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Effect of cooling on the performance of photovoltaic panel under enhanced illumination: A short review

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Abstract

An attempt has been made to presents a short review of various cooling methods and their effects on the performances of the photovoltaic systems when these are exposed to enhanced illumination. It is generally observed that when the solar cells work under enhanced illumination (generally May and June month) it experiences both short term and long term degradation,(efficiency loss and irreversible damage respectively) because of far more increase in the operating temperature. This incremented temperature can be reduced by applying any one of the appropriate cooling method. Cells under high level of insolation need more efficient cooling system for the better performance. Cooling affects both electrical and thermal performances of the photovoltaic system. In this paper authors review different designs of hybrid PVT system and finds that further research is required for better design and the improvement in the efficiency of the system along with the reduction in the cost.

***Keywords*: Enhanced illumination; photovoltaic; Active and Passive cooling system; Thermal and Electrical efficiencies.**

1.Introduction

Photovoltaic Cell converts incoming solar radiation into electricity, but full spectrum of solar radiation is not converted into electricity due to the band gap of solar cell materials (i.e. silicon poly-crystalline, amorphous).So the unwanted solar radiation(like UV and IR) enhanced the solar cell operating temperature, due to which the performance of solar cells affected considerably and electrical efficiency of the pv system falls down.

To increase the efficiency of the pv system, it is necessary that the pv system should work at lower temperature, but it is not possible when it is exposed to concentrated sunlight so for the reduction of temperature, cooling of the pv system is required which can be done by coupling it with the heat extraction unit that is called as hybrid photovoltaic thermal system or PV/T system. The main purpose of the heat extraction unit is to extract heat from the photovoltaic system and lower its operating temperature.

In PV/T system applications, the production of electricity is our priority, and it is found that a PV system in Southern India will have a maximum system voltage that is lower than the same system in northern India (with the same materials) because of the higher temperatures in southern India and PV panels are more efficient at lower temperatures.

Extensive research has been carried out by various researchers in designing and optimizing hybrid photovoltaic system for its commercialization. H. Zondag, M. Jong and W. Helden[1] analyzed several concept of PVTs like sheet-and-tube constructions vs channel construction also added a secondary absorber beneath the PV. A. Hegazy[2] used air cooled PVT systems for evaluating and comparing the performances. He designed four models for extracting the heat in which air flow over the absorber (I), under the absorber (II), on both sides of the absorbers in a single pass (III) and double pass (IV) were included. It was observed that the efficiencies of models II-IV were very similar and better than model I. Arvind Tiwari, M.S. Sodha, Avinash[3] Chandra and J.C. Joshi.studied the performance of panel with an air duct. They found that the experimental results are similar to the predicted results. The results show that a flow rate of about 2m/s, a lenght of ~3 m and a duct depth of 0.03-0.06m produced the optimal efficiency. Kalogirou [4] has studied experimentally an unglazed hybrid PVT system under the force mode of operation for climatic condition of Cyprus. He observed an increase in the mean annual efficiency of a PV solar system from 2.8% to 7.7% with a thermal efficiency of 49%. Swapnil Dubey et.al. [5]worked on the combined system of photovoltaic thermal(PV/T) solar water heater system. The designed system with solar water heater of capacity 200 l was tested in outdoor condition for composite climate of New Delhi.

The objective of this paper is to show the research activities conducted last decade to till date all over the world and the Indian universities about the effect of cooling on the performance of PV/T collector under enhanced illumination(generally in May and June in India/ at higher temperature range).

A heat extraction unit can work actively or passively depending on the requirement and the various configuration of pv modules.

2. Passive/Active Cooling System:Heat can be extracted from the PV system in broad sense by two modes of cooling namely (i) Passive cooling (ii) Active cooling.

A passive system requires no added power ,while some external power source is required for an active cooling system.

(i) Passive cooling system : Passive cooling system may be a series of panels that are placed and set on the roof, in which air is allowed to flow naturally above and below the pv panels and some lateral projections which are also called as fins may be provided at the rear surface of the panel to draw some heat from the system, or for the prevention of heating the surface around the panels white-color is provided to the roof .

(ii) Active cooling system: when the heat is drawn from the panel forcefully then some fans are provided to blow air above and below the panels and also pumps are provided for circulating the water above and rear side of the panel. Active cooling system may be of great use in certain situations such as where the added efficiency to the panels is greater than the energy needed to run the system, for example a solar power plant in a desert, domestic water heating etc.

3.Comparative studies of the passive and active air cooling systems

Y. Tripanagnostopoulos et al.[6] the researchers of the department of Physics, University of Patras worked alot from 2000 to till date, on the performance,modeling, design modifications and parametric studies of the photovoltaic thermal system to the best of author's knowledge. In the paper [6]they have shown both passive and active air cooling of the PVT collector. So during the experiments, two combinations of the three configurations (REF, TMS and FIN) were used at a time namely (i) Reference system,The typical single pass air system in which the air channel attached at the rear surface of the PV module which can be used as a reference(REF)system for further explaination.(ii)TMS PVT/Air system,shown in fig.1. The sheet in TMS provided behind the PV module which creates a kind of double-pass configuration and doubles the heat extraction surface. and(iii) Fins PVT/Air system, The FIN system consists of fins with rectangular profiles attached to the back wall of the air duct,and oriented parallel to the flow direction.

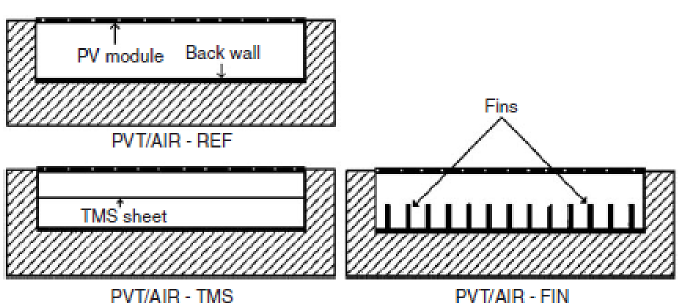

Fig.1 Different PVT air flow system with low cost modifications[6]

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Table.3.Specifications of the prototype model used for the experimentation[6]:

S.No.	Name of the part	Specifications
1.	2 PV panel(pc-si)	Length of each panel-1m
2.	Aperture area	A_a -0.4m^2
3.	Rated power	46Wp
4.	Absorber plate and air	15 cm
5.	Air channel casing	Thickness-5c
6.	Inlet and outlet vents	Diameter-5cm
7.	Fins	Height and spacing distance-

The rear surface of TMS, Fins and PV have painted black to improve the cooling of the PV panel. They observed that the thermal efficiency for the passive cooling system for all above configurations is lesser than the active cooling system. For the active cooling system(Forced air flow mode) it was observed around 30%,28% and 25% for the Fins, TMS and REF respectively[6].Similarly in the passive cooling it was found 16%,18% and 20% for the REF,TMS and Fins respectively[6].

Y. Tripanagnostopoulos et.al [7] extended their experiment for the same module and same configuration. But for the different combinations they have used glazed and unglazed surfaces. For the glazing they have used upper glass cover and perform the experiment under natural air flow mode. They observed that the additional glazing improves the heat production, but lowers the electrical efficiency of a PV/T collector under enhanced illumination.

A. Shahsavar et.al.[8] also worked on the natural(passive cooling) air flow for photovoltaic thermal collector in the climatic condition of Iran. They have done energy and exergy analysis of the PVT system. For the performance evaluation they have developed a model with two polycrystalline silicon type PV panels.Each rated at 45Wp having length, width and height 0.98, 0.46, and 0.04 m respectively. The air channel constructed from wood, a thin metal (Aluminum) sheet (TMS) suspended at the middle of air channel ,two lamps of 35 W and 5 mm-thick glass cover for the glazed configuration have been used. They have made two configuration with glazing and without glazing and computed the total performance of the system. For the glazed system, they have found that the thermal, electrical, and total energy efficiency ranges between 31.6–36.2%, 8.1–9.1%, and 39.8–44.9%, respectively[8], For the unglazed system, it was analyzed that there are variations of thermal, electrical, and total energy efficiency between 12.2–24.8%, 9.6–10.6%, and 22.5–34.6%, respectively[8]. On the other hand, it has been seen that the glazing decreases the electrical and total exergy efficiency and increases the thermal exergy efficiency of the PV/T system.

H. Mortezapour[9] also from Iran investigated the influence of air flow rate on the solar collector performance ,in their experimental set up PV panel is placed between the air channel so it was called two way hybrid system and for active cooling system,a 12V DC fan was used to make the air flow through the duct. They were found that the maximum experimental electrical, thermal and overall thermal efficiencies for glass to tedlar PV module were 10.35%, 57.90% and 84.5%, respectively[9].

A. Shahsavar, M. Ameri [10]extended their work for the same climatic condition on the PV/T air collector with thin metallic sheet suspended in the air channel. This PV/T system is tested in natural convection and forced convection with and without glazing. In the case of natural convection mode electrical efficiency is higher as compared with the forced mode of operation with four and eight fans. They have concluded that for the maximum electrical efficiency achievement the optimum number of fans is two whereas by increasing the number of fans, electrical efficiency decreases because the fans consumed power has a more effect than the effect of cooling panels. They have also noticed that the use of eight fans without resistive load electrical power generated by PV panels are consumed by fans and therefore electrical efficiency in this case is equal to zero. Furthermore, electrical efficiency in unglazed system is more than glazed system.

F. Sarhaddi , S. Farahat[11] from Iran worked more on the performance analysis of PVT air collector. They have made some improvement in the thermal and electrical model developed earlier. The experimental setup consists of one polycrystalline silicon PV module (45 W) integrated with an air duct, two dc fan (12 V) in which air has blown into air duct, an active cooling system was analysed by F. Sobhnamayan F. Sarhaddi, S. Farahat et al [12]in the term of exergy and energy analysis. A detailed study has been done on PV-T air collector by Adel A.Hegazy [8] to evaluate the thermal, electrical, hydraulic and overall performance of four types of flat-plate PVT air collectors as shown in Fig. 2 .These included channel above PV as Mode 1, channel-below PV as Mode 2, PV between single- pass channels as Mode 3, and at last the double-pass design as Mode 4.

The numerical analysis showed that:

(i) when air is flowing through the rectangular channel above the absorber the system got least performance, efficiency goes down;

(ii) when air is flowing through the rectangular channel below the absorber the system performs better than the previous one;

(iii)when air is flowing through single pass then the performance of the system will be enhanced in comparison of (i) and (ii) but more fan power will be required for the proper flow of air;

(iv) when air is flowing through two identical channel above and below the absorber (through the double pass) the system performance is better than all four configurations discussed.

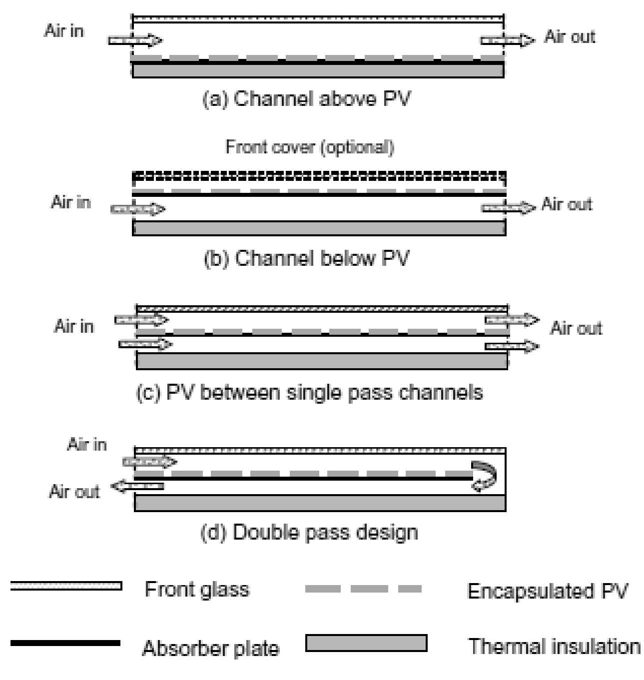

Fig.2 Some Common PVT air collector configuration[8]

4.Comparative studies of the passive and active water cooling systems

Y.Tripanagnostopoulos and S.A.Kalogirou[14] has worked on the active and passive water cooling system for the PVT .The experiment was carried out in three different places namely Nicosia, Athens and Madison. For the passive system thermosyphonic mechanism which is based on the natural convection has been used to transfer the heated water from the collector to storage. In thermosyphon systems, the collector is connected with a water via storage tank which is placed always at a higher position to avoid reverse flow of water in the night.

on the other hand for circulating the water from the collector to storage a water pump has been used. A typical active cooling system is shown in Fig. 3.

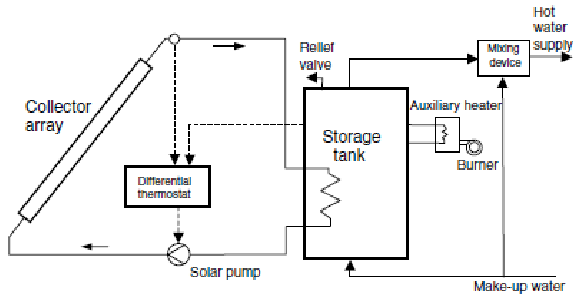

Fig.3A typical Active cooling system[14]

For the experimentation they have used two different solar system namely(i) small solar system with thermosyphonic mechanism (ii) Larger solar system with the flow of water forcefully. They have analyzed that the small solar system can work effectively on the passive cooling mode but the large solar system is required some added agency to flow of water through the pipe. System specification which was used by them are shown in the table 1,and 2[14]

Table 1
Specification of the small solar system considered

Parameter	Specification
Collector area	4 m^2
Collector slope	Latitude + 5°
Storage capacity	160 l
Auxiliary capacity	3 kW
Hot water demand	120 l (4 persons)

Table 2
Specification of the large solar system considered

Parameter	Specification
Collector area	40 m^2
Collector slope	Latitude + 5°
Storage capacity	1500 l
Auxiliary capacity	10 kW
Hot water demand	1200 l (40 persons)

Other than S.A.Kalogirou,Adnan Ibrahim et.al.[15] from the Solar Energy Research Institute, Malaysia designed and developed different water flow pattern for extracting the heat from the PV unit and also evaluated the performance of the system under water cooling mode in the enhanced solar insolation period.
In their study they have designed and evaluated the specially made Spiral flow absorber collector as shown in fig. which is made of rectangular hollow tubes of stainless steel material with dimension of 12.7×12.7 mm. The tube is joined through welding method. The spiral flow absorber, as shown in Fig. 4 consist of a single unilateral channel for the flow of water in it, the size of the channel is 815 × 628 x 30 mm before it is inserted at the back of the photovoltaic panel with the size of 1 m height, 0.65 m length and 0.3 m thickness and 80 Wp has been used. He has found that when the mass flow rate increases, the surface temperature decrease and at the same time the electrical and thermal efficiencies increase.

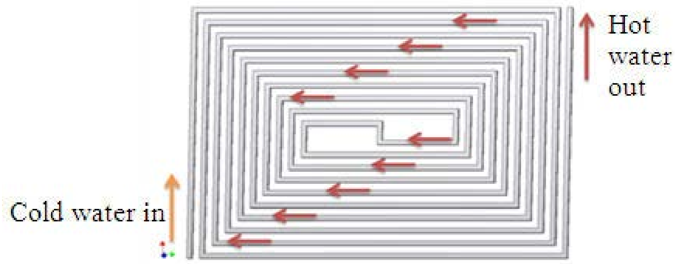

Fig.4Spiral flow absorber collector[15]

Adnan Ibrahim et.al.extended his effort on the design of different flow patterns, and much effort has been spent by them on the improvement of the PVT performance due to that seven new design configurations of absorber collectors namely,(i) Direct Flow Design,(ii)Oscillatory Flow Design,(iii)Spiral Flow Design, (iv)Serpentine Flow Design ,(v)Parallel-Serpentine Flow Design,(vi)Web-Flow Flow Design,(vii) Modified Serpentine-Parallel Flow Design, are designed, investigated and compared by them. They have been performed Simulations with various parameters, such as solar radiation, ambient temperature, and flow rate conditions to determine the best absorber design that can give the maximum overall efficiency.

All seven design configurations of absorber collectors are shown in the fig.5.

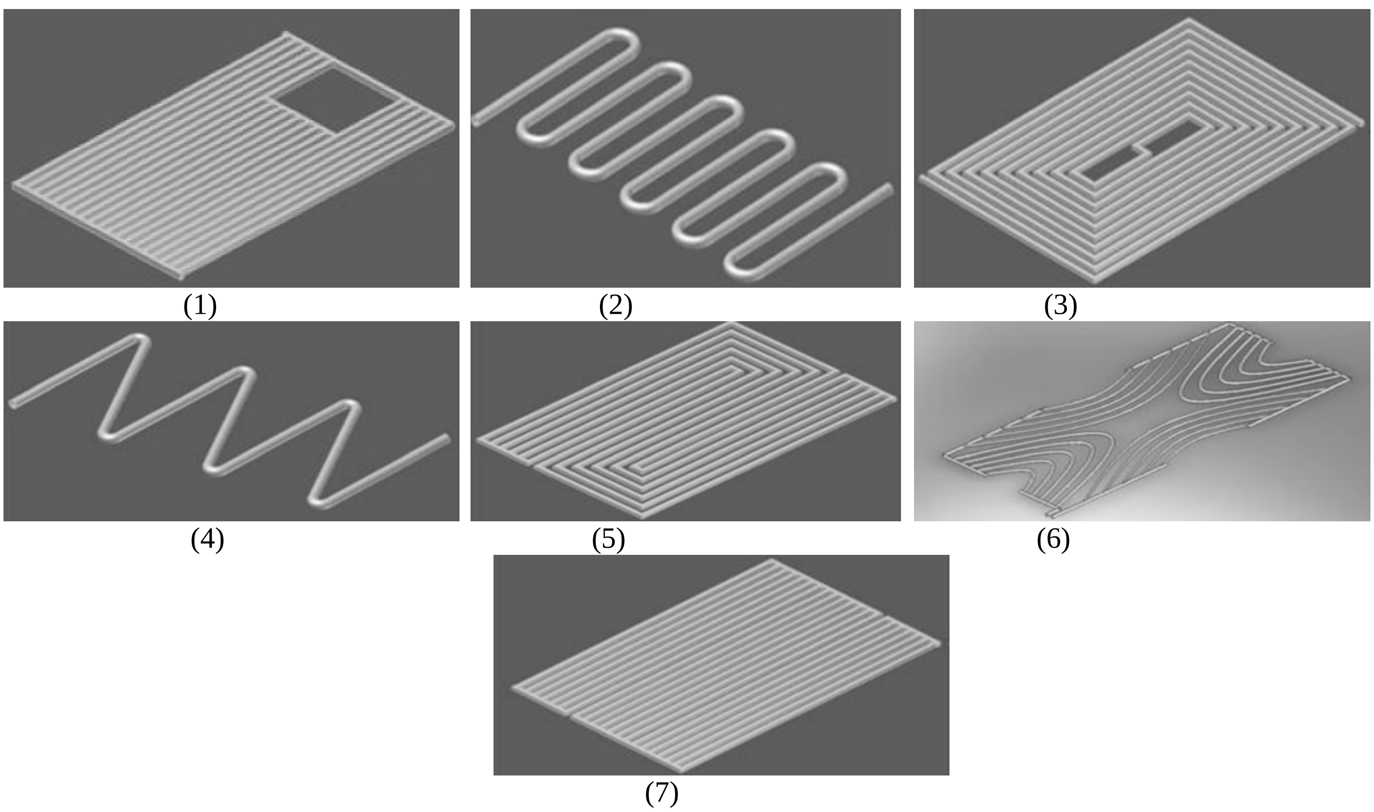

Fig.5 Different Flow pattern (1) Direct Flow (2) Oscillatory Flow(3) Spiral Flow(4) Serpentine Flow(5) Parallel-Serpentine Flow(6) Web Flow(7) Modified Serpentine-Parallel Flow.[16]

They observed that the Spiral flow pattern shows the highest thermal efficiency,(50.12%) compared to other design configurations. and the Serpentine flow pattern shows the lowest (32.35%)

It is also observed that there is not much change can be done for the cell efficiency. The highest cell efficiency recorded In the Spiral flow pattern. The collector efficiency factor for cell efficiency of Spiral flow design is 11.98% and the lowest in the Oscillatory flow design at 11.94%.[16]

Team of researchers[17] in Thiland worked upon the water cooled system for PVT. They have conducted much experiment for the climate of Bangkok and the results obtained can be used to predict the performance of PVT systems working in Bangkok. For the experimental analysis they have used a-si and mc-si with collector area 0.9 and 1.96 m^2 respectively.PVT collectors produce hot water which is consumed by a dummy heat load to emulate hot water used in a medium-sized family while the generated electricity was connected to a dummy load as well via DC/AC inverter. They have observed that the a-Si and mc-Si PVT both recovers almost the same amount of heat. On the other hand, mc-Si PVT supplies 1.2 times as much electricity as a-Si PVT because the mc-Si has higher nominal efficiency. They have also mentioned that the relatively high ambient temperatures in Bangkok decreases the performance of electricity generation of mc-Si PV cells.

Various researchers from Germany as Patrick Dupeyrat[30] are also involved in the performance improvement of the PV/T system, like Y.Tripanagnostopoulos[6] they also conducted experiments on the PVT with glazed and unglazed systems.For the same firstly they investigated the thermal and electrical performances of several single glazed flat plate PV–T concepts based on water circulation by using a simple 2D thermal model, then presented the different ways of improvement.

In netherland several scientists and research scholars are involved in the study of PVT for better utilization of the available energy. Zondag et al.[18,19] worked on the PVT water collector energy performance analysis. they obtained the efficiency curves of nine different PVT water collector configurations for performance evaluation. They found that at zero reduced temperature, the thermal efficiencies of the uncovered and single covered sheet-and-tube collectors(fig.6) were found 52% and 58%, respectively, that of the channel-above-PV design is 65%. The channel-below-PV (transparent) configuration gives the better performance,while the single-cover sheet-and-tube design is a good alternative because it is more economical still its efficiency is only 2% less. The single cover sheet-and-tube design is introduced as one most promising for domestic hot water production. For low-temperature water-heating, the uncovered PVT water collector is recommended, It is assumed that the losses due to the reflection at the cover are eliminated, while the front heat loss is small because of the low working temperature level.

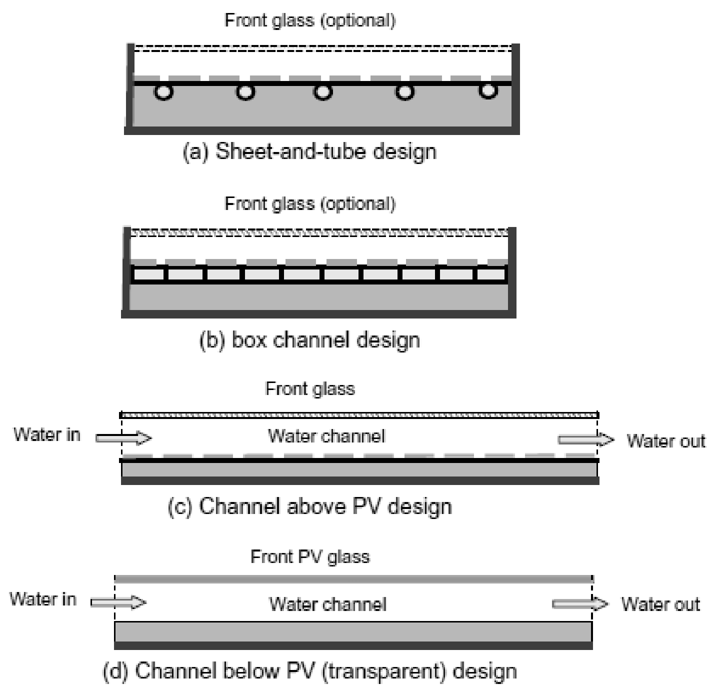

Fig.6 Some common PVT water collector configuration.[18,19]

Ilhan Ceylan et.al[31] also worked on the PVT water collector of spiral flow design but the cooling of photovoltaic module was done by the temperature controlled solar collector .For the purpose a process control equipment(PCE) is attached to the output of the collector. PCE opens the solenoid valve which is normally closed, temperature sensor is attached to the collector output. When the temperature of the solar collector decreases PCE closes the solenoid valve. Since the water entering the collector pass through the transparent pipes behind the "PV modules" each time, it will cool the modules at the same time. In that way, a pre-heating is applied to the solar collector. They observed that the module efficiencies with cooling and without cooling are 13% and 10% respectively. As the set temperature increased, module temperature can be increased or decreased. So temperature control cooling can be done and the efficiency of the PVT system is improved.

Other than Y.Tripanagnostopoulos and Adnan Ibrahim G.N. Tiwari[32] extended his effort to water based collector for finding the exergy and energy from the collector for gaining the good performances from the system.

5.Comparative studies of the passive and active dual cooling systems

Y.Tripanagnostopoulos[20]extended his research and worked on the active dual cooling of PVT system in which he has taken three combinations of air and water shown in fig.7 namely(i) Mode A,in which water heat exchanger is placed below the PV panel and above the air channel(ii) Mode B, in which water heat exchanger is placed inside the air channel and (iii) Mode C in which water heat exchanger is placed below the air channel or on air channel opposite wall.He has observed that the Mode A is giving the better performance rather than other two modes.For the mode A the thermal efficiency is about 55%.[20]He also tested the same model with three different configurations and found that the thermal efficiency for PVT/dual-TMS type is 39%, 42% for PVT/dual-FIN type and close to 44% for PVT/dual-TMS/RIB type.[20]

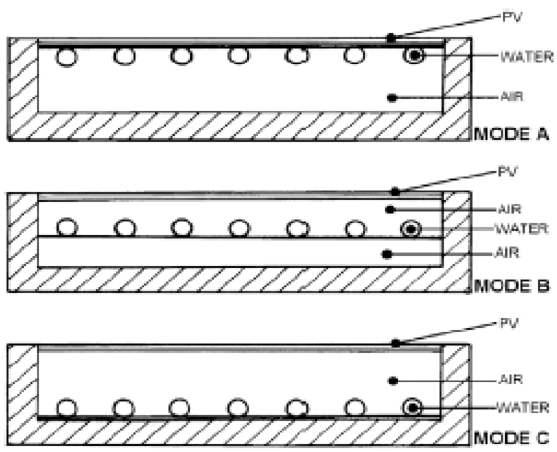

Fig.7 Dual cooling with different design mode[20]

6.Experimental studies conducted at the Indian Universities:

G.N.Tiwari et al. [21] involved much in the performance improvement of PVT in India.They have covered almost all the aspects related with the PVT technologies their work is very much worth full and helpful for the several researchers.They conducted the several experiment on the PVT systems technology for the evaluation of the overall efficiency performance of an unglazed PVT air collector .The results showed the optimal air flow rate, duct length and duct depth. Energy matrices equation were derived considering the embodied energy at different processing stages [22]. In the continuation of their work, Raman and Tiwari [23,24] studied the annual thermal and exergy efficiency of the PVT air collector for five different Indian climate conditions namely New Delhi, Bangalore, Mumbai, Srinagar, and Jodhpur. It was observed that the exergy efficiency is 40–45% lower than the thermal efficiency under strong solar radiation. Also the double-pass configuration shows better performance than the single-pass. On the other hand, Joshi and Tiwari [25] carried out exergy analysis of an unglazed PVT air collector for the cold climate region of India. The instantaneous energy and exergy efficiencies were found in the ranges of 55–65% and 12–15%, respectively. The effect of fill factor was also evaluated [26].

Dubey and Solanki et al. [27] from the Indian Institute of Technology, Delhi basically worked on the different configurations of glass-to glass and glass-to-tedlar PV modules.They have developed certain analytical expressions by considering climatic and collector design parameters for electrical efficiency with and without air flow. They have carried out several experiments on the above mentioned configuration with different combinations.They found that the glass-to-glass type configuration is able to achieve higher electrical efficiency this can be due to the radiation that falls on the non-packing area of the glass-to-glass module which is transmitted through the front cover. Its annual average PV efficiencies with and without duct were determined as 10.4% and 9.75%, respectively, hence a difference between is about 0.7%. The percentage differences between the PV efficiency of the glass-to-glass to the glass-to-tedlar type were found to be, 0.24% with duct and 0.086% without duct respectively. They extended their work to derive the analytical expressions for multiple PVT air collectors connected in series, including the testing procedure[28,29].

7. Comparison of the thermal performance of Air/Water based PV System

When the system becomes water cooled then the overall performance of the system increased, various researchers have computed the data related with the air cooled /water cooled system, here in the table 4 we have summarized the effects of different cooling systems and thermal performance of such systems.

Table.4 Thermal performance of various PVT systems

S.No.	Different systems Configurations For Air cooling modes	Air based PV System (Passive cooling) η_{th}	Air based PV System (Active cooling) η_{th}	Different systems Configurations For water cooling modes	Water based PV System (Passive cooling) η_{th}	Water based PV System (Active cooling) η_{th}	Different systems Configurations For dual cooling modes	η_{th}
(i)	**REF PV/T**	16%	25%	**Water channel above PV**	33.5%(Thermosyphonic effect)	65%	**water heat exchanger is placed below the PV panel and above the air channel**	55%
(ii)	**TMS PV/T**	18%	28%	**Water channel below PV**	----------	66%	**water heat exchanger is placed inside the air channel**	<55%
(iii)	**Fins PV/T**	20%	30%	**Sheet and tube design**	----------	58%	**water heat exchanger is placed below the air channel**	<55%
(iv)	**Air flow over the absorber**	----------	Least	**Box channel design**	----------	54%	**PVT/dual-TMS**	39%
(v)	**Air flow under the absorber**	----------	Better	**Spiral Flow Design,**	----------	50.12%	**PVT/dual-FIN**	42%
(vi)	**Air flow through the single pass**	----------	Good(but more power is required for the proper flow of air)	**Serpentine Flow Design**	----------	32.35%	**PVT/dual-TMS/RIB type**	44%

(vii)	**Air flow through the double pass**	------------	**Better than all three**		----------	----------	----------	----------
(viii)	**TMS PV/T Glazed**	31.6–36.2%,	----------	----------	----------	----------	----------	----------
(ix)	**TMS PV/T Unglazed**	12.2–24.8%	----------	----------	----------	----------	----------	----------

8.Conclusion

The performance of PVT collector under various cooling modes had been studied experimentally, theoretically and numerically for more than three decade. Earlier the researchers, professionals and scientist worked and spent their effort on design modifications and performance improvement of the PVT system with low cost criterion. On the basis of geographical locations the use of PVT collector has been decided. At low latitudes where ambient air temperature is about 20 °C for many months of the year so the PVT air system is not much effective in comparison of PVT water system. At locations where the solar insolation as well as ambient temperature is low so the PVT air system may be useful for space heating. PVT system is expected to have potential for future applications. The lack of awareness and information of the PVT system limits its utility. Technical design ,high cost and low efficiency are some issues which are associated with the air PVT system if these are resolved then it became a very promising technology. But all types of PV/T systems are not successful due to the high operating temperature when it is exposed to the enhanced illumination. That is why efficient cooling system is required to reduce the temperature of the system without any efficiency drop and the electrical performance of the system is enhanced. This review of different cooling systems exposed that none of the above discussed technology are much more capable for enhancing the overall efficiency at certain expected level, further research is required for better design of a cooling system which can fulfill the required demand efficiently.

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