loss was changed to 23 to 80% in PC-Si and mc-Si, respectively. The output voltage and the open circuit voltage are not affected by the accumulated dust of both photovoltaic models.

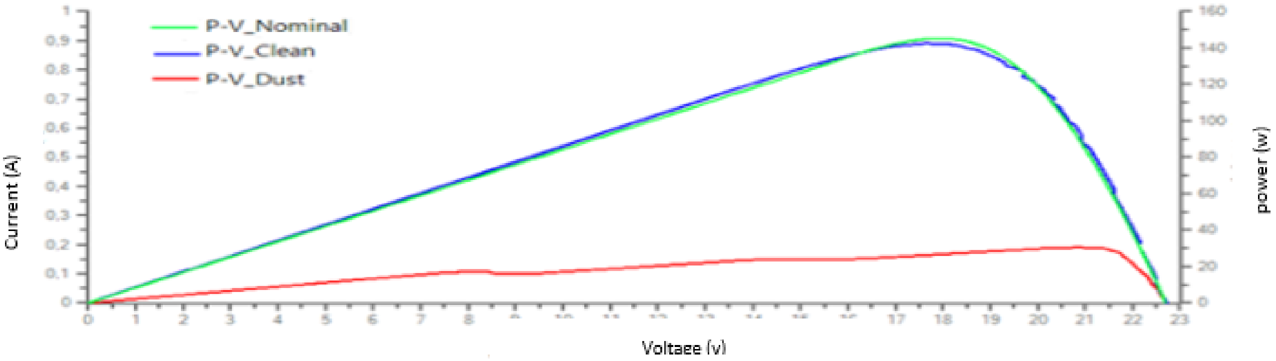


a- Monocrystalline PV module

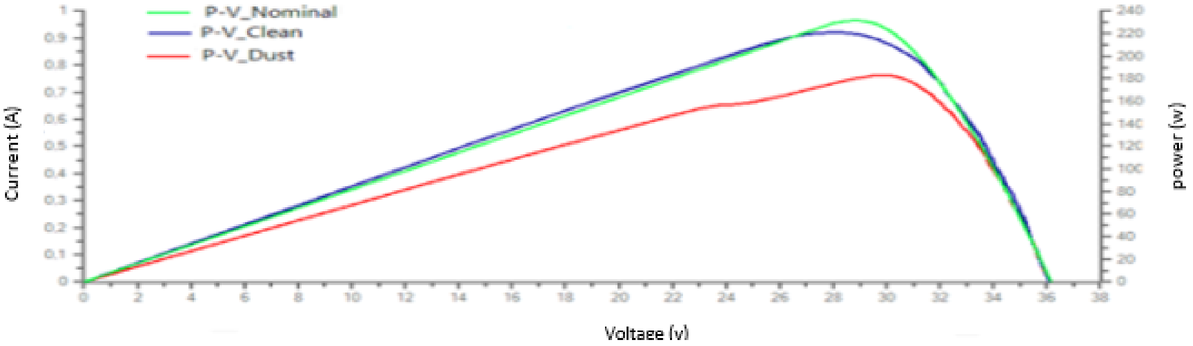


b- Polycrstalline PV module

Fig. 11. Comparison of I-V properties of clean and dusty PV modules after exposure for one year [17]



a- Monocrystalline PV module



b- Polycrstalline PV module

Fig. 12. Comparison of P-V properties of clean and dusty PV modules after exposure for one year [17]

2.2 Design Parameters

2.2.1 Duct/channel/collector length

Tonui and Tripanagnostopoulos studied [18] effects of channel length variation on electrical and thermal efficiency. When the channel depth is 0.05 m and the flow rate is 0.02 kg / s, the thermal efficiency increases with the length of the channel increases and remains constant with the length of the collector increased, as shown in Figure 13. On the other hand, electrical efficiency decreases by increasing the length of the channel, while the PV temperature increases as a function of channel length and reduces electrical efficiency.

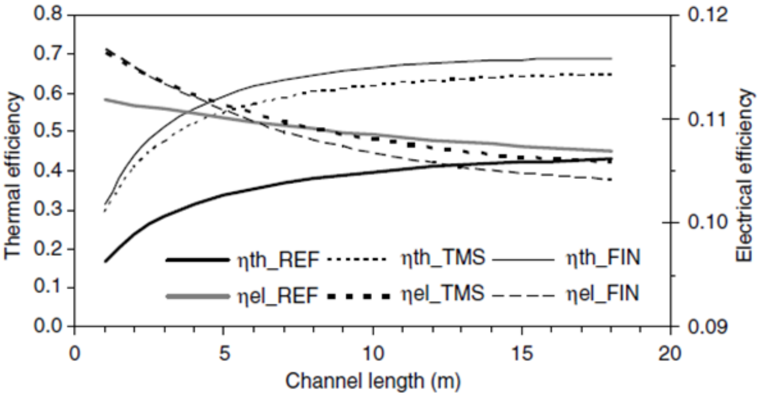


Fig. 13. Effect of different channel lengths on collector performance [18]

Koech *et al.,* [19] investigated the effect of changing the length of the PVT air collector while maintaining constant cell PV coverage. Results obtained as shown in Figure 14 shows that thermal efficiency has improved as the length of the collector increases, in which offset by a drop in the electrical efficiency resulting from maintaining the packing factor constant as the length of the collector.

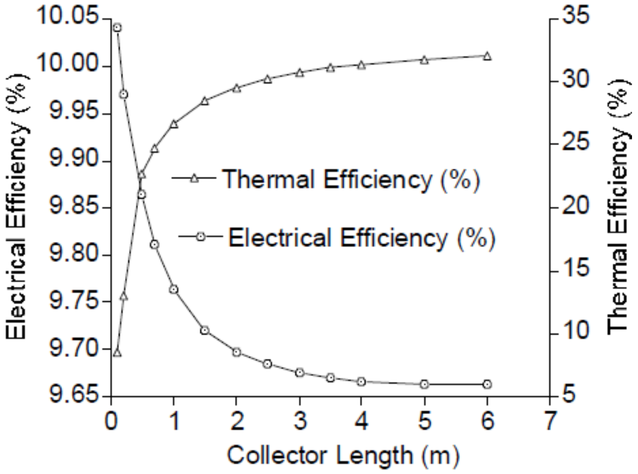


Fig. 14. Effect of different collector length on system performance [19]

2.2.2 Duct/channel/collector depth

Adeli *et al.,* [20] studied the effects of changes in electrical and thermal efficiency at channel depth. According to Figure 15, the results revealed that increased duct depth from 0.001 to 0.2 m, thermal efficiency increases from (0 to 48%). On the other hand, electrical efficiency has a slight effect when changing duct depth (8%) increase.

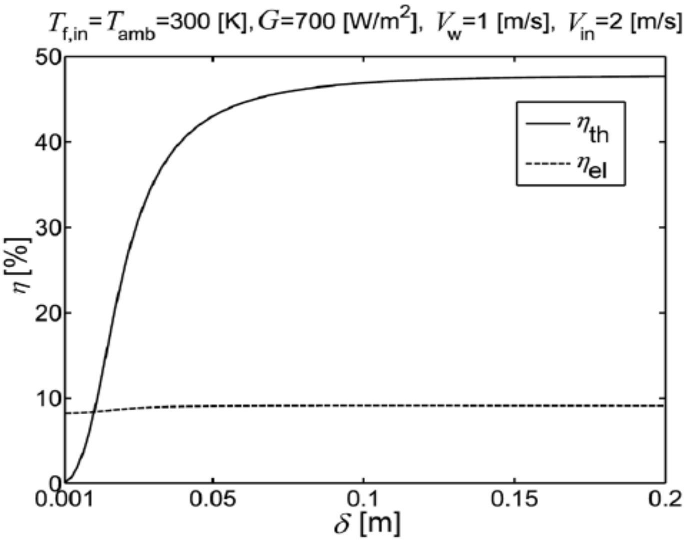


Fig. 15. Variations of thermal efficiency and electrical efficiency with respect to duct depth[20]

Tonui and Tripanagnostopoulos [21] duct depth optimized to improve the system performance. They found that the optimum value of the duct depth at 0.15m reduced the temperature of the PV panel by 3°C and improve the heat transfer rate from 1 to 2%. As shown in Figure 16.

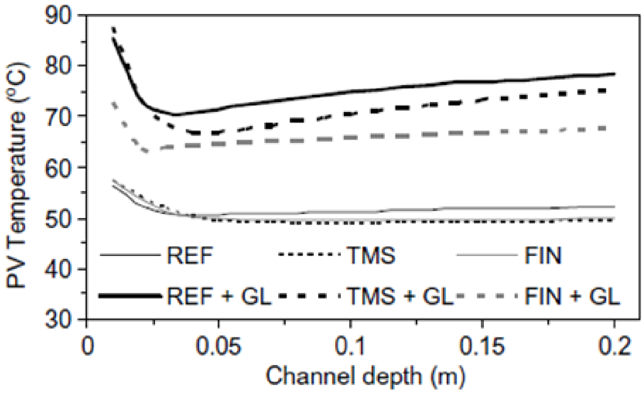
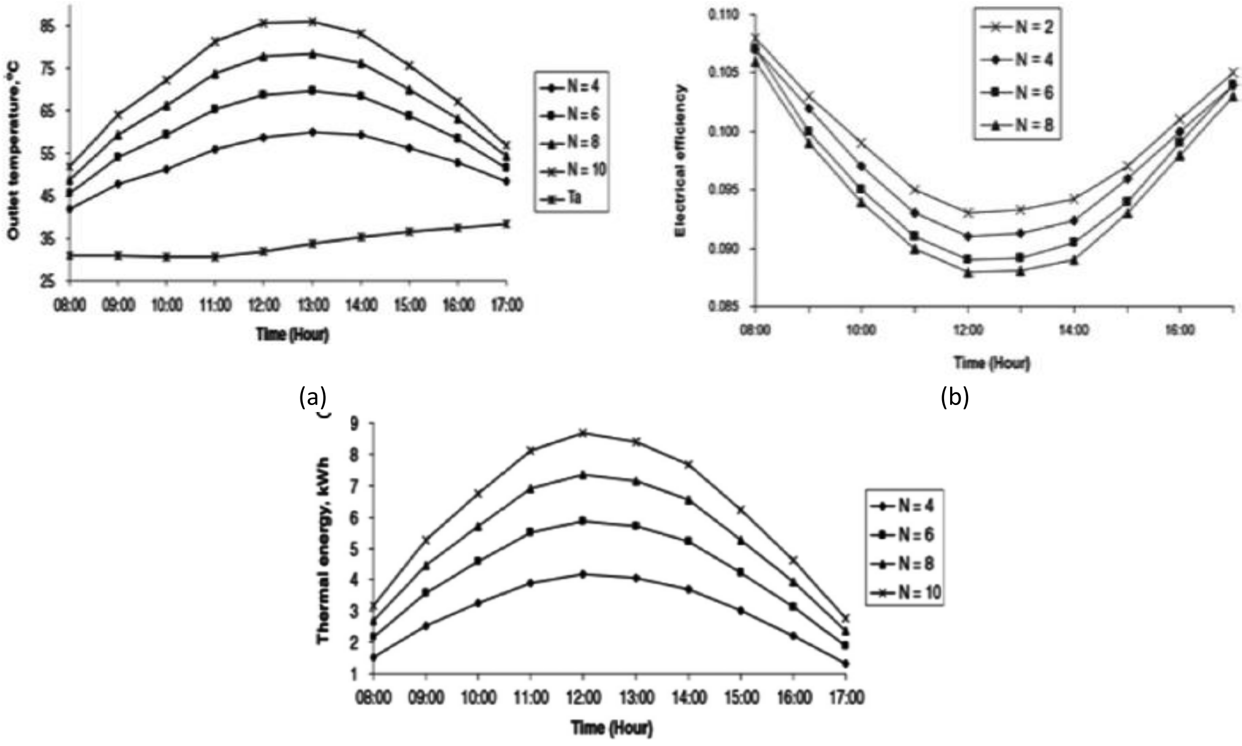


Fig. 16. Thermal efficiency and electrical efficiency depend on channel depth [21]

2.2.3 Number of collectors

A theoretical study on Tiwari.[22] investigated the effect of a number of collectors (2 to 8) under a constant flow rate (0.04kg/s). As shown in Figure 17(a)-(c). The results showed that with the increase in the number of collectors in the chain, the temperature rises, thermal efficiency increases, and electrical efficiency decreases. As Figure 17(b) shows, increasing the number of collectors increases the PV temperature and reduces cell efficiency from 9.1 % to 8.6 %.



(a) (b)

(c)

Fig. 17. (a)-(c) The increase in the number of collectors increases the temperature, thermal efficiency and decrease electricity efficiency over time [22]

2.2.4 Sun tracking system

Solar tracking systems are devices that provide maximum power. Efficiency by tracking photovoltaic units in the optimal direction towards the sun. This can be done using a single-axis or two-axis system. Dual Axis Tracking is used by multiple or single researchers. Axis tracking systems increase the energy generated in the PV model [23].

Turkey by Kacira *et al.,* [24], Figure 18 shows the total amount of solar radiation measured vertically on the surface of fixed and pivotal tracking plates on certain days of 18-06-2003. They concluded that there was a large amount of solar radiation that could be used to produce electricity in the early morning and in the late afternoon. The output results obtained from Figure 19. With the use of the solar tracking system, the average daily gains of solar radiation improved by 29.3%, followed by the improvement of power generation by 34.6%.

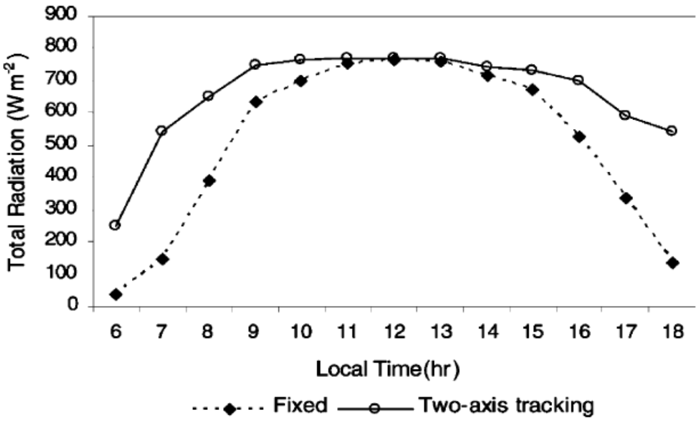


Fig. 18. Total radiation at the receiving time by the fixed and pivot track panel in Sanliurfa [24]

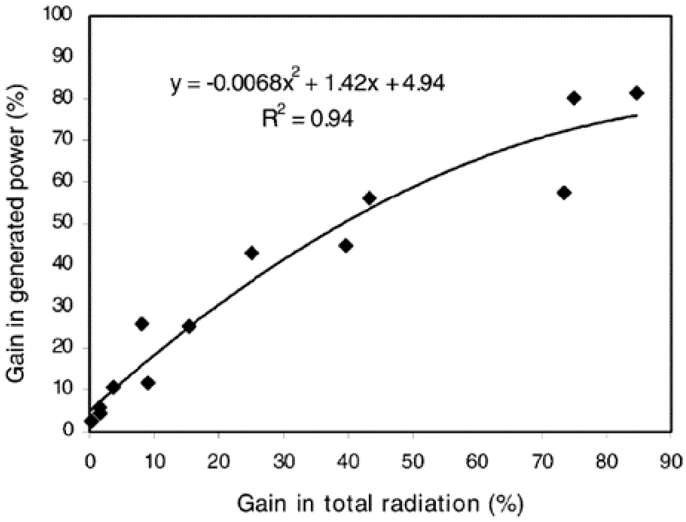
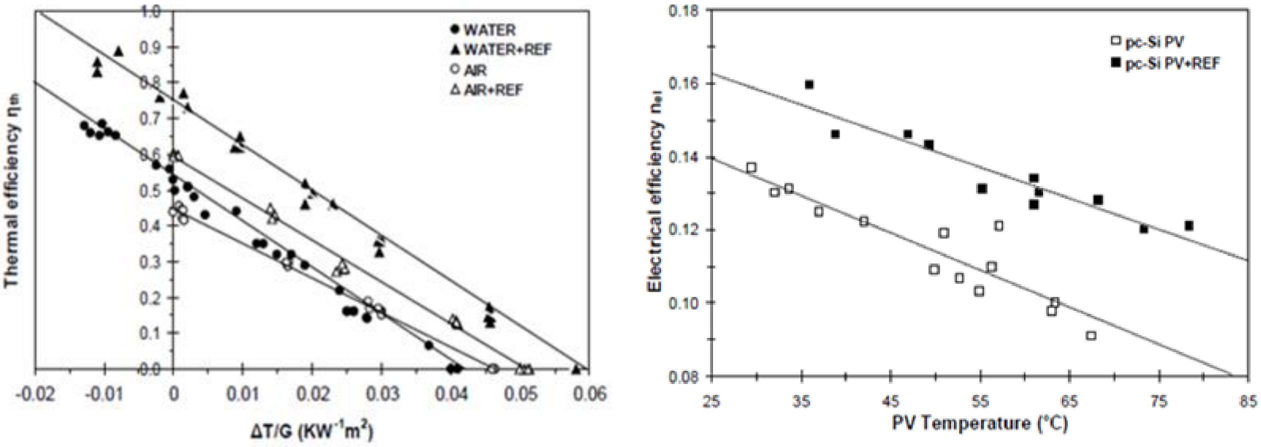


Fig. 19. Gain in generated power versus gain in total solar irradiance by PV panel [24]

2.2.5 Booster diffuse reflector

A booster diffuse reflector received a great deal of attention. Many researchers focus on sunlight on solar panels to increase electricity generated. The dual heat extraction system using PVT was tested with air or water as a fluid for heat removal outdoor by Tripanagnosto Poulos *et al.,* [25] It integrates the proposed system and the booster diffuse reflector and adjusts the reflector to achieve an additional 35% solar radiation from the booster diffuse reflector on the PV surface and improve the total energy output of the system by 30%. As shown in Figure 20 (a), thermal efficiency was improved from 55% to 75% in the case of water, but from $T_a = T_{in}$, the air efficiency was improved from 45% to 60%. In addition, an enhancement in the electrical output is shown in Figure 20(b).



(a) (b)

Fig. 20. (a) and (b)The thermal and electrical efficiency results of a dual PVT modulation of general and proposed mode with booster diffuse reflector [25]

2.2.6 Collector tilt angle

The thermal and electrical performance of the PVT collectors was analyzed by Kaya [26]. Under climatic conditions in Ras Al Khaimah, United Arab Emirates. The PVT system is designed for residential use and simulated using the Polysun simulation program. They tested 19 different tilt effects from 0 ° to 90 ° for the performance of the designed system as shown in Figure 21. As a result, a 25 ° angle was found to provide maximum electrical output throughout the year.

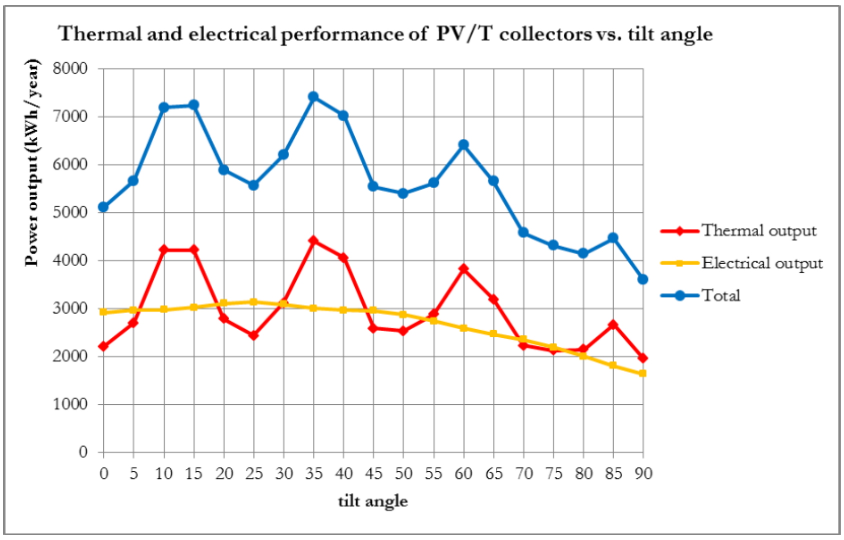


Fig. 21. Thermal and Electrical Performance of PVT Collectors against Tilt Angle [26]

Studied by Irwanto [27] on Optimum Tilt Angles of PV Module as shown in Figure 22 that the tilt angle has a very significant effect on the solar irradiance throughout the year. For the different tilt angle, the PV module has different solar irradiance throughout the year. For horizontal PV module, the minimum, maximum, and average solar irradiance are 934.7 W/m^2, 1081 W/m^2, and 1016 W/m^2, respectively. The optimum tilt angle of the PV module is determined by searching a yearly maximum total and average solar irradiance. This choice is based on that under constant temperature if the solar irradiance increases, output power and efficiency of the PV module will increase.

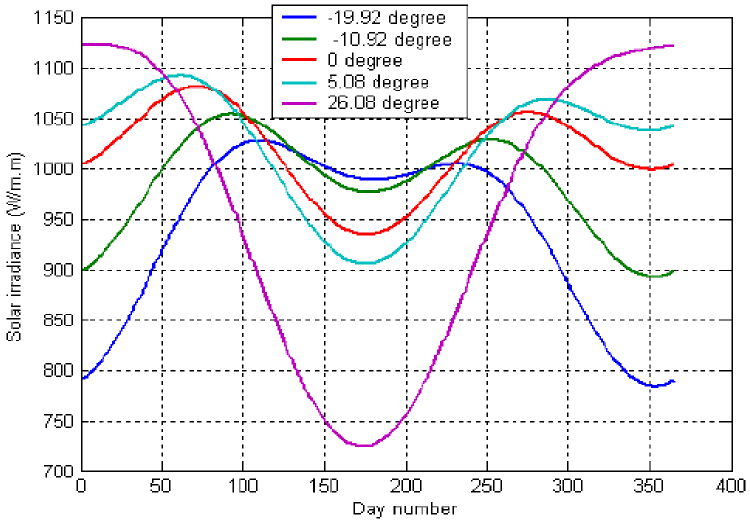


Fig. 22. Solar irradiance through the year on different tilt angle of PV module [27]

2.2.7 PV module type

Daghigh *et al.,* [28] Design and evaluation of a new design concept for PVT collectors used to build integrated applications. The units and the following assumptions are considered: Si type and c-Si, solar radiation between 700-900 W/m^2, Malaysia climate and fluid flow rate at 0.02 kg / s and ambient temperature between 22 - 32°C. As a result, the electrical, thermal, and total efficiency of PVT a-Si was 4.9%, 72%, 77% respectively, 11.6%, 51%, and 63% for PV-c, as shown in Figure 23. They also observed that c-Si has higher electrical efficiency than a-Si. The mc-Si and PC-Si solar cells are better than the a-Si solar cells in improving electrical production.

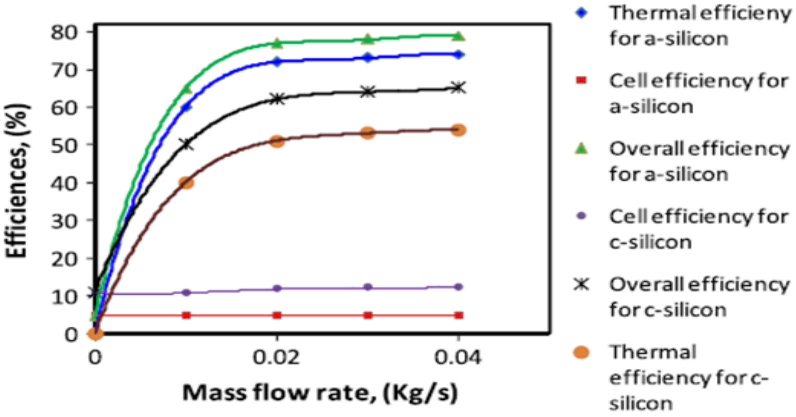


Fig. 23. Efficiencies versus mass flow rate of coolant [28]

2.2.8 Number of glaze and thickness of glass

The effects of thickness and various glazing material on the performance of flat solar collectors were analysed by Bakari *et al.,* [29]. They found that the performance of solar collectors has been affected by several parameters such as glass transmittance, glass absorptance, and glass reflectance. In theory, four solar collectors were studied with a low iron glass thickness of 3 mm, 4 mm, 5 mm, and 6 mm, and were experimentally verified. As shown in Figure 24, the thickness of the 4 mm low iron glass has a significant effect on the efficiency of the collector and the efficiency is 35.4% compared with 27.8% of the 6mm glass thickness.

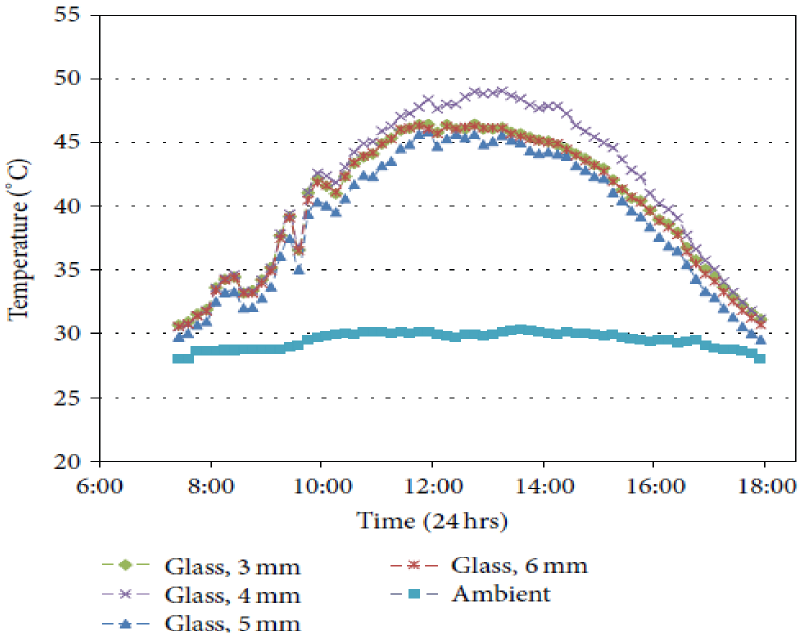


Fig. 24. Personal energy of different glass thickness [29]

Zondag *et al.,* [30] confirmed the choice of glazed or unglazed PVT collector depends on the application. Therefore, for applications at low temperatures and high demand for electrical power, th e unglazed PVT collector used at high temperatures application is the best option, as shown in Table 1.

Table 1
Thermal and electrical efficiency with glass and without glass [30]

Panel type	Thermal efficiency	Electrical efficiency
PV laminate	-	0.097
Sheet and tube PVT-collector 0 cover	0.52	0.097
Sheet and tube PVT-collector 1 cover	0.58	0.089
Sheet and tube PVT-collector 2 cover	0.58	0.081

Rosli *et al.,* [31] studied and determined the thermal efficiency of a polymer collector with unglazed (PVT) system. Overall heat loss was predestined using the heat energy balance method. Based on the analysis, the heat removal factor of the PVT system was found to be 0.55. The thermal performance of the system was 47% as shown in Figure 25. The figure shows the thermal efficiency of the unglazed PVT polymer collector. The unglazed PVT polymer collector could replace the conventional PVT collector, which encountered problems such as high cost, weighting issues, and corrosion.

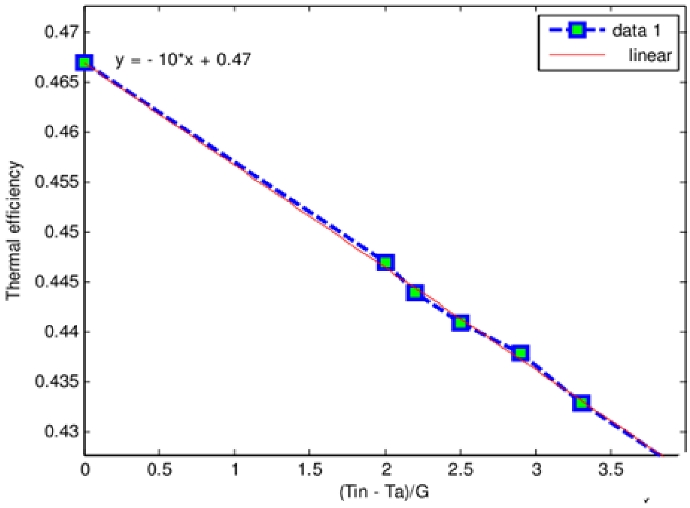


Fig. 25. Thermal efficiency of unglazed PVT polymer collector [31]

The study by Khaki *et al.,* [32] focused on the improvement in the energetic and the energetic performances of glazed and unglazed building integrated photovoltaic/thermal (BIPV/T) systems. The results optimized glazed system has higher than the unglazed system, values of thermal and electrical efficiency 39.27% and 10.75%, respectively and unglazed system (33.68% and 10.51%, respectively) as shown in Figure 26. Additional empirical studies for each major type of absorption described in this section are summarized in the table below and in Table 2.

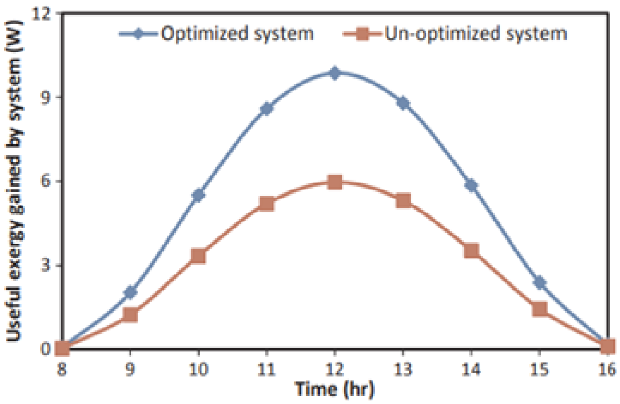
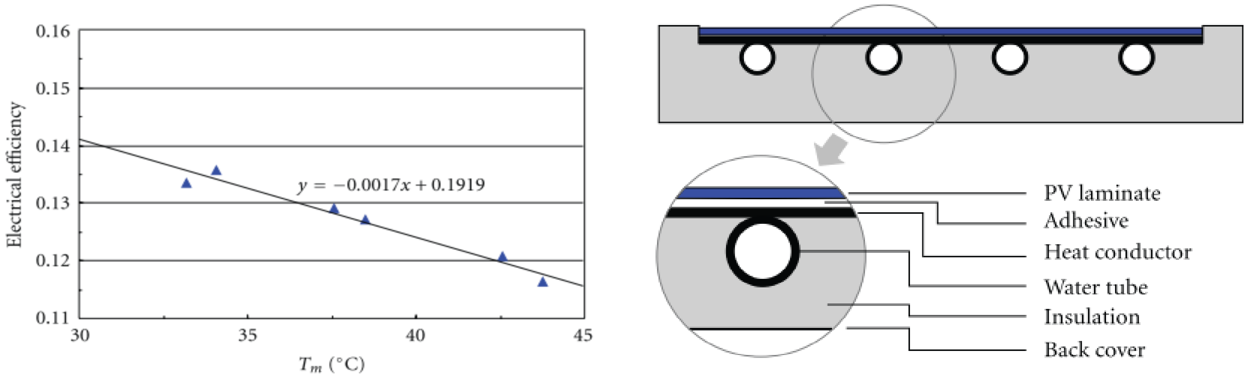


Fig. 26. Useful exergy gain for un-glazed and glazed BIPV/T system [32]

Table 2
Key Features Were Analyzed

Plate type	PVT Type	Mass flow rate (kg/s)	Thermal efficiency	Electrical efficiency	Analysis type	Refs.	Result
Sheet and tube	Uncovered	0.02	66%	14%	Experimental	Kim and Kim [33]	Figure 27 (a)(b)
Roll Bond	Uncovered	0.02	31.5 32.9 % 33 %	Paris 13% Milan 13.6% Athens13.4%	Experimental and Analytical	Aste *et al.,* [34]	Figure 28
Sheet and tube	Uncovered			12.18 %	Experimental	Qu *et al.,* [35]	Figure 29
roll bond	Uncovered	0.011 to 0.041	(41.1-48)%	(11.9-12.4)%	Experimental &Numerical	Fudholi *et al.,* [36]	Figure 30



(a) (b)

Fig. 27. (a) Electrical efficiency of the sheet and tube PVT collector and (b) cross section of the sheet and tube PVT [33]

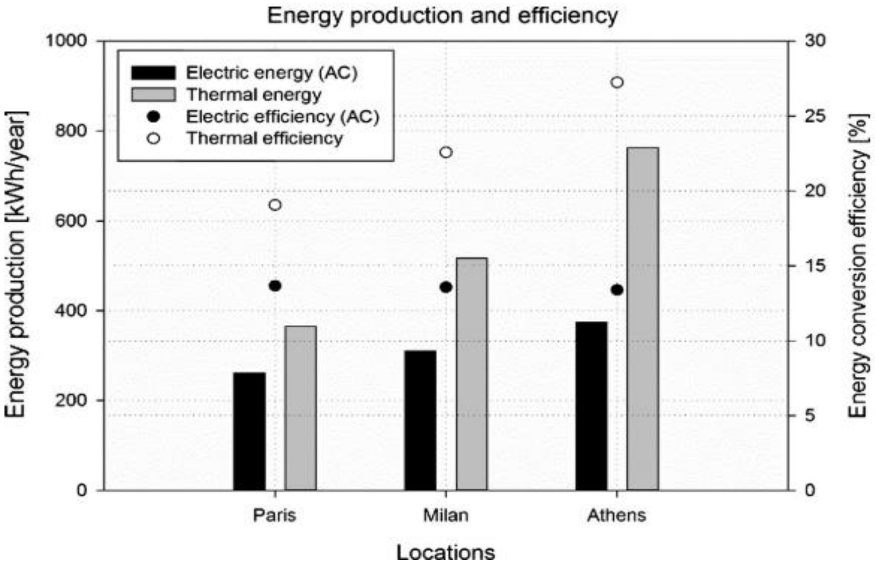


Fig. 28. Electrical and thermal energy production and efficiencies of the system [34]

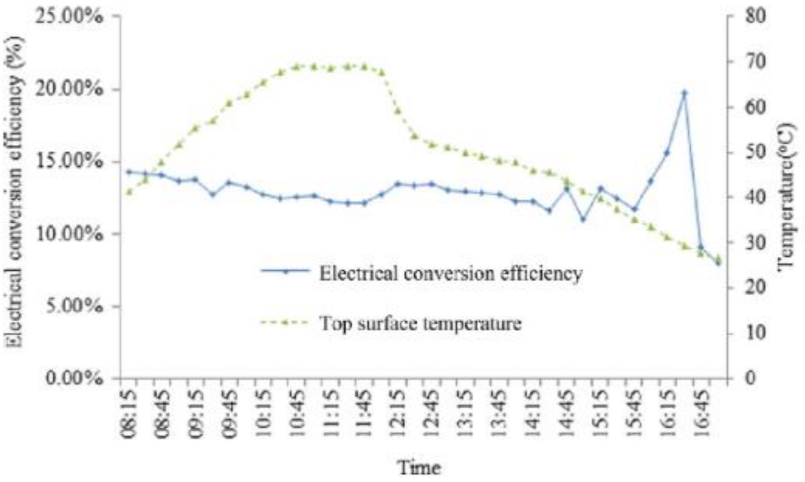


Fig. 29. The variations of top surface temperature of the PV panel and the electrical conversion efficiency [35]

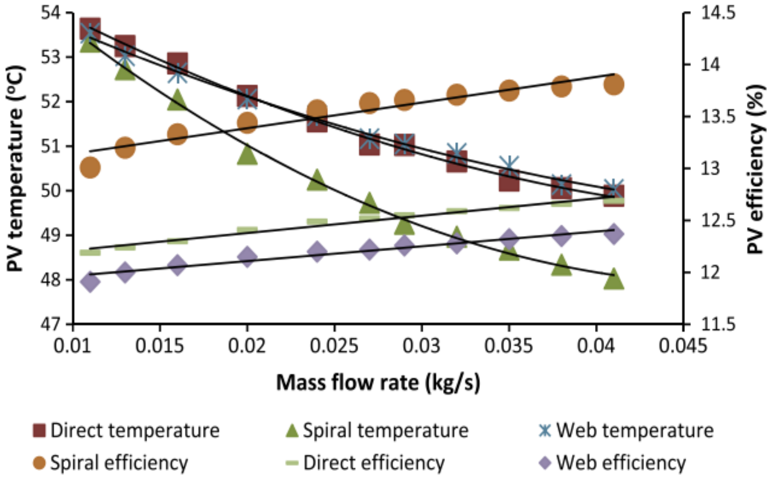


Fig. 30. Change in PV efficiency with average PV temperature for PVT absorber collectors at 800 W/m ^{2}of solar radiation [36]

Studies by Abakam *et al.,* [37] Compare the daily average electricity, thermal and total efficiency of the new PVT system (without cover or cover) compared to the conventional PVT. The results are shown in Figure 31.

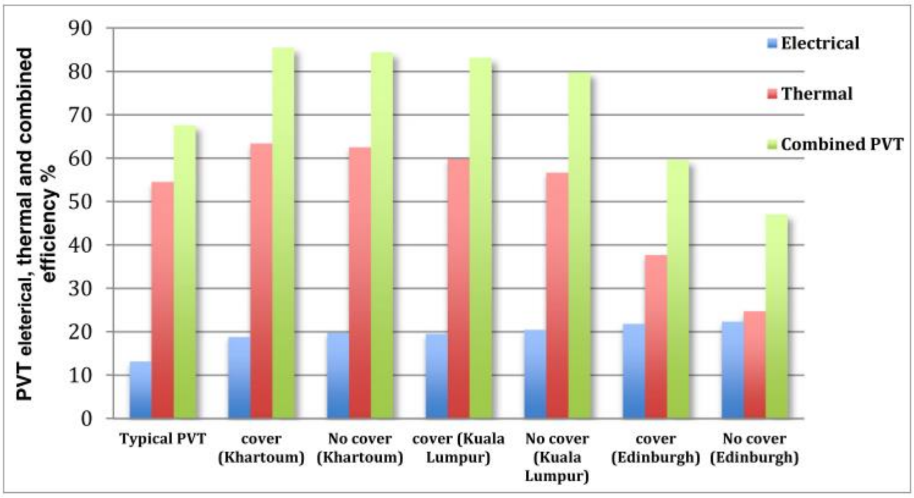


Fig. 31. Comparison of total PVT efficiency in three regions and conventional PVT located in Kuala Lumpur [37]

2.2.9 Anti reflection coating "ARC"

The study of Mahadik *et al.,* [38] on anti-reflective coatings "ARC" was very important because of its ability to improve the efficiency of solar cells and reduction of light falling from the upper surface. A silica “SiO2” single layer anti-reflection coatings when they have been exposed to the air for 1 year, the transmittance decreases about 0.6% as shown in Figure 32.

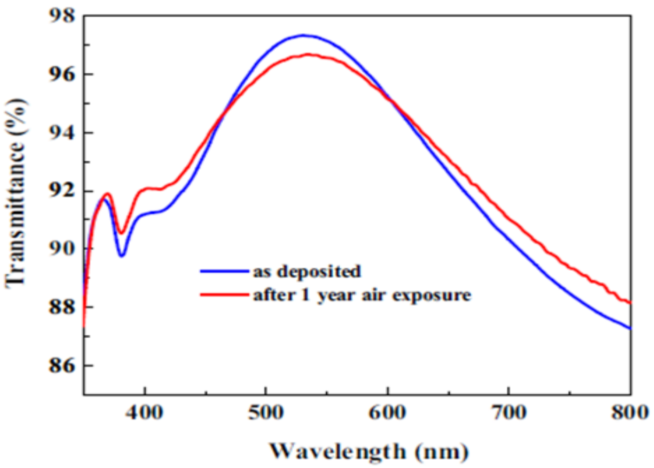


Fig. 32. Transmittance spectra of AR coating before and after exposure to air for 1 year [38]

2.2.10 An absorber plate design parameters

The studies by Yahia *et al.,* [39] are on the effect of Tube Diameter and length on collector`s efficiency with a range of available Copper tube diameters (8, 8.64, 13.84, 16.92 and 19.94 mm), the result shown in Figure.33, the effect of the tube diameter on the efficiency in the range of 8 (mm) to 19.94(mm)did not exceed 2 %.

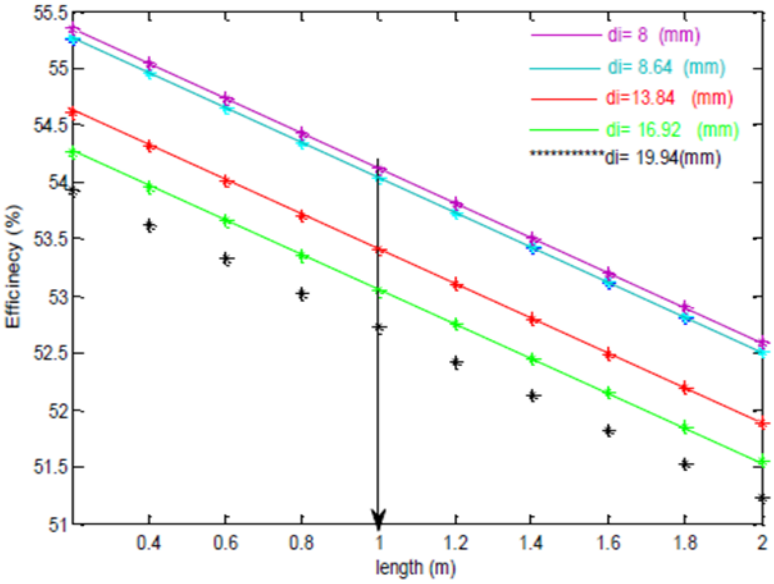


Fig. 33. Effect of Tube Diameter and length on collector’s efficiency [39]

Studies by Rosli *et al.,* [40] is about the four designs of the serpentine absorber collector. Table 3 shows the analysis parameters and profile details of the serpentine collectors. From the calculations, design 4 has the highest heat removal factor, followed by designs 2, 3, and 1. This finding shows that a small diameter gives high heat removal. The number of tubes of design 3 gave the design advantage. Design 3 has 13 tubes compared with design 2 that has only 9 tubes. A high number of tubes result in efficient heat transfer due to the high effective area, which in turn increases the FR value.

Table 3
Configuration detail of serpentine profile

Design	1	2	3	4
Shape	Square	Round	Rectangle	Round
Dimensions(mm)	Length*Height 20*20	Diameter 15	Length*Height 25*15	Diameter 20

2.2.11 Riser configuration

In order to investigate the effect of different riser configurations on heat transfer in the FPC flat panel collector, four simulations were studied by Ekramian *et al.,* [41] such as (f) triangular, (g) square, (h) hexagonal and (c) circular shape riser tubes as seen in Figure 34. The simulation results were performed at a constant mass flow rate of about 0.02 kg / s. They have stated that the circular shape (model c) is the most efficient design to produce a high collector efficiency, as shown in Figure 35.

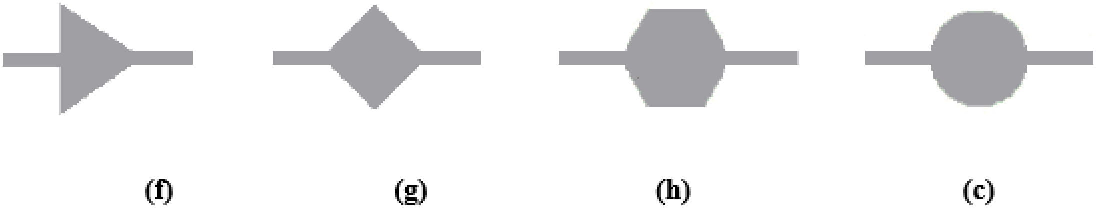


Fig. 34. Four various of riser tube form proposed by [41]

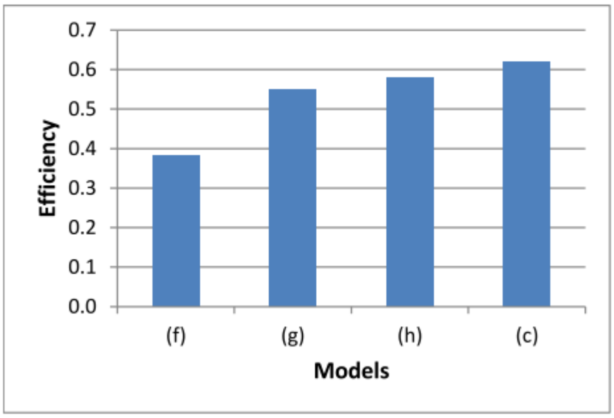


Fig. 35. Efficiency of collector with circular and non-circular riser tube [41]

The photovoltaic-thermal PVT water collectors thermal and electrical performance was investigated by Sachit *et al.,* [42] for two absorbers design and comparative study between them. The first design, where a new PVT (serpin-direct) is shown in Figure 36. The second design of PVT (Serpentine Flow Design) is shown in Figure 37. The results indicated that serpin-direct PVT design achieved 53% thermal and 14.3% electrical efficiency, respectively as shown in Figure 38 and Figure 39.

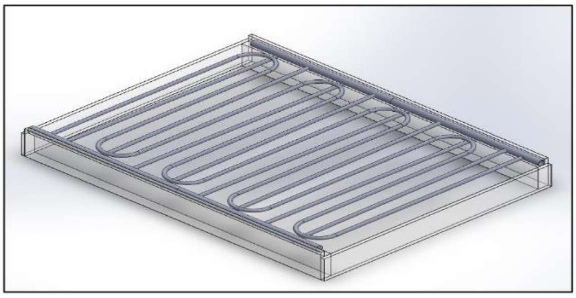


Fig. 36. Serpin- Direct Design of PVT [42]

Fig. 37. Serpentine Flow Design of PVT [42]

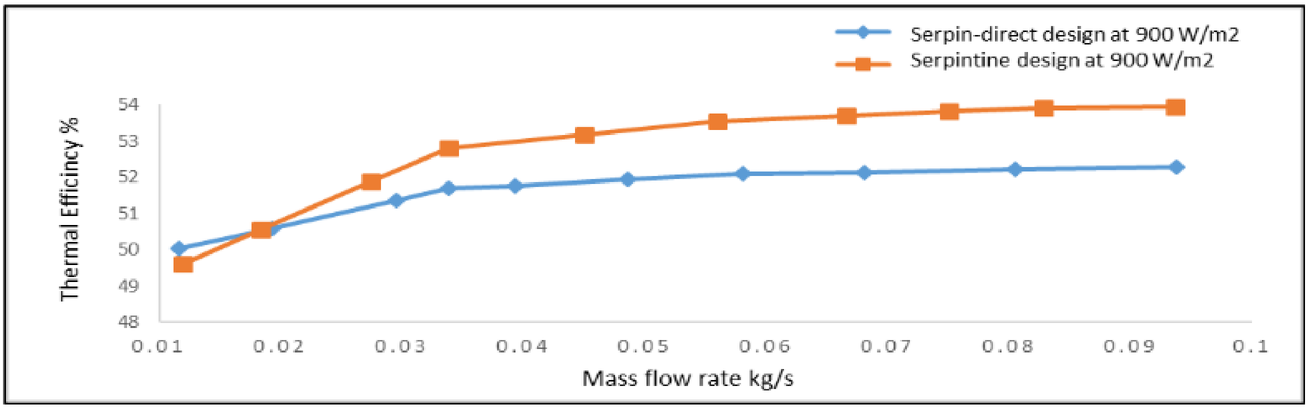


Fig. 38. Variations in Thermal Efficiency of the PVT collectors under 900 W/m^2 of solar radiation [42]

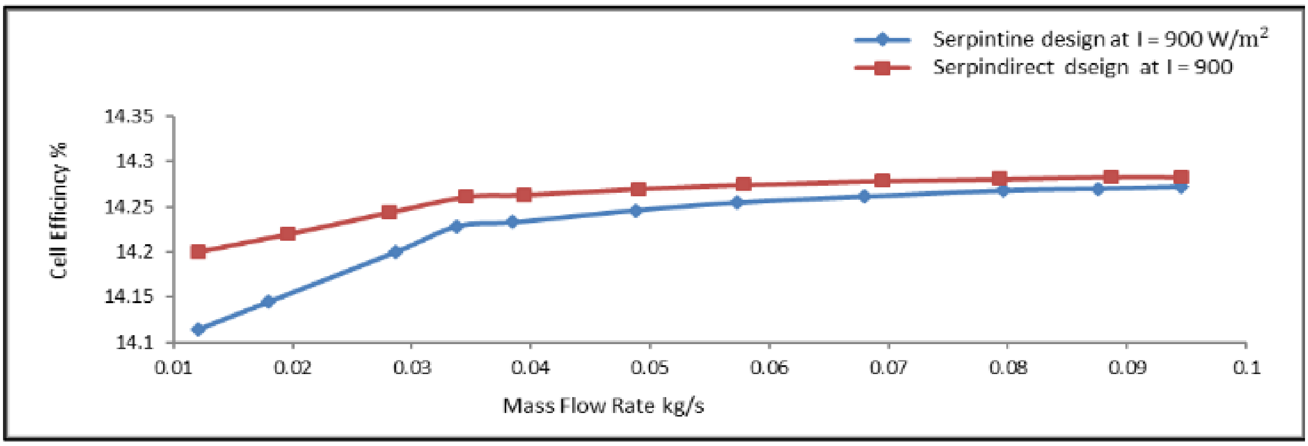


Fig. 39. Variations in Cell Efficiency of the PVT collectors under 900 W/m^2 of solar radiation[42]

2.2.12 Riser location

A three-dimensional numerical simulation was performed by Ekramian *et al.,* [41] to investigate the effect of the riser position on the thermal efficiency of the collector. In their study, the five positions of the riser's effect of the absorption plate are related. Figure 40 shows the form (a, b). The riser tube is connected to the upper surface of the absorption plate. The model (c) shows the riser located in the middle of the absorption in the model (d, e). The risers are attached to the bottom surface of absorption. The numerical results showed that the collector efficiency decrease with tube riser position changed from the top of the absorber to the bottom surface of the absorber plate as shown in Figure 41, and configuration (a) is found more efficient than the other configurations due to more collector's surface is available for heat transfer.

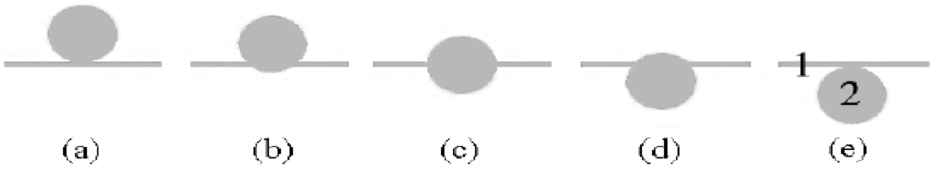


Fig. 40. Different locations of riser and absorber (1) plate absorber (2) riser tube [41]

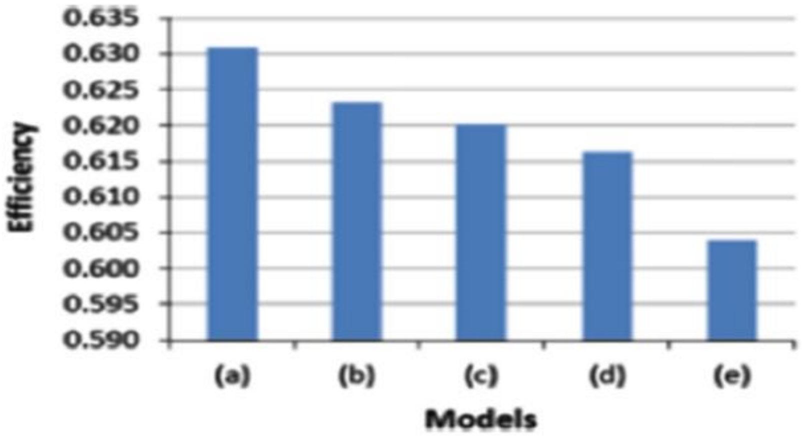


Fig. 41. Efficiency of collector with various riser positions [41]

2.2.13 Thermal conductivity of Tedlar

Tiwari and Sodha [43] tested the performance of four configurations of hybrid PVT air based collectors experimentally namely, unglazed Model (a) with Tedlar (b) without Tedlar, glazed model (c) with Tedlar, and (d) without Tedlar as shown in Figure 42. The result showed that the glazed hybrid PVT system without Tedlar showed the best choice in enhancing the system performance compared to the other configurations as shown in Figure 43.

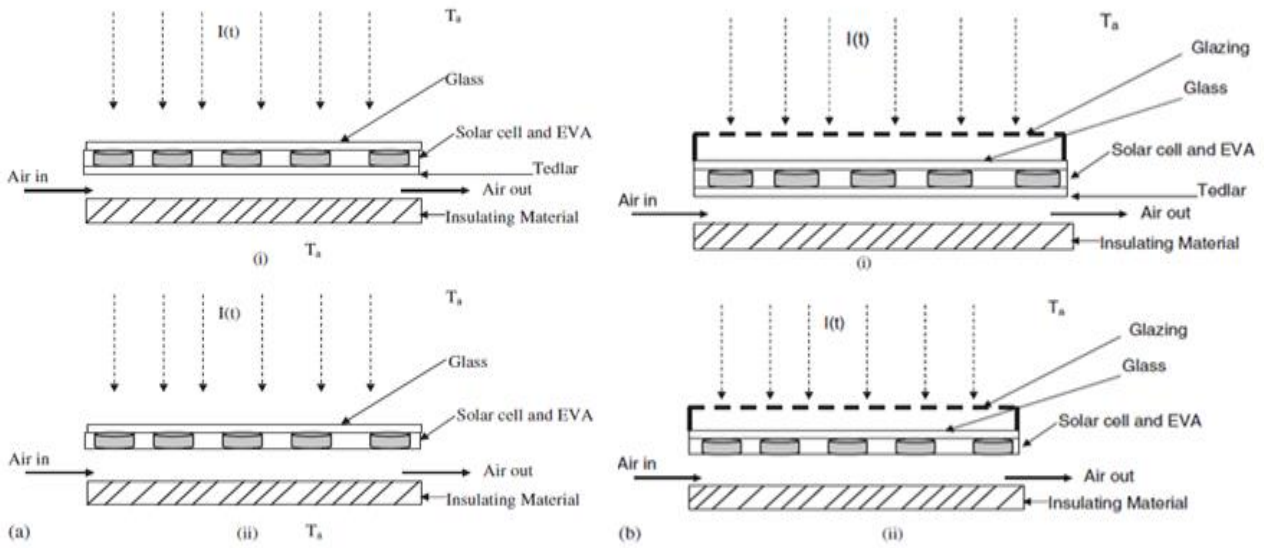


Fig. 42. (a) Cross-sectional view of unglazed PVT air (i) with tedlar (Model I), (ii) without tedlar (Model II). (b) Cross-sectional view of glazed PVT air (i) with tedlar (Model III), (ii) without tedlar (Model IV) [43]

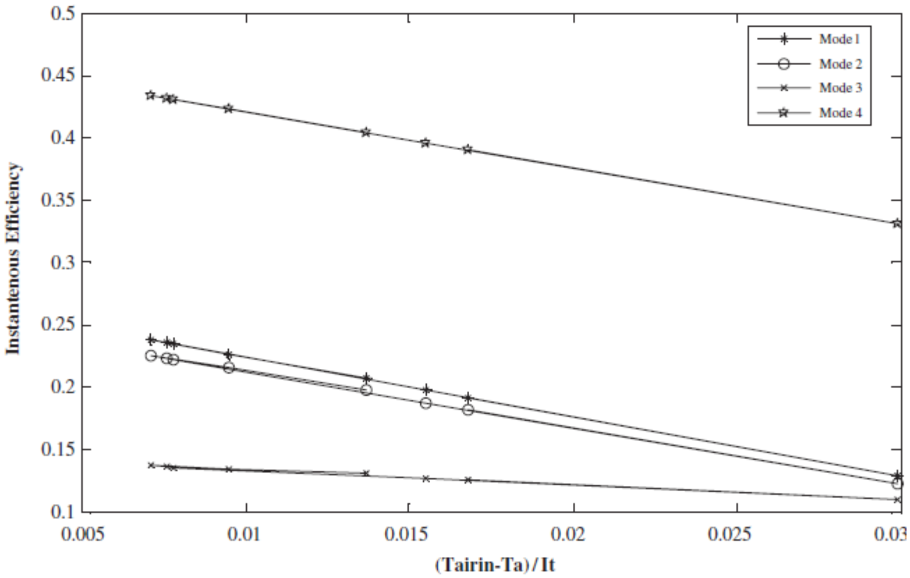


Fig. 43. Variation of instantaneous efficiency[43]

2.2.14 Thermal insulation

Saxena and El-Sebaii [44] classified the mostly used insulation materials as seen in Figure 44. From the result obtained, they found the glass-wool is widely used in solar air heating system "SAHS".

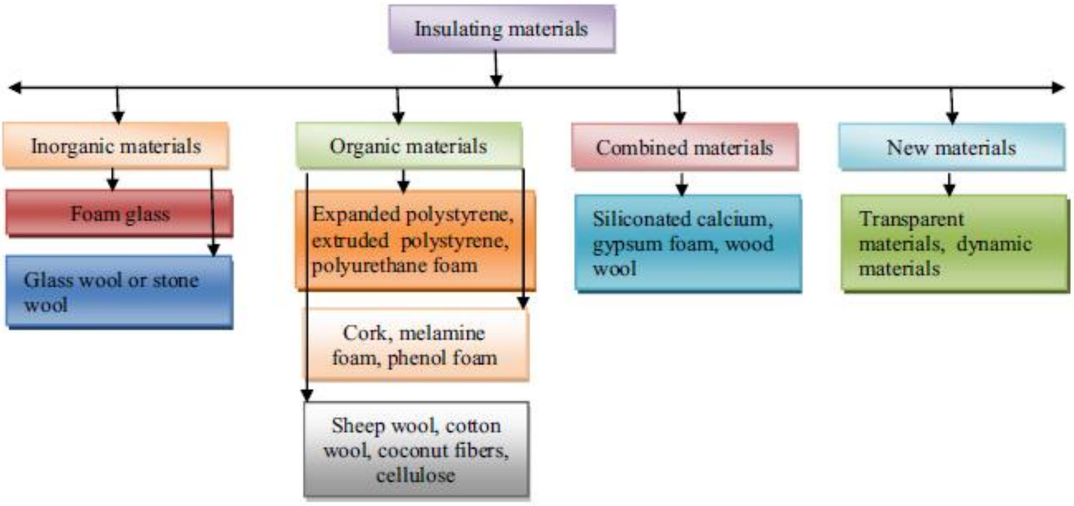


Fig. 44. Classification of the most used insulating materials [44]

The study by Kehrer *et al.,* for insulation materials and their properties [45] are as shown in Table 4. They found that solid PUF perform the best performance compared to the other various materials due to good thermal insulation.

Table 4
Specifications for commonly used insulation materials [45]

Insulation material	Density (kg m^{-3})	Thermal conductivity (W/mk) at 10°C	Compressive strength	Relative moisture absorption
Expanded Poly-Styrene 15	15	0.04	35	Medium
Expanded Poly-Styrene 30	30	0.037	100	Medium
Extruded polystyrene	32	0.27	300	Medium
Polyurethane foam	36	0.018	200	Low
Plenolic foam	32	0.027	170	Low
Cellular foam	125	0.41	700	Low
Mineral wool	24	0.045	Nagligible	Very high

2.2.15 Effect of absorber (material, absorptivity, thickness)

For key characteristics that affect efficiency, including thickness, density, thermal conductivity, and thermal capacity, the main absorbent materials commonly used as a major component of PVT, Alobaid *et al.,* [46] are listed in Table 5.

Table 5
Main characteristics of absorption [46]

Absorber material	Thickness [mm]	Density [kg/m^3]	Thermal conductivity [W/mk]	Heat capacity [j/kgK]
Copper	~0.3	8,920	380	350
Aluminium	~1	2,700	160	900
Steel	~2	7,860	50	450
Polymer	~2-3	900-1,500	0.2-0.8	1200-1800

Ekramian *et al.,* [41] studied on the examination of the effect of absorptivity of the absorber on thermal efficiency. In Figure 45, increasing the absorbance absorption rate from 80% to 98% leads to a linear increase in the collector efficiency up to 4.2%. For the other hand shape; they simulated the effect of absorption thickness on the efficiency of the collector. Based on the results obtained, the compound efficiency increases by 15% when the absorption thickness increases from 0.1 mm to 0.6 mm, emphasizing that this is due to the low heat resistance of the higher thickness absorption joints, as shown in Figure 46.

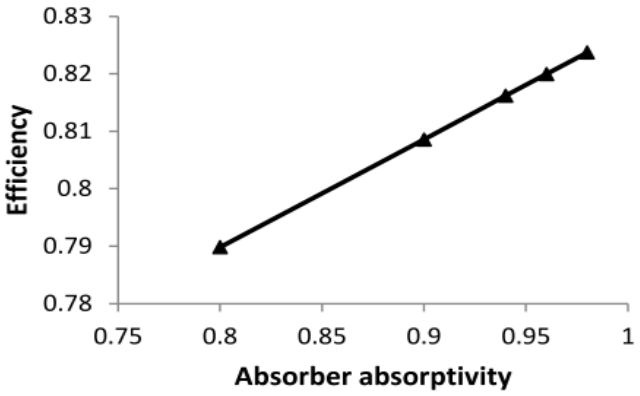


Fig. 45. Collector efficiency of different absorber absorptivities [41]

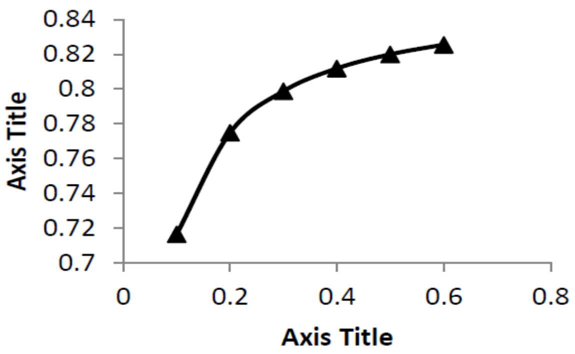
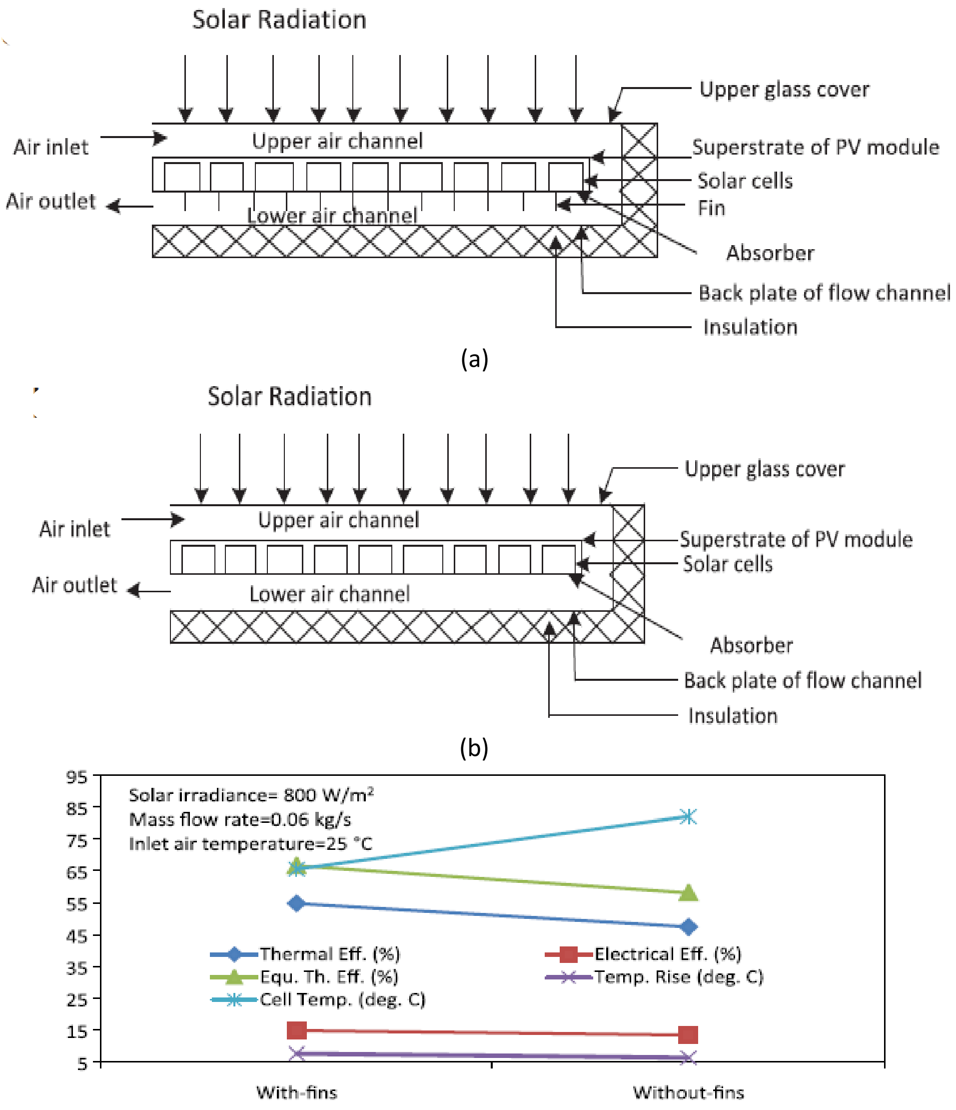


Fig. 46. Collector efficiency of different absorber thicknesses (mm) [41]

2.2.16 Effect of fins

As shown in Figure 47(a) and (b), fins at the double pass PVT system were added by Kumar and Rosin [47] to improve heat transfer and improve efficiency. The proposed system has been tested with various design, climate, and operating standards that can affect PVT efficiency. They found that using fins at the lower duct, the cell temperature was reduced from 82 ° C to 66 ° C as shown in Figure 47(c), and packing factor played an important role in PVT design.



(a)

(b)

(c)

Fig. 47. (a) A cross section of a double-pass PVT solar heater with a fins, (b) a cross section of a double-pass PVT solar heater without fins and (c) Comparison of values of different efficiencies and the rise in air and cell temperatures for a solar PVT system with and without fins [47]

Tripanagnostopoulos [48] studied the PVT collector with a double heat extract of water or air, which looked at three different configurations to improve air heat extraction at low cost. These modifications include a composite TMS in the middle of the air channel, fins connected to the corresponding wall on the back of the PV module, and TMS is applied to the centre of the air duct with a small rib on the opposite air duct wall. As shown in Figure 48 (a)-(c), TMS, FINS, and TMS / RIB have improved the thermal efficiency of AHE by 22, 33, and 36%, respectively. Figure 49(a)-(d) is compared with the reference model before modification.

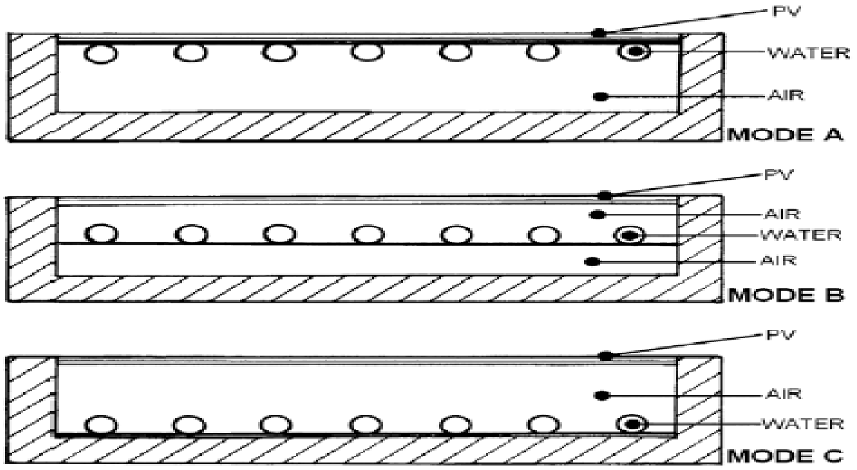
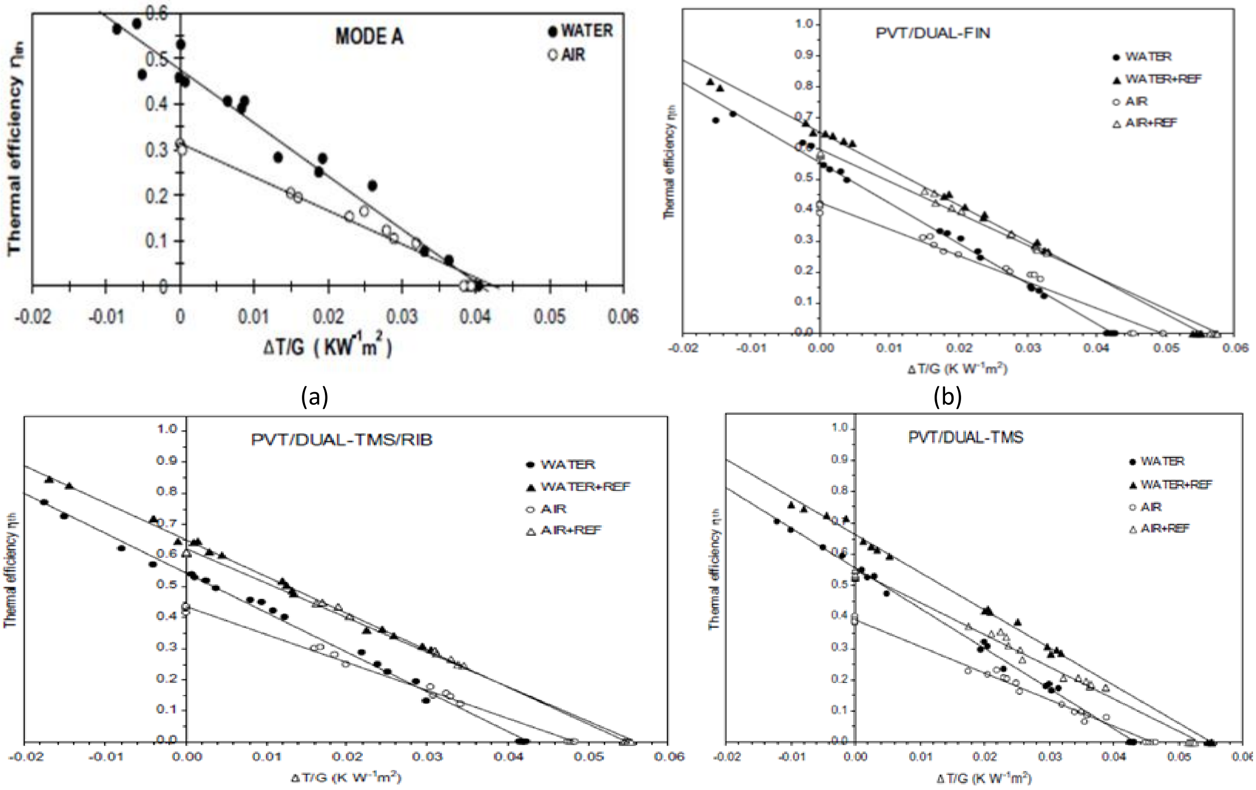
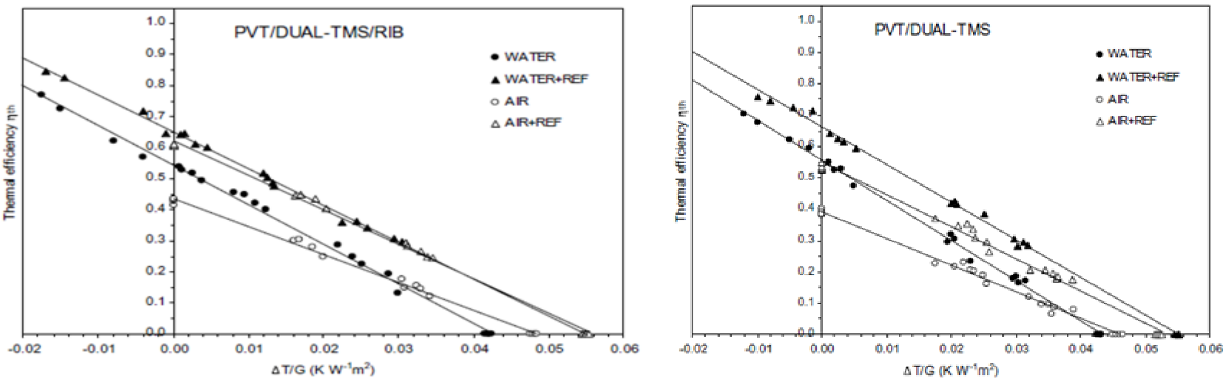


Fig. 48. A Cross section of the studied PVT dual solar systems with (a) The thin metallic sheet (TMS) modification (b) The fins on opposite air channel wall (FIN) modification and (c) the combination of TMS with ribs on opposite air channel wall (TMS / RIB) [48]



(a) (b)

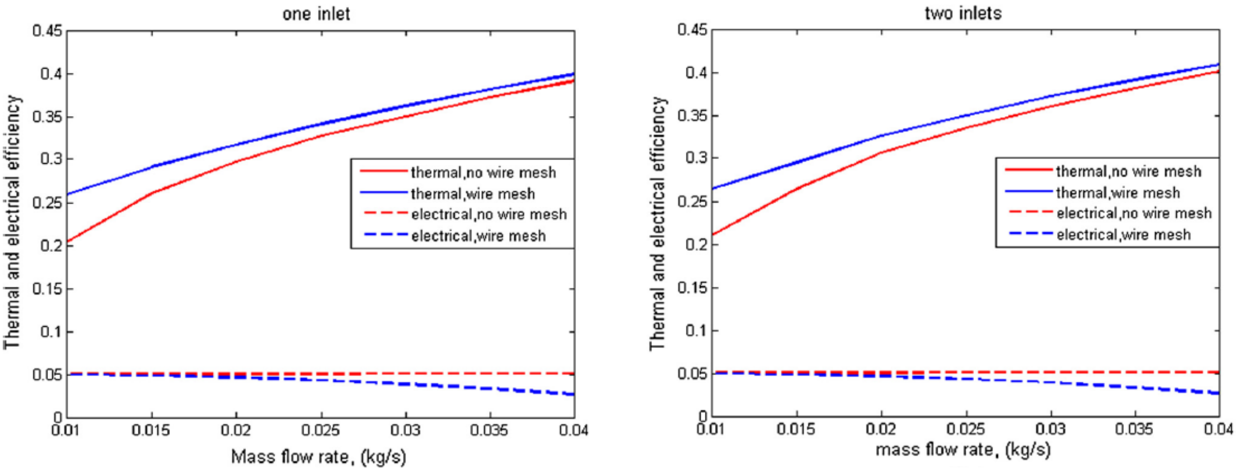


(c) (d)

Fig. 49. Thermal efficiency steady case results of PVT dual collector related water and air heat extraction ,in model form as well as combined with diffuse reflector (a) PVT dual collector before modification (b) PVT dual FINS (c) PVT dual TMS /RIB type and (d) PVT dual TMS [48]

2.2.17 Effect of multi inlet

The typical PVT system consisting of a single entry was tested by Yang and Athienitis [14] and the simulation model was developed and validated with experimental results. This model is used to study the performance of PVT systems with two inputs. Figure 50 shows the thermal and electrical efficiency below the single and two inlets. The design of two entrances has been reported to increase thermal efficiency by about 5% and increase electrical efficiency. The same author [49] designed a model for air PVT system with five entrances, developed a multi-input air channel and proposed a mathematical model of a five-entry system. Numerical studies show that the five air intakes can increase the thermal efficiency of a PVT system by 6.4% compared to conventional PVT systems with a single input. A comparison between the evolution of air temperature for one input and (5) PVT input as shown in Figure 51.



(a) (b)

Fig. 50. (a) Thermal and electrical production in a one-inlet BIPV/T system with the glazed solar air collector with or without wire mesh; and (b) thermal and electrical production in a two-inlet BIPV/T system with the glazed solar air collector with or without wire mesh [14]

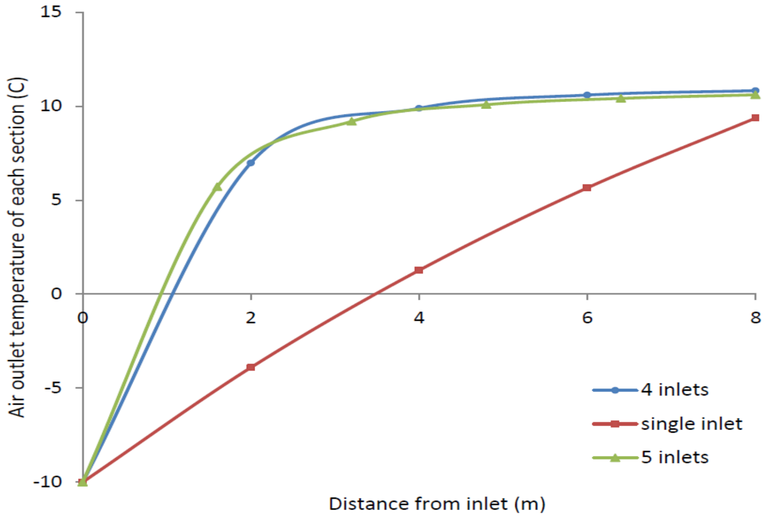


Fig. 51. Comparison of the air temperature development of the one inlet, four inlets and five entry BIPV/T systems [49]

3. Operating Parameters

3.1 Mass Flow Rate

Integrated photovoltaic systems were manufactured and tested by Rahou *et al.,* [50] to improve solar efficiency. The main component of PVT solar collectors consists of silicon solar cells. The combined structure of the copper tube absorption was combined with the oscillating flow configuration on an insulated electronic panel insulated with glass wool from the ocean. The effect of changing the parameters such as the water mass flow rate was made on the efficiency of the compound. Figure 52. illustrates the effect of changes in the flow rate of mass on electricity, heat, and efficiency of collection.

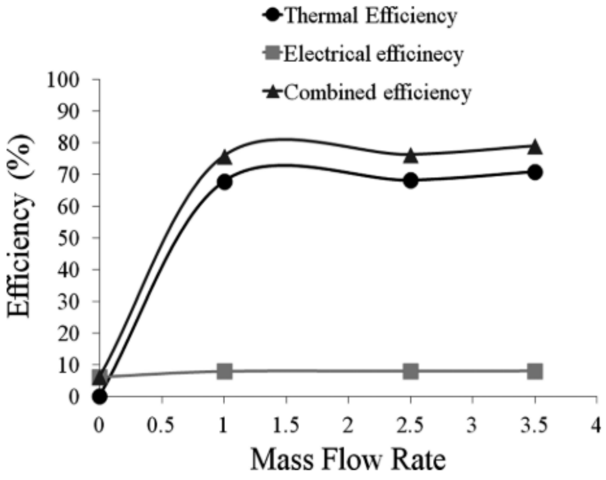
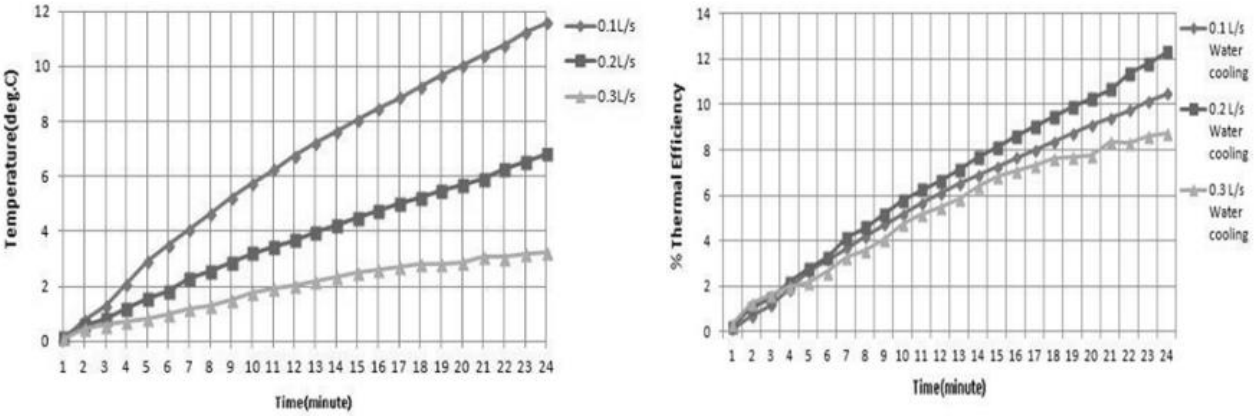


Fig. 52. The effect of Mass flow Rate on PV, Thermal and Combined PVT Efficiency [50]

Hussain *et al.,* [51] proposed a PVT system to cool the photovoltaic array using a heat exchanger and reduce the heat stored inside the photovoltaic cell while running the water circulation tube located below the photovoltaic module. This test was performed at different mass flowrates (0.1, 0.2, 0.3) kg/s, they found that the minimum mass flow value (0.1 kg / s) provides better thermal gain and thermal efficiency as shown in Figure 53(a) and (b) compared with rising of water mass flow rate.

The temperature of the PV unit decreases from (76.8 °C at 0.1kg/s) to (74.5 °C at 0.2kg/s) and (70.1 °C at 0.3 kg/s). This temperature decreases led to an increase in the efficiency of the solar panel to (8.6%, 9.1%, and 9.6%), respectively as seen in Figure 54.



(a) (b)

Fig. 53. (a) Impact of Water Mass flow rate on Thermal gain and (b) Impact of Water Mass flow rate on Thermal Efficiency [51]

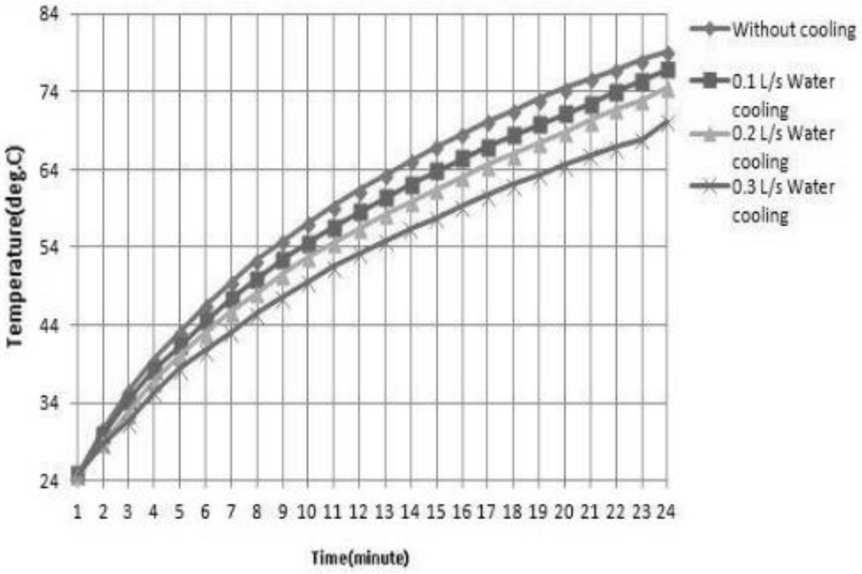


Fig. 54. Impact of water mass flow rate on PV panel temperature [51]

Three units of mc-Si solar cells were studied analytically and experimentally by Solanki *et al.,* [52] They are installed in wooden channels to allow the air to pass through to extract the heat from the back of the PV panels to improve the performance of the proposed system. As a result, thermal, electrical, and total efficiency increased with the increase of the MFR mass flow rate to 42%, 8.4%, and 50%, as shown in Figure 55.

The other PVT collector designs were simulated by SARDOUEI *et al.,* [53] using methods of computational fluid dynamics. The input water temperature is 25 ˚C, the mass flow rates are 30, 90, and 180 L / h as a result, the mass flow rates has emerged. Increasing the mass flow rate from 30 to 90 L / h reduces surface and outlet temperatures by 6 and 18%, respectively. The maximum average thermal efficiency value was achieved by 56% experimentally at a flow rate of 90 L/ h as shown in Figure 56 and increasing the mass flow rate decreases the operating state of the photovoltaic cell, thus improving the electrical efficiency, where the maximum electrical efficiency is 13.6% at a mass flow of 90L / h as shown in Figure 57.

The performance of two PV/T systems based on different absorber designs was determined, and a comparative study of the system performance between the serpen-direct and conventional serpentine flow designs was conducted by Sachit *et al.,* [54]. The results showed that the increment in the water mass flow rate can enhance the PVT collector performance for both designs in terms of PV cell and thermal efficiencies under various rates of solar irradiance.

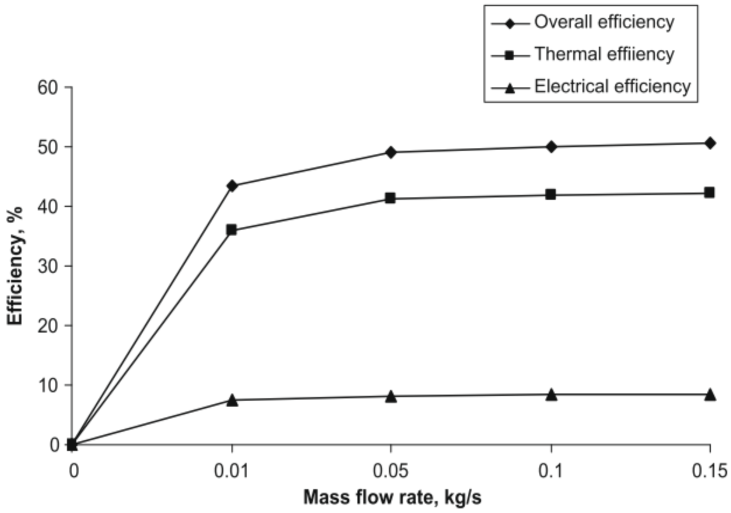


Fig. 55. Electrical Efficiency difference with Mass Flow Rate [52]

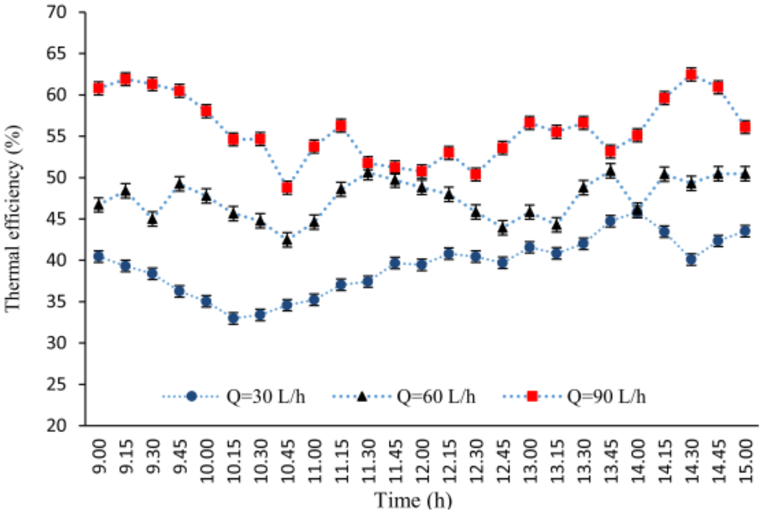


Fig. 56. Thermal efficiency of the designed PVT collector at the different mass flow rates [53]

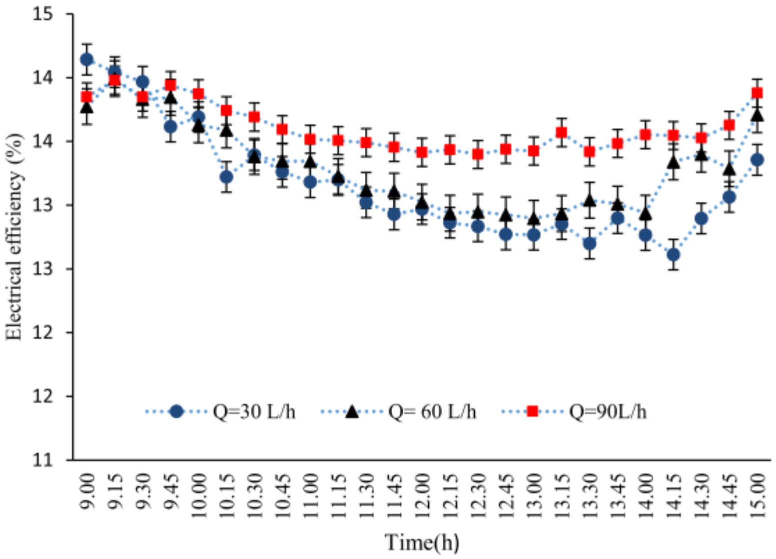


Fig. 57. Electrical efficiency of the designed PVT collector at the different mass flow rates [53]

3.2 Thermal Resistance

Many researchers have recommended by Zondag [55] that reduce the heat resistance generated between PV photovoltaic and collector fluid. The first consideration is that all the material layers between the silicon and the absorbent should be as thin as possible, the material made of high thermal conductivity. Figure 58 shows the effect of thermal resistance on the heat removal factor (FR) of the glazed and unglazed PVT collector.

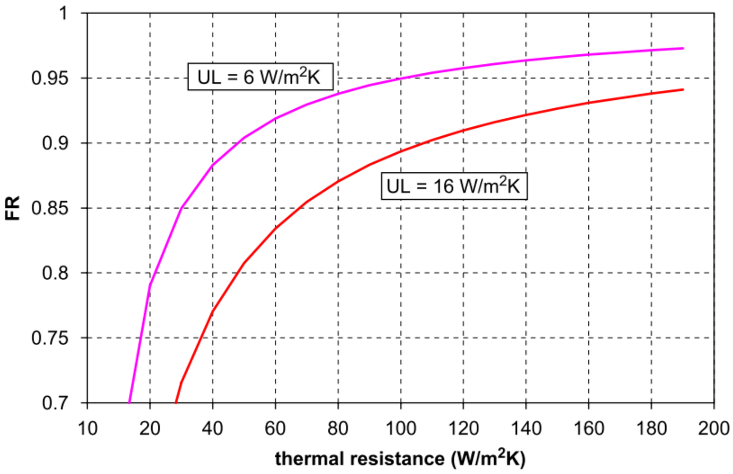


Fig. 58. Influence of thermal resistance on heat removal factor of glazed and unglazed PVT collector [55]

A numerical investigation studies on flat solar collectors by Hamed *et al.,* [56]. They studied the effects of inlet water temperature and the rate of mass flow on overall heat system losses as shown in Figure 59. It shows the effect of the input temperature on the output temperature. As the input temperature increases, the solar intensity of the sunlight does not change and the thermal loss increases as shown in Figure 60.

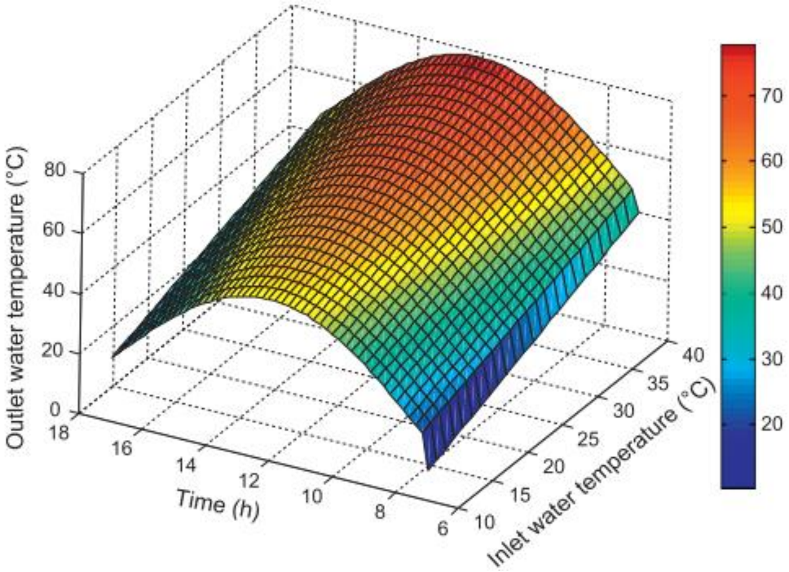


Fig. 59. Change in outside water temperature against to entry water temperature [56]

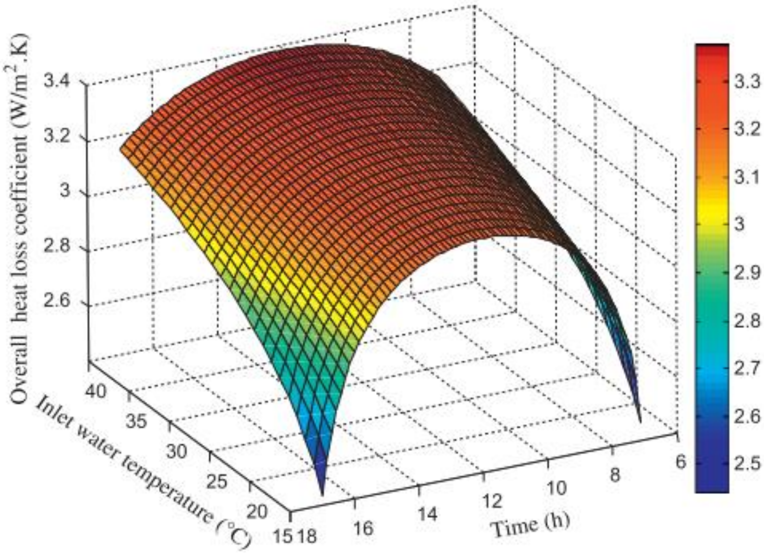


Fig. 60. Change of overall heat loss coefficient against inlet water temperature[56]

3.3 Inlet and Outlet Fluid Temperature

The effects of inlet water temperature on the electrical and thermal efficiencies of the system were studied by Hongbing *et al.,* [57]. The results showed that the thermal efficiency of the solar PVT system decreases with the increase in inlet water temperature and low electrical efficiency with increasing the temperature of the incoming water, as shown in Figure 61.

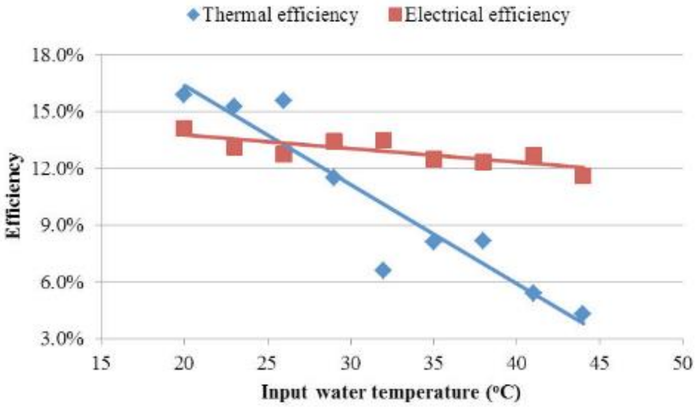


Fig. 61. Difference, of Thermal and Electrical Efficiencies with Input Water Temperature [57]

Experimental analysis of outlet water temperature on the electrical and thermal efficiencies of the system by Khatiwada and Ghimire [58]. The data is taken at a different temperature, especially, at temperatures of 28 ˚C, 32˚ C, 36 ˚C, and 40 ˚C. The results showed that the thermal efficiency of the PVT and electrical efficiency are as shown in Figure 62 and Figure 63, respectively.

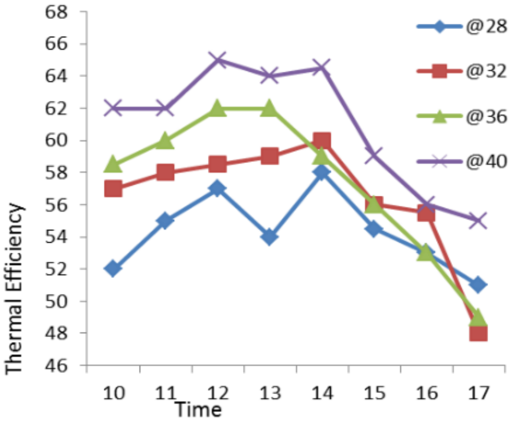


Fig. 62. Time versus thermal efficiency for the water based PVT system [57]

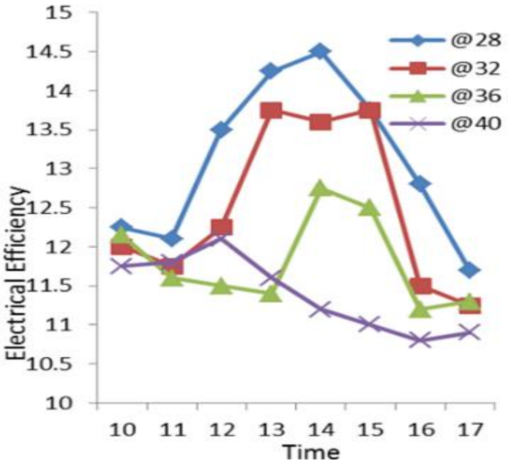


Fig. 63. Time versus electrical efficiency for the water based PVT system [57]

3.4 Heat Loss Coefficient

Heat pipe photovoltaic thermal PVT hybrids system collector has been proposed by Wu *et al.,* [59]. The results showed that the temperature of the solar cell decreases when increasing the heat loss coefficient UL. Meanwhile, the PV module temperature varies in the range of 48.88 –50.78 °C, 48.23–49.95 °C, and 47.64–49.21 °C with respect to heat loss coefficient as 6 W/m^{2}K, 8 W/m^{2}K, and 10 W/m^{2}K, respectively. Accordingly, they found the electrical efficiency change in the range of 7.99–8.30%, 8.04–8.32%, and 8.07–8.35% while the thermal efficiency is 61.29–63.65%, 57.24–60.20%, and 53.55–57.10 %, respectively, as shown in Figure 64.

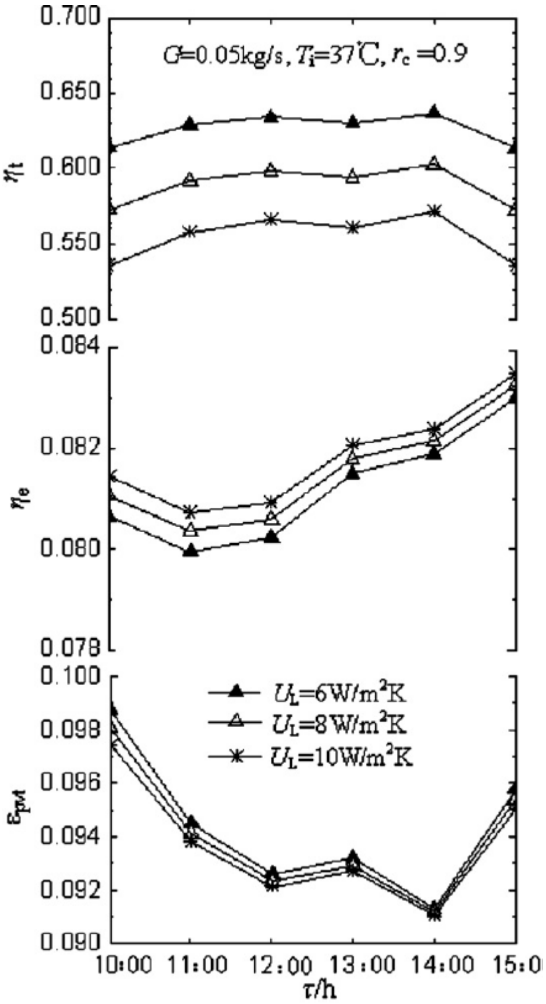


Fig. 64. Variations of the thermal, electrical and exergy efficiencies with the local time at different heat loss coefficients [59]

3.5 Heat Removal Factor

FR of an unglazed PVT with serpentine tube collector was studied by Rosli *et al.,* [60]. Heat removal factor (FR) is an important parameter for determining the thermal efficiency of a photovoltaic thermal (PVT) system with focusing on the thickness of a plate of a serpentine flat plate tube. The highest FR value of 0.88 was obtained for the thickness of the plate of 0.015 m followed by 0.84 for the thickness of the plate of 0.03 m as shown in Figure 65. The difference between the FR in both designs was only 4.54%, which can be considered within the acceptable range for the flat plate thickness.

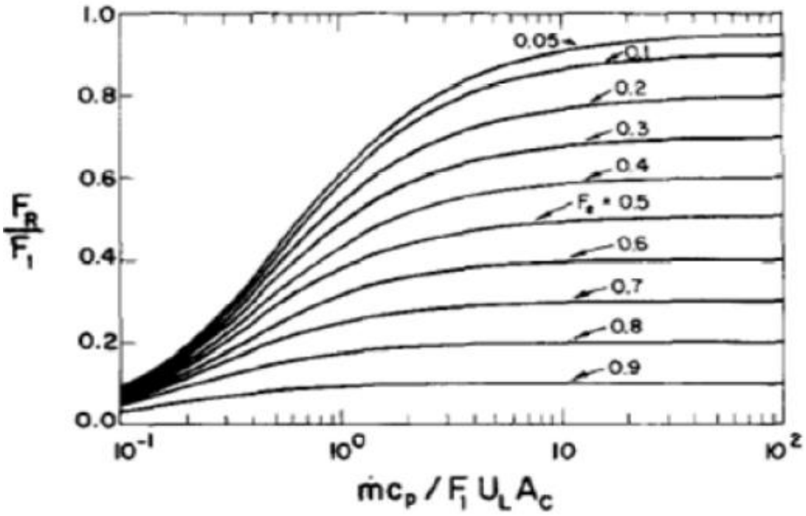


Fig. 65. Heat Removal factor (F_R)) for the Serpentine Collector plate [60]

3.6 Packing Factor

Modelled and simulated PVT hybrids with natural rotation were studied by Ji *et al.,* [61] for a PF 63% and front glazing transmissivity of 83%, energy efficiency, electricity, total energy, and primary daily energy were 10.15 %, 45 %, 52 %, and 65 %, respectively. In a similar study, Fargley *et al.,* [62] calculated the effect of PF on energy performance. By increasing the PF, thermal efficiency deteriorates as shown in Figure 66 and Figure 67, respectively.

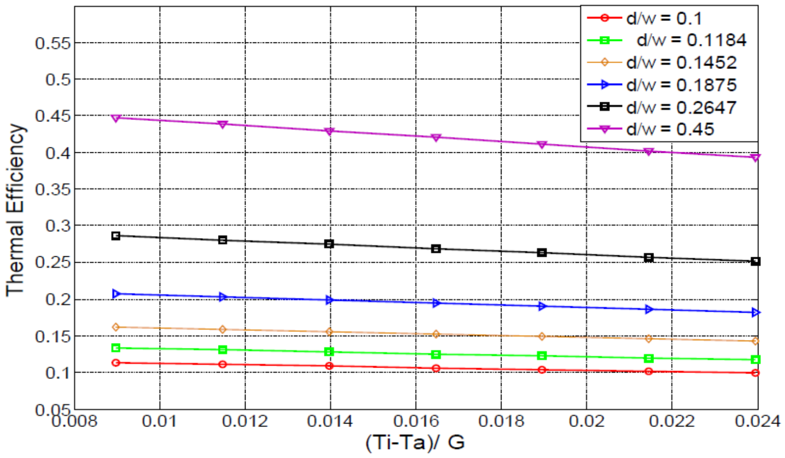


Fig. 66. Thermal efficiency varying with variable the packing factor [62]

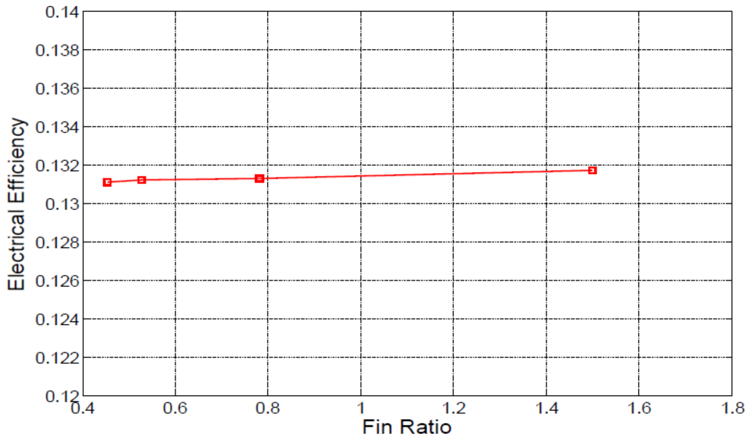


Fig. 67. The effect of varying the PF on the electrical efficiency [62]

3.7 Effect of Fans

The theoretical model of unglazed PVT collector tested experimentally is validated by Shahsavar and Ameri [63]. In the proposed prototype, they studied the effect of using different numbers of fans of two, four, and eight fans. The optimal number of fans required to increase electrical efficiency are two fans, but with the increase in the number of fans, this will lead to decreasing the electrical efficiency, the energy consumption of fans is more effective than the effects of cooling panels as shown in Figure 68.

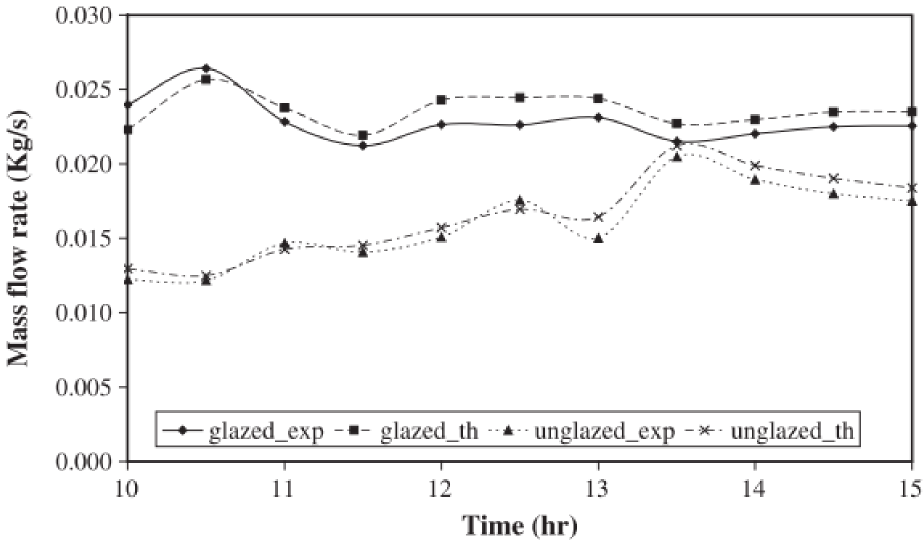
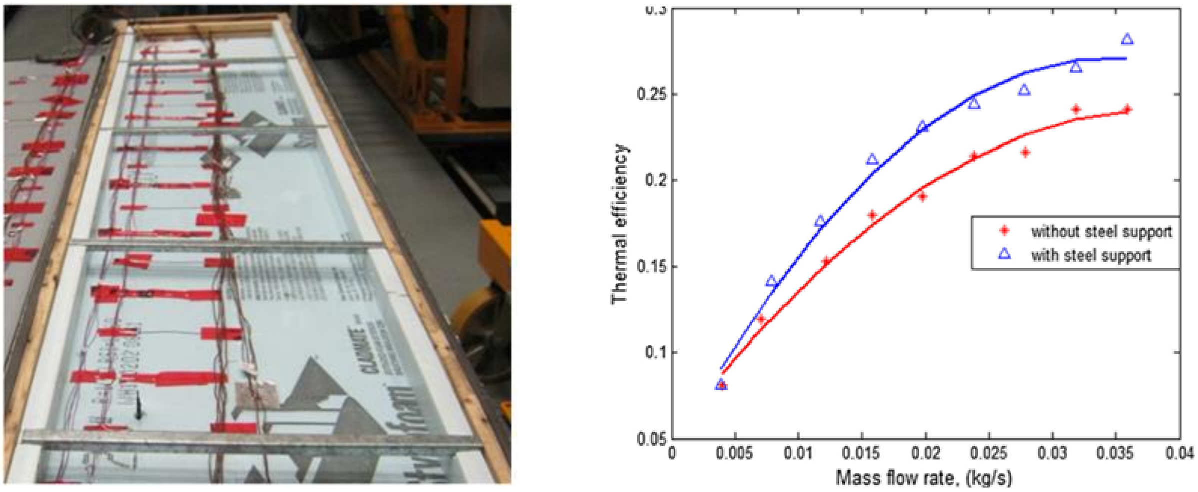


Fig. 68. Hourly variations of air Mass flow rate for forced mode of operation (two fans) with resistive load (glazed and unglazed) [63]

3.8 Effect of Metal Bars Support

Yang and Athienitis [14] assessed the effectiveness of removing commonly used metal bars to support the weight of PVT systems. In their experiment, four steel bars were placed directly below the non-crystalline PV module to support their weight, as shown in Figure 69(a).Thereafter, these bars were then removed from the collector. The increase in the thermal efficiency of the PVT system after adding a metal bar is acting as fins as shown in Figure 69(b).



(a) (b)

Fig. 69. (a) Section of the Steel bars placed underneath the PV module as Structural Support,(b)Thermal Efficiency of the BIPV/T system with and without the structural support steel bars under the PV module [14]

3.9 PV Solar Cell Materials

3.9.1 Silicon solar cells

3.9.1.1 Single crystalline silicon

The biggest advantage of these materials is the low cost and high quality reported by Franklin *et al.,* [64]. Monocrystalline silicon solar cells are semiconductors that have been widely used. Their optimum efficiency is 24.7% and commercial module efficiency is 18%. Monocrystalline silicon tape is the most widely used in R&D. As shown in Figure 70, the cell unit of a cell with 50% cell scale shows the absorption and reflection ratios of possible light pathways.

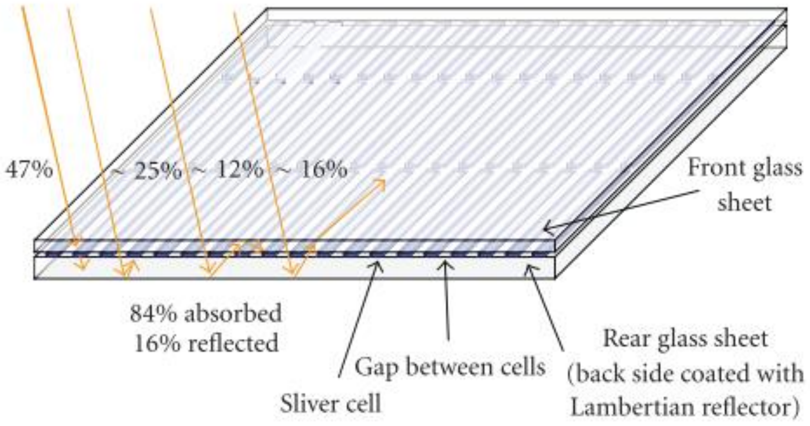


Fig. 70. Description of a sliver Cell module with 50% cell coverage [64]

3.9.1.2 Polycrystalline silicon

The energy conversion efficiency of commercial units made of polycrystalline silicon ranges from 10% to 14% [65]. Cited two advanced ways to produce polycrystalline silicon PV cells. Some of the advantages of polycrystalline silicon are

i. Stronger than single crystals.
ii. t can be cut to one- third of the thickness of individual crystals.
iii. EFG has a slightly lower chip cost.
iv. The EFG Group has less stringent growth requirements.
v. Low cost compared to the cost of manufacturing one crystal.
vi. Electricity production is higher than non-crystalline products.
vii. Improved efficiency when compared to amorphous silicon.
viii. Only a small amount of material is called

3.9.2 III-V group solar cells

Gallium arsenide is chemically composed of two main components, gallium, and arsenic. Its crystalline structure resembles the same silicon. Achieve photovoltaic conversion efficiency more 25% [66] . One of the most common applications of solar GaAs-based solar cells is space applications because they are highly resistant to solar radiation and save photovoltaic devices from enormous amounts of radiation. Some of the advantages of this type of materials are as below.

i. High level of absorptivity.
ii. Low thickness is required to absorb sunlight (fewer materials are needed compared to other solar cells).
iii. High Heat Resistance.

4. Conclusion

This paper reviewed the effects of different control parameters. The efficiency is the most important parameter, which must be considered in PVT technologies. A critical review on parameters of climatic, design, and operational factors is taken out to evaluate their effect on the thermal, electrical, and overall efficiency of PVT systems. Thermal efficiency decreases with increasing values of the following parameters, Inlet Temperature, Packing Factor, Duct Length, Channel Depth, Thermal Resistance, Ambient Temperature, Mass Flow Rate. When the optimal value is exceeded, Inlet Mass Flow Rate Velocity, Wind Speed, Tilt Angle far from latitude angle, Thermal Conductivity of the Insulation Material and Heat Loss Coefficient. Thermal efficiency increases with the increasing values of the following parameters. Solar Irradiance, Tilt Angle Close to latitude angle, using Booster Diffuse Reflector, Tracking System, Number of Air Inlets, Absorber Absorptivity, Supporting Metal Bars as shown in Figure 71. Photovoltaic materials played a large role in electrical efficiency. This paper briefly reviews the most promising materials in the PVT industry. The fluid on the PVT is usually air, liquid, or both. Air is cheap and clean and can be used for almost any purpose on the earth. Among other liquids, water is cheap (less air), clean, and usable. Maintenance costs for air-based systems are lower than those of water-based systems. But for a specific application, using other liquids may be needed, in which special configuration or design must be applied. The sheet and tube geometry is considered as the one with highly efficient and less expensive in water-based PVTs for practical applications, such as building integrated systems.

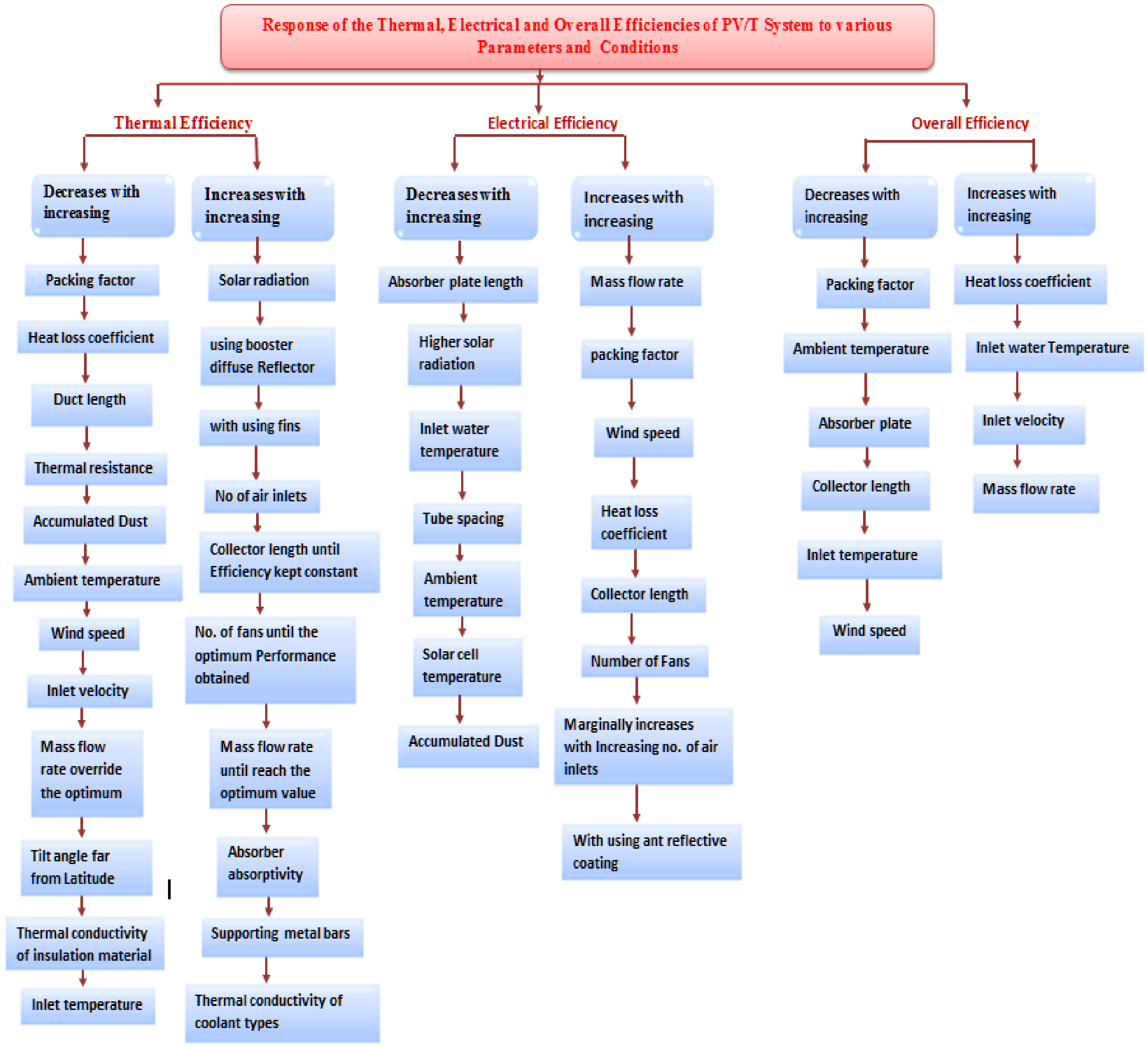


Fig. 71. Thermal, electrical and overall efficiency response of different factors and conditions of the PVT system

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