A REVIEW ON EFFECTIVE COOLING METHODS FOR SOLAR PHOTOVOLTAIC CELLS

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ABSTRACT

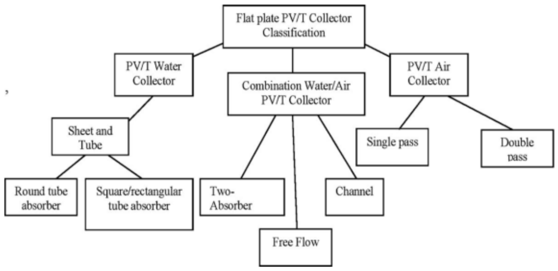
In this paper an attempt is made to study solar energy harvesting with the use of Flat Plate Solar Photovoltaic collector. The collector uses photoelectric semiconductor material for the conversion of solar energy into both electric and thermal energy. These solar cells on continuous operation it gets heated up and its temperature gets elevated above the optimum temperature of operation. This reduces the performance of the solar cells. Cooling of solar cells can sort out this problem. Further the heat extracted by the cooling fluid can be used for various applications like room heating, solar desalination, solar pond. The effective methods of cooling solar cells, experimented earlier in international journal papers are studied in detail and their results are reviewed.

Key words: Solar Cells, Photovoltaic/ Thermal (PV/T) system, Cooling, Solar flat plate collector

INTRODUCTION

In this 21st century several non-conventional and renewable energy sources have been recognized. Among them solar energy is the most abundant energy available on earth. Even though, solar energy harvesting is the most expensive than that of other sources, it is most emerging method of harvesting renewable energy at this juncture. Many researches have been conducted and further going on regarding the optimal and efficient design of solar collector. Solar collectors have found its applications in various arenas.

A brief classification of flat plate collectors is presented in the following flow chart [1].



Today the solar systems have evolved into an eco-friendly source for power generation [2].Thus solar based generation will have huge impact in replacing fossil fuels.

The Solar Photovoltaic/Thermal (PV/T) cells (as stated earlier) are of photoelectric semiconductors and the most commonly used photoelectric material is Silicon (Si). These cells work on the principle, Photoelectric Effect [3]. The Solar radiation consists of energy bundled in form of particles called Photons. The solar cells absorb these photons and emit electrons and this is known as photoelectric effect. These emitted electrons and gets collected. Thus electric energy is generated from the solar energy. This emission of electrons is always associated with heat generation. This heat should be dissipated to ensure efficient operation of the solar collector. A selective metal surface is (usually copper) [4] coated beneath the solar cell layer to absorb heat radiated by the solar cells during the operation. A suitable coolant (say water or air) is surpassed beneath this selective layer to carry away the radiated heat.

In countries where hydel power generation is not enough to power demand, solar power generation become increasing and approaches to build economic solar systems are happening at a rapid rate [5, 6].With such a demand, it is essential to achieve maximum efficiency in the solar collectors. Thus it becomes important to minimize the losses that occur during the conversion (solar energy into electrical energy) [7].

It is noted that operating solar collectors at low temperature was proven to have higher conversion efficiency. At low temperature the solar conversion property is observed to be in enhanced state [8].

To achieve higher efficiency, recent researches were proved that PV cells can be manufactured with higher conversion efficiency by modified cell structure [9]. But these methods increase the cost of the solar cells. Hence operating the solar cells at optimum temperature by cooling solar cells can considerably increase the conversion efficiency at low cost. Cooling is usually done by water cooling and air cooling [10 - 12].Also oil cooling can be done on solar collector to achieve the operation of solar collector at optimum temperature and achieve better conversion and increased life of solar collectors [13, 14].

In this paper we have selected various available methods for cooling PV cells which are identified from the various journals and an attempt is made to describe those methods are discussed in detail. This paper elaborates the each methodology and posts the results for discussion.

2. PREVIOUS WORKS:

Rok Stropnik et. al [15] have presented an article that showed the use of the Phase Change Material (PCM) increases the efficiency of PV panel. They modified the PV panel with a Phase Change material

RT28HC and compared actual data with conventional PV panel output. The modified PV panel layout sketch is shown in Fig 1.

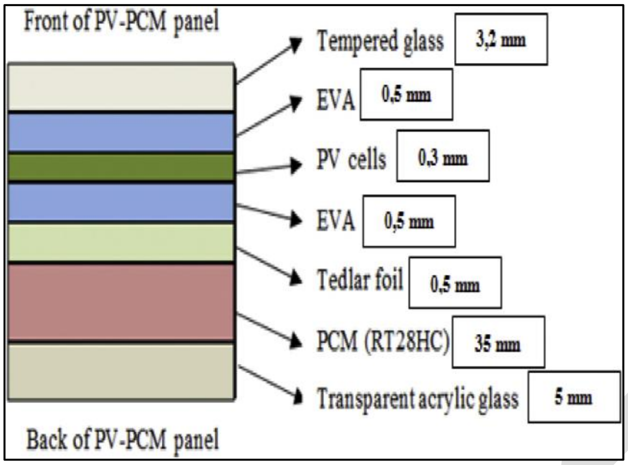


Fig 1: Modified PV-PCM Panel

The PCM used is paraffinic organic type and utilizes the phase change between solid and liquid to store and radiate large volume of heat at nearly constant temperature as in the form of latent heat. An experiment was conducted between 08:30-13:30 on the terrace of the Faculty of Mechanical Engineering in Ljubljana, Slovenia to analyze the modified design on October, 2013. The results showed that during the phase change, the PCM absorbed maximum heat radiated by the panel and maintained the panel temperature at an average of 30°C to 40°C. When all PCM is converted into liquid again temperature began to reach 44°C. Comparing with the conventional panel the maximum temperature reached by the modified Panel was about 23°C lesser. Also it is noted that maximum energy efficiency was 0.5-1% higher than that of conventional panels.

H.G. Teo, et. al [16] designed and fabricated a hybrid solar photovoltaic / thermal (PV/T) system to overcome the adverse effects caused by the increase of cell operating temperature during adsorption of solar radiation. A test setup (Fig 2) was designed and its thermal and electrical performances were investigated.

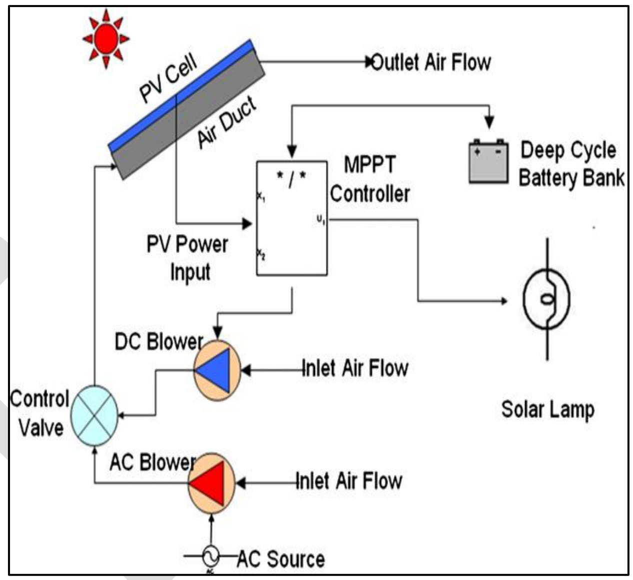


Fig 2**:** Experimental setup

This investigation showed how the temperature affected the efficiency and power output of PV panel. An array was attached underneath the panel to pass the air. A direct blower, attached to the batteries supplied the air extracted from the surroundings. A pyranometer was used to record daily solar radiation. The air manifold design was modeled using CFD Package Fluent 6.3. It was found that the proposed design helped in reduction of temperature variation throughout the panel. It was absorbed that the module temperature was proportional to irradiance. The electrical efficiency of the module increases with the flow rate until the flow rate reaches 0.055 kg/s. Then the efficiency remains almost constant even the flow rate increases above

0.055 kg/s and the average electrical efficiency of the panel was about 10.1% to 10.9%. The temperature profile showed that the temperature of silicon cell was the maximum because of the high adsorption of solar radiation. Thus by cooling the module by the air flow rate of 0.055 kg/s the module temperature was maintained at 38°C and performance of the solar panel is enhanced.

M. Benghanem et. al [17] have presented the performance of solar cells to show that efficiency of solar cells decreases with increasing temperature and found that efficiency drops by 0.5% per °C rise in temperature. Hence cooling of the solar cells is required and has to be operated at lower temperature. This enhances the performance of the solar cells. The team conducted experiment on their proposed Hybrid Photovoltaic / Thermoelectric Module (PV/TEM) at Taibah University, Faculty of Science, Physics Department, Solar Energy, Madinah(KSA) (Latitude=24.46°N and Longitude=39.62°E) which is a semi-arid region. The ambient temperature of this site is between 40°C and 50°C during summer months and as a result the cell temperature reaches about 80°C. The experiment was conducted by measuring the panel temperatures before and after the cooling the PV Panel (Fig 3). The hot surface of the TEM is connected to a sink to enhance heat extraction. The other side of the TEM, i.e. the cold side, is attached to the other back side of the solar cell. When the solar irradiance increases, the PV panel powering the module gives more voltage to drive the TEM.

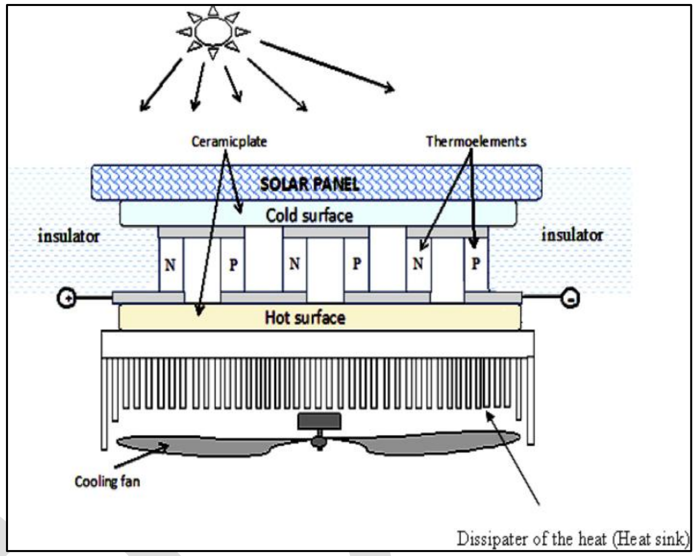


Fig 3: Proposed PV/TEM Design

If the voltage is increasing, the cold side of the TEM becomes colder. Then the cell temperature of PV panel decreases and best performance of hybrid PV/TEM system is obtained. The maximum cell without the cooling was 83°C. But with cooling, the PV panel temperature was maintained about 65°C without loss of solar cells. Thus by operating the solar cell at a lower temperature (cell temperature cooled down to 18°C), more power can be drawn from solar cells for the same solar irradiance and its life gets increased.

Rakesh Kumar et. al [18] have made a comprehensive steady state analysis on a solar air heater with a double pass configuration and vertical fins. They studied the effects of climatic on solar collector. They used fins arranged perpendicular to the direction of air flow to enhance heat transfer rate efficiency. The cross sectional view of (PV/T) with fins is shown in Fig 4.

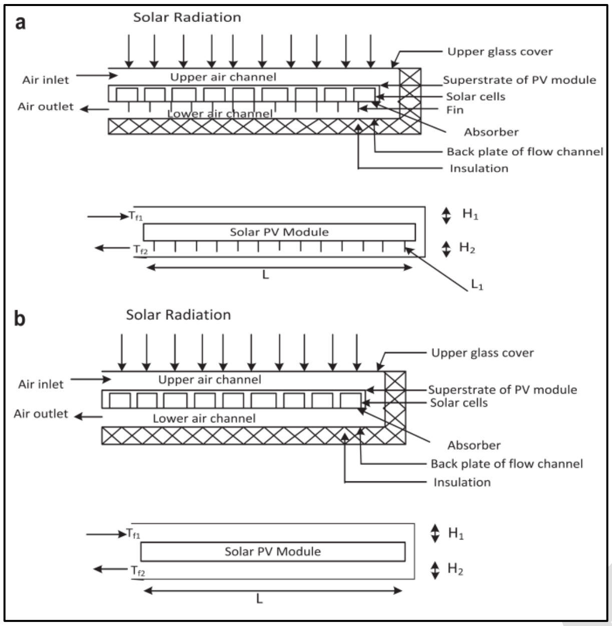


Fig 4: C.S. of Double pass collector (a-with fin and b-without fin)

In this investigation the total number of fins is taken to be 24 per meter length of the collector. The vertical fins increased the heat transfer area. The height and thickness of fins is taken as 2.5 cm and 0.1 cm respectively while length and width of the air heater is taken to be 1m.The bottom of the air heater is covered with fiberglass of thickness 5cm. The directions of air movement in both the channels are shown above. The solar radiation incident on the upper glass cover is transmitted to the absorber surface. A fraction of the incoming solar radiation is converted into the electrical energy by photovoltaic cells and remaining is converted to heat. This heat is transferred to the flowing in the upper and lower channels. In the PV/T air heater with fins, the air flowing in the lower channel is exposed to the extended area of back surface and its influence on the on the electrical and thermal performance is investigated. This investigation showed that there was a considerable reduction in cell temperature from 82°C to 66°C. The thermal and electrical efficiency was described as a function of ratio of the difference between the fin and ambient air temperature (Ratio) to that of fin length in the following plots at different mass flow rates and are shown respectively in Fig 5 and Fig 6.

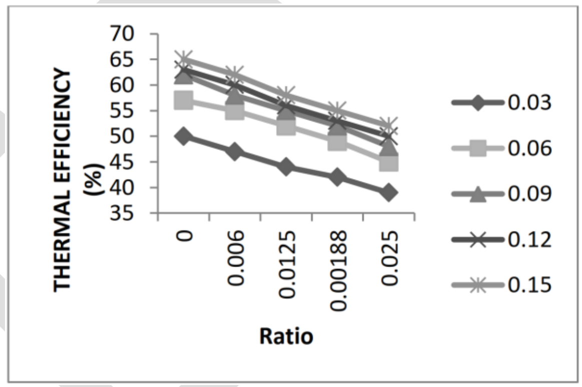


Fig 5: Thermal Efficiency

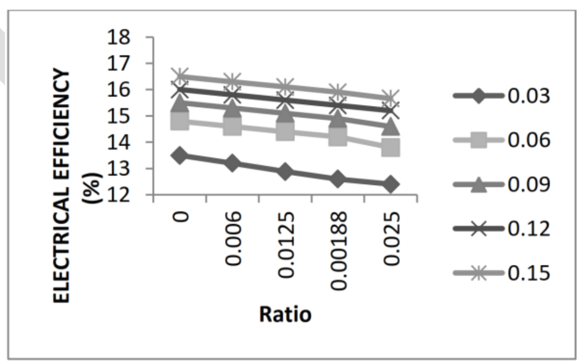
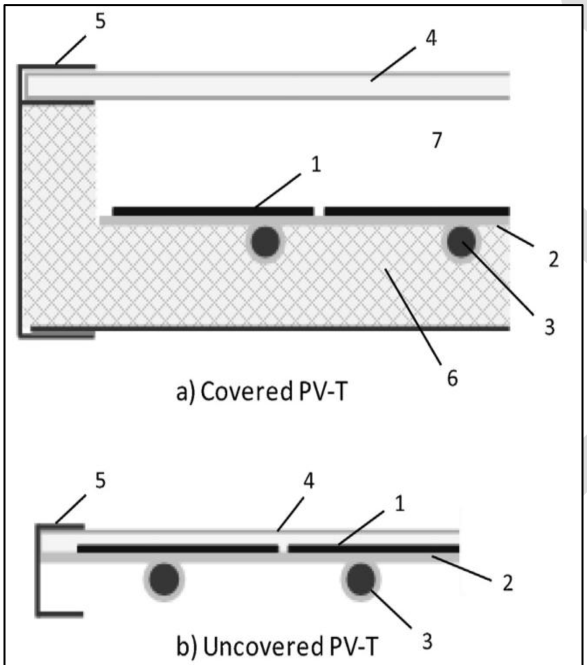


Fig 6: Electrical Efficiency

Thus the investigation resulted in the increase of electrical and thermal efficiencies respectively to 15.5% and 10.5%.

P. Dupeyrat et. al [19] aimed at presenting an paper to access the performance of Photovoltaic-thermal hybrid collector. An experimental flat plate collector was developed and test results were described to compare with the performance of the hybrid collector. Comparisons were made assuming the same surface area and under the same climatic conditions. The hybrid system was developed with a surface area of 1.01 m^2 which is one of the optimal areas for solar radiation absorption. The single crystalline silicon cells were laminated onto the surface of a specially coated metal absorber and covered by a high transmission polymer film. This absorber was built into collector and tested with and without glass cover as shown in Fig 5.



lam-inated solar cells (1), heat exchanger construction (2), heat removal fluid (3), glasscover (4), aluminum frame (5), thermal insulation (6) and static air layer (7).

Fig 7: Cross Sections of the collector

The thermal and electrical measurements were carried out at the indoor test facility of Fraunhofer ISE. The measurements are with hybrid mode (both thermal and electrical energy is produced). The thermal efficiency of the glass covered PVT collector was 72% with a corresponding electrical efficiency of 11% whereas the thermal efficiency of non-covered PVT collector was only 67%. Thus glass cover leads to the better operating efficiency and reduction in operating temperature range due to increased heat transfer rate in comparison with that of the non-covered collector. Also the heat transfer between the PV cells and heat removal fluid has been increased by the coating of the absorber polymer. The hybrid system is both electrically and thermally more efficient than a standard PV collector.

Ahmed Elnozahy et. al [20] have done an experimental investigation to study the performance of the automatic cooling and cleaning of Photovoltaic (PV) Module in arid areas and compared its performance with that of a module without cooling and cleaning. The module cooling is controlled automatically according to the rear side temperature always close to the ambient by rejecting the none-converted solar energy to the ambient. The experimental setup (Fig 8) has been developed using a thin film of water (about 1 mm thickness) and effect of automatic cooling is studied. The proposed automated cooling system for PV module was built at Energy Resources Engineering Department at Egypt-Japan University of science and technology. Two SF80-A thin film PV modules were in the study. The measurements were recorded during a clear day (10th of April 2014). Irradiance was measured by a pyranometer at the same plane of the module: south at an elevation angle of 30°.The recording of data was done for every hour by a data logger.

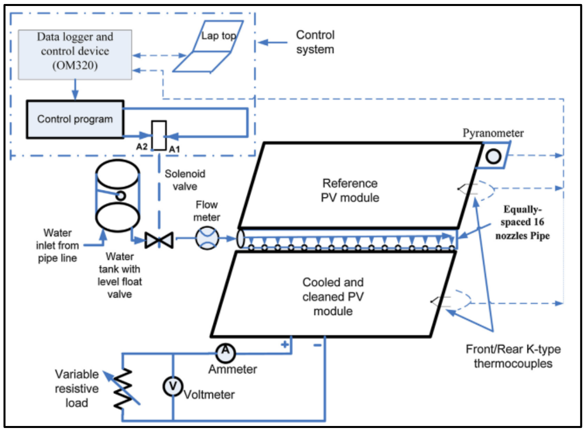


Fig 8: Experimental Setup

The cooling consists of a copper pipe with equally-spaced 16 nozzles (as shown in Fig. 8) to maintain the uniform temperature which is assisted by an automated cooling system. Results show that both rear and front face temperatures was 20°C less when compared to the conventional PV module. This is due to the water flow and cooling by evaporation. Also the conversion efficiency was improved to 11.7% against 9% of the conventional PV module. Thus a maximum power of 89.4 W is obtained with the cooling system against 68.4 W of conventional module.

J.K. Tonui et. al [21] presented a paper in which describes how suspended thin flat metallic sheet at the middle fins at the back, increases heat transfer in an air cooled photovoltaic thermal (PV/T) solar collector to its overall performance. The steady-state thermal efficiency of the modified system was compared with those of typical PV/T air system. The typical collector was referred as "REF" and the one, modified with Thin Metal Sheet is referred to as TMS while another one modified with fins is referred to as FIN. The REF system consists of single-pass air channel attached behind the module. The sheet in TMS creates a double-pass air channel. The FIN system consists of rectangular fin attached to the back side of the module. The test module was constructed from two pc-Si PV panels of length 1 m, aperture area of 0.4 m^2 with an air-channel of depth of 15 cm attached at the rear surface of the TMS and FIN modules. The channel surfaces, thin metallic sheet and the fins were painted black. The fins height and spacing distance is each equal to 4 cm. The air was forced through the air channel through the air pump. Also natural air flow was allowed through the inlet vent and exit is provided by an outlet vent. The schematic diagram of the experiment is shown in Fig 9.

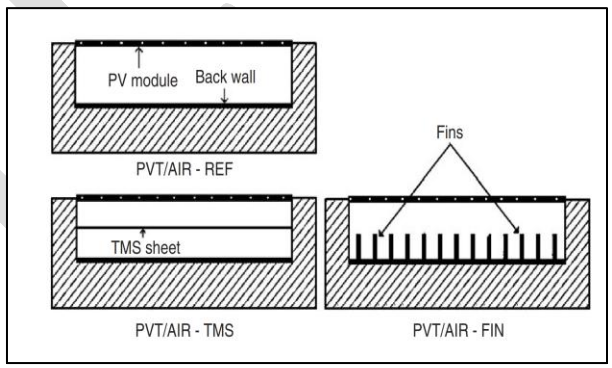


Fig 9: Configurations of TMS, REF, FIN

The experiments were performed in an outdoor clear sky conditions. The results of the experiments are plotted in terms of electrical efficiency in the plot (Fig 10). It is noted from graph that at lower temperatures the electrical efficiency is higher than that at higher temperatures at given solar irradiance at a linear fashion. The thermal efficiency of the panel followed the same trend as thermal efficiency and it is shown in Fig.11.

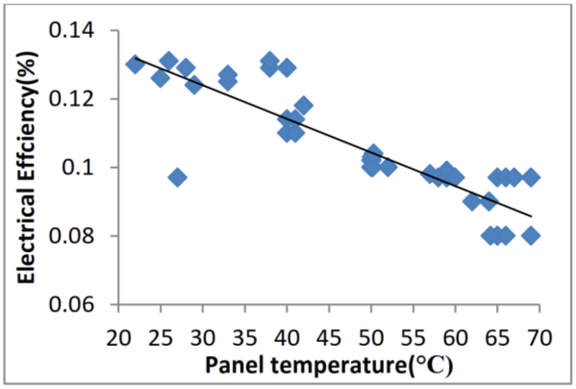


Fig 10: Electrical Efficiency Vs Panel Temperature

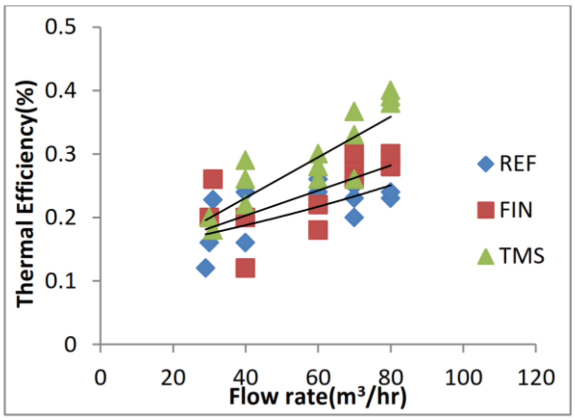


Fig 11: Thermal Efficiency Vs Panel Temperature

Thus the TMS has better performance than those of the REF and FIN. Also the FIN and TMS shows the lower PV panel temperature and back wall temperature than REF. The forced air circulation reduces the PV module temperature by at least by 6°C. It is noticed that the thin sheet metal reduces the back wall temperature by 2°C. Thus the modification yields better thermal efficiency than the normal system with enhanced electrical performance due to the PV cooling. Under the forced convection with flow rate of 60m^3/hr, the use of fins yield an efficiency of 30% while the use of TMS yielded an efficiency of 28% due to suggested PV cooling. The FIN type system gave higher efficiency than that of the TMS system.

Catalin George Popovici et. al [22] presented a study that approached the reduction of photovoltaic panels by using the air cooled heat sinks. The heat sink is constructed as a ribbed wall with a high thermal conductive material. The cooling efficiency is studied for different configurations of the heat sink, obtained by modifying the angle between the ribs and the base plate. The operating temperature of photovoltaic panels represents an important parameter that influences their conversion efficiency. At high operating temperatures a decrease of maximum output power under same conditions of solar radiation was noted and air cooling was implemented to sort out this problem. The influence of the operating temperature over the photovoltaic panel during a clear day of summer was studied. The position of the panel is considered vertical, integrated into a ventilated double skin facade (DSF). The PV panel was a part of exterior glazing of the double skin facade and enhances the cooling of photovoltaic panel, by attaching a heat sink (Fig 12) to its back. The width of double skin facade channel is considered constant, of 0.1 m. The ribs of the heat sink with circular holes of 0.003 m radius was placed at a distance of 0.03 m one to another. These holes were intended to improve the air circulation near the heat sink and to extract more heat from the PV panel. The geometry of the proposed system is shown in Fig. 12. The different cases studied in this paper by modifying the height of ribs from 0.01 m to 0.05 m with the steps of 0.01 m. The inclination of the ribs toward the vertical is also varied at 45°, 90° and 135° and represented in Fig 13.

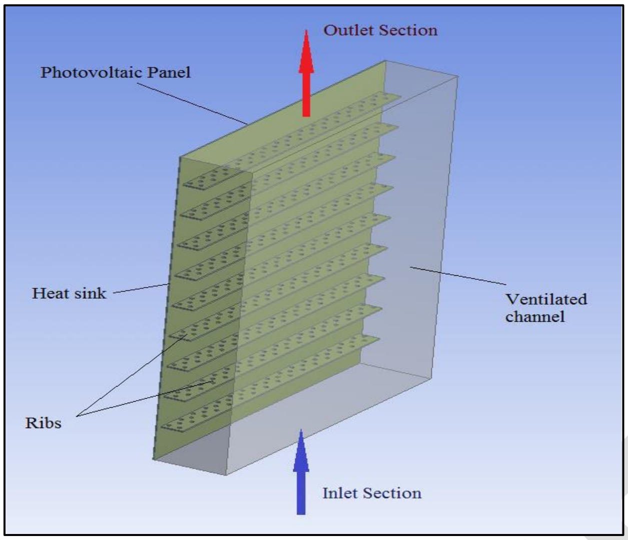


Fig 12: Geometry of the heat sink

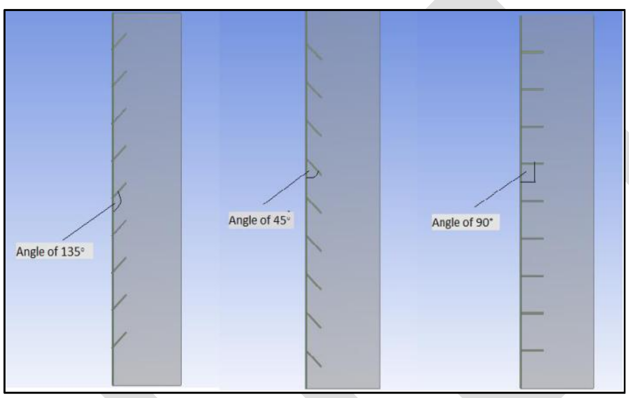


Fig 13: Inclinations of the ribs

The simulation is performed with ANSYS-FLUENT and following plots regarding temperature. It is noted that the cooling of the photovoltaic panel is directly proportional with the height of the ribs and inversely proportional with their inclination angle. The operating temperatures of the cell are registered for the angle of 45° is lower. The contours of average temperature of the PV cell were shown in Fig. 14. At 45° angle, about 1°C drop in average temperature is seen while at 135°, the drop in temperature was about 2°C.

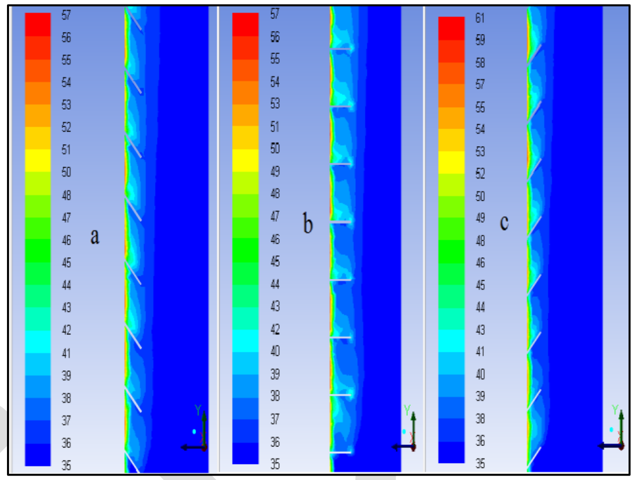


Fig 14: Temperature spectra a) 45 °, b)90°, c) 135°

The angle of the ribs has a less important influence at greater heights but to contrast a reversed effect is noticed for the height of 0.01 m. The registered values of temperatures with varying rib height (with respect to rib angles) are shown in Fig 15.

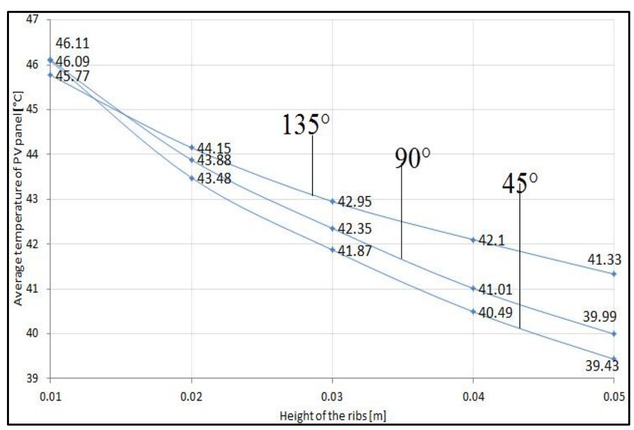


Fig 15: Average temperature of PV panel vs. Rib heights (For 3 rib angles)

In the study the operating temperature of PV panel reaches about 56°C, if no ribs are used and the maximum produced power is 86%

of the nominal one. In case of using a heat sink, even for small heights of the ribs, the average temperature of the PV panel decreased. It was noticed that the temperatures were reducing with at least 10°C below the values obtained in the basic case. This aspect was favourable for the conversion efficiency, determining a maximum power produced above 90% of the nominal one. For the studied configuration, the rise of maximum power produced by photovoltaic panel is from 6.97% to 7.55% comparing to the base case, for angles of the ribs from 90° to 45° respectively.

Fahad Al-Amri et. al [23] presented a paper which they developed a heat transfer model for a multi-junction concentrating solar cell system. The model presented in this work includes the GaInP/GaAs/Ge triple-junction solar cell with a ventilation system in which air is forced to flow within a duct behind the solar cell assembly and its holders and accessories (anti-reflective glass cover, adhesive material, and aluminum back plate). In the study, a thermal model to actively cool the concentrator multi-junction solar cells by air convection with the aid of surface radiation is developed and presented. This in-house developed and validated code enabled the optimization of the channel width for the effective removal of heat from the CPV systems.

The geometry of the triple-junction cell assembly consists of a triple-junction GalnP/GaAs/Ge solar cell, a CueAgeHg front contact to the solar cell, a 2 mm glass cover and a 1.5 mm thick aluminum back plate. The solar cell was attached to the cover glass and rear aluminium plate via an adhesive material. The cooling air was forced to flow within the ducts behind the back plate, whose external wall was assumed to be adiabatic. The two walls of the duct were assumed to be grey, opaque, and diffuse. The inlet and outlet channel areas were assumed to be black at the ambient temperature (T_∞=27°C) and exit bulk temperature (T_e), respectively. The efficiency of the triple-junction solar cell (h) is 0.38. The geometry of the triple-junction cell assembly is shown in Fig. 16.

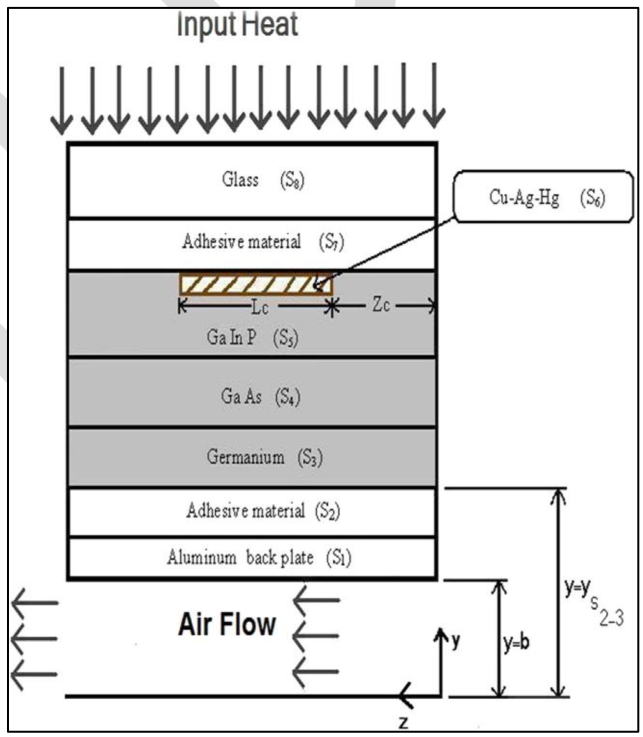


Fig 16: Schematic of the system geometry

The variation of the maximum cell temperature with the concentration ratio for three selected values of emissivity, namely, 0 (i.e., no radiation exchange), 0.5, and 0.98 were plotted in Fig 17.

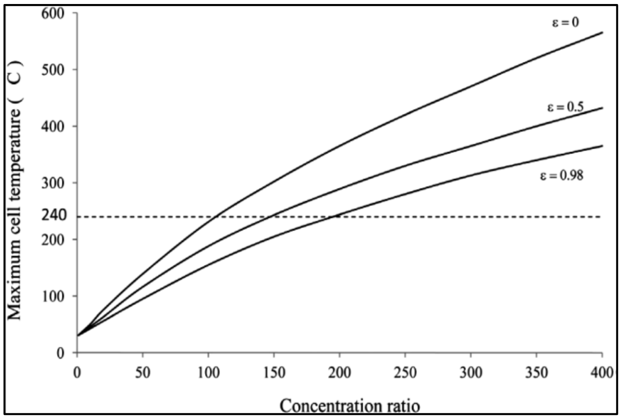


Fig 17: Maximum cell temperature Vs Conc.Ratio (For three emissivity values)

It is clear from the Fig 17 that surface radiation has a noticeable effect on the maximum cell temperature. The radiation effect occurs by transferring some of the input heat from the aluminum back plate to the opposite duct wall, hence reducing the cell temperature. As the emissivity of the walls increases, the effect of the surface radiation increases. The higher the concentration ratio, the higher is the radiation effect. On the other hand, for a given value of operating temperature, increasing the emissivity of the walls leads to operating the solar cell at a higher concentration ratio without affecting its efficiency.

Also the maximum cell temperature drops from 240°C to 150°C (i.e., by about 37.5%) as emissivity increases from 0 (pure conjugate convection) to 0.98 for concentration ratio=100. In addition, the critical concentration ratio increases by 96%, from 100 to 196, as emissivity increases from 0 to 0.98. Thus, the two walls of the duct should be a good emitter, either to achieve the highest possible reduction on cell temperature and hence improve the cell efficiency, or to operate the PV cell at a higher concentration ratio 200. However, the level of concentration could be raised up to 345 by narrowing channel width to 0.5 mm. Thus the interaction of surface radiation and air convection could adequately cool the solar cell at medium concentration ratios.

Ilhan Ceylan et al[24], in their study, conducted experiments with different PV/T systems and analyzed for the cooling photovoltaic modules. A simple pipe was placed on 21 PV modules which acted as a spiral heat exchanger in order to provide active cooling. The result of experimental research shown that the module efficiencies with cooling were 13%, the module efficiencies without cooling were about 10%. The designed and experimentally analyzed system is given in Fig.18 and its flow scheme of the control system is given in Fig. 19.

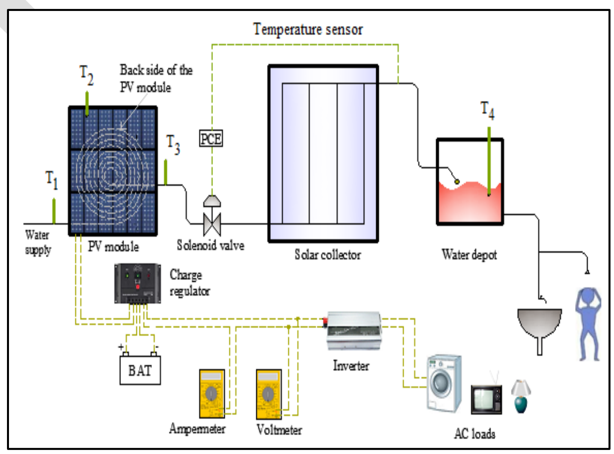


Fig 18: Designed PV/T system

The cold water flowing into the system from "T_1" point in Figure 18 passes through a transparent spiral pipe rolling behind the PV Module and gets out from "T_3" point. When the process control equipment (PCE) reaches the set temperature a normally closed solenoid valve is opened. The temperature sensor of the PCE was attached to the collector output. The water supplied to the solar collector fills the hot water in the water depot at the point of "T_4". When the temperature of the solar collector decreases, "PCE" closes the solenoid valve. The water entering the collectors pass through the transparent pipes behind the "PV modules" each time and cool the modules at the same time.

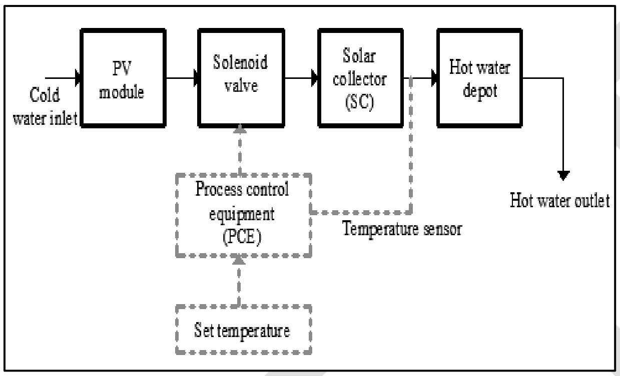


Fig 19: Flow chart of the PV/T system

The experimental results were plotted in following plots (Fig 20, Fig 21).

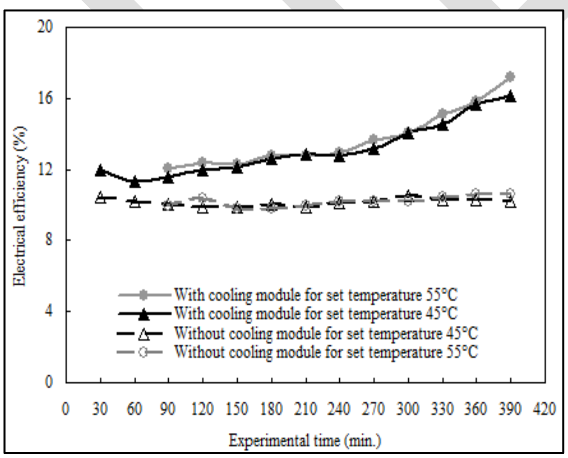


Fig 20: PV Panel Electrical efficiency (for 45 °C and 55°C)

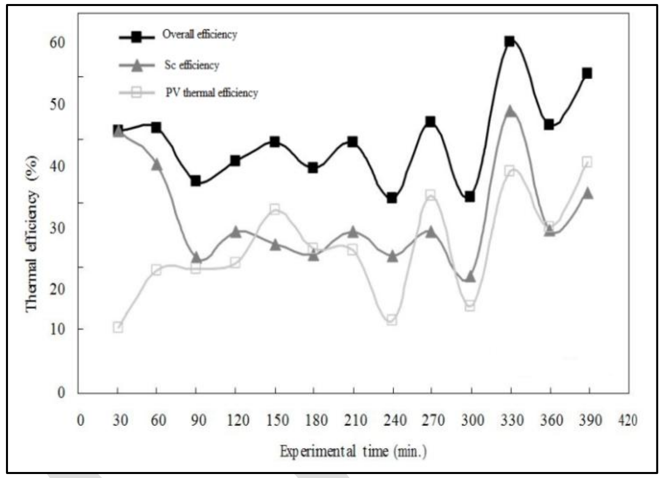


Fig 21: PV Thermal efficiency (at 45 °C)

It was observed that he module placed on the front of the solar collector decreased the collector efficiency but increased the system efficiency. The module temperature was changed according to solar radiation and set temperature. As the solar radiation increased, the module temperature decreased in this system. This situation can be seen for the 45^{o}C experimental results. The efficiency of the module with a cooling was higher at a rate of 3% than that of the one without a cooling. Also cooling the panel increased electrical efficiency.

Mohd Nazari Abu Bakar et al[25] presented a paper which talks about the improved design of a photovoltaic/thermal (PV/T) solar collector integrating a PV panel with a serpentine-shaped copper tube as the water heating component and a single pass air channel as the air heating component. In addition to the generated electricity, this type of collector enables the production of both hot air and water, increasing the total efficiency per unit area compared to the conventional PV/T solar collector. The use of both fluids (bi-fluid) also creates a greater range of thermal applications and offers options in which hot and/or cold air and/or water can be utilized depending on the energy needs and applications. The paper presents comparison between performances of the collector when the fluids are operated simultaneously and independently.

The design of a simple unglazed bi-fluid photovoltaic thermal (PV/T) solar collector which integrates a conventional serpentine-shaped copper tube flat plate water solar collector with a single pass air solar collector (pictured in Fig 22) was presented in the paper.

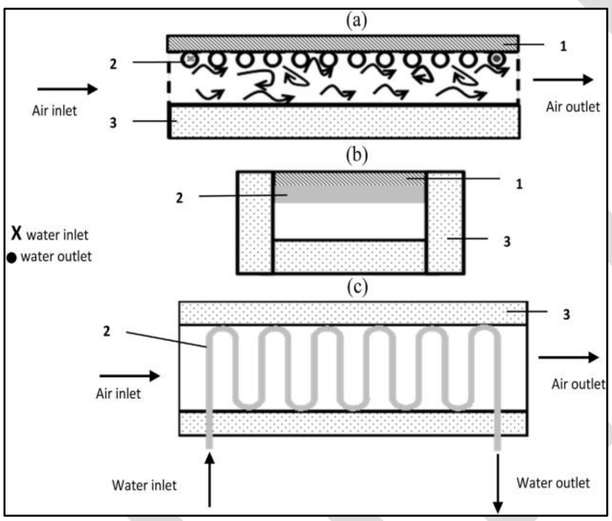


Fig 22: Schematic diagram of single pass bi-fluid PV/T solar collector ((a) Side view cross-section, (b) front view cross-section, and (c) top view cross-section, (1) PV module, (2) serpentine copper tube, and (3) insulation layer)

The collector is designed such that air is forced to flow in the air channel. The surface that facing the air flow comprises the serpentine-shaped copper pipe and the back surface of Tedlar (back of PV module). The air then flows transversely to the long-direction of the copper tube hence a cross flow condition was achieved. For an internal fluid flow, the presence of the fluid laminar sublayer increases the thermal resistance between the channel wall and the working fluid. A roughened or corrugated surface will break this sub-layer which causes flow separation and reattachment of streamlines between the consecutive rough surfaces.

The electrical, thermal performance as a function 'total thermal equivalent' efficiencies, for air and water and also the temperature rise of the fluids under simultaneous and independent mode of operation were illustrated in Fig 23.

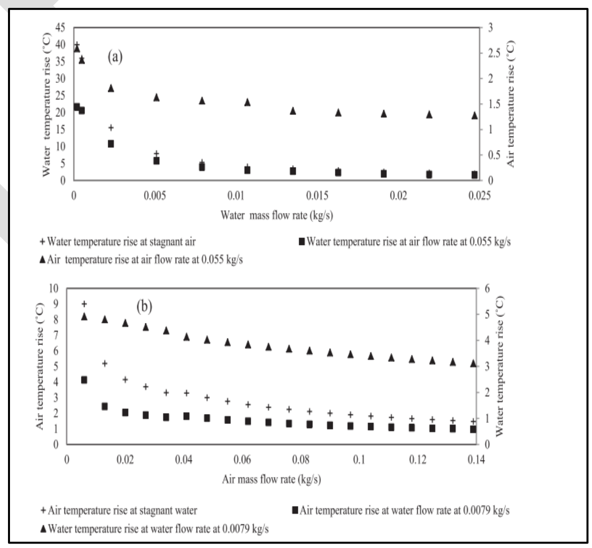


Fig 23: Thermal equivalent efficiency

At optimum mass flow rate for the parameters stated, the total thermal equivalent efficiency when the fluids are operated simultaneously is predicted to be as high as 76%. The temperature rise of both fluids in either independent or simultaneous mode have shown that the latter is efficient than that of the former.

RESULTS:

TABLE 1

S.No:	Author	Fluid Type	Observations	Remarks
1.	Rok Stropnik et. Al	Phase Change Material (PCM)	During the phase change, the PCM (RT28HC) absorbed maximum amount of heat radiate by the panel and maintained the panel temperature at an average of 30°C to 40°C.	When all PCM is converted into liquid again temperature began to increase and it can be sorted out by providing a reservoir.
2.	H.G. Teo, et. Al	Air	The efficiency remains almost constant even the flow rate increases above 0.055 kg/s and the mean electrical efficiency of the panel was about 10.1% to 10.9%.	The panel's electrical efficiency increases with the flow rate until the flow rate reaches 0.055 kg/s and after that the efficiency neither increases nor decreases.
3.	M. Benghanem et. Al	Air(Along with the fin blower)	The maximum cell without the cooling was 83°C but when cooling was done the PV panel temperature was temperature of PV/TEM was maintained about 65°C without loss of solar cells.	Some amount of energy is required to operate the fan blower (to distribute the air across the fins). This decreases the output from the panel as some part of panel output electrical is utilized by the blower.
4.	Rakesh Kumar et. Al	Air (fins heat exchange)	The investigation showed that there was a considerable reduction in cell temperature from 82°C to 66°C and resulted in the increase of electrical and thermal efficiencies respectively to 15.5% and 10.5% than that of conventional one.	Even though the fins in the air channel increases the heat-transfer rate, the size of the panel increases to accommodate the air channel and fins. It increases the cost of the panel and increases complexity.
5.	P. Dupeyrat et. al	Heat transfer fluid (through channels)	This absorber was built into collector and tested with and without glass cover and heat transfers in both the cases were compared.	It is seen that glass cover improves the operating efficiency & reduces operating temperature range.

S.No:	Author	Fluid Type	Observations	Remarks
6.	Ahmed Elnozahy et. al	Thin film of water(assisted by automated system)	The cooling consists of a copper pipe with equally-spaced 16 nozzles to maintain the uniform temperature which is assisted by the automated cooling system. This maintains uniform throughout the PV panel.	The temperatures of rear and front faces were 20°C than that of conventional one and the panel's conversion efficiency improved to 11.7% against 9% of that of conventional one.
7.	J.K. Tonui et. Al	Air (forced through air channel)	The PV modules with TMS and REF arrangements were designed and their thermal and electrical performances were studied in detail. The performances were compared with that of conventional PV module.	The TMS is efficient than those of the REF and FIN. Also the FIN and TMS shows the lower PV panel temperature and back wall temperature than REF. A better thermal efficiency than the normal system with enhanced electrical performance due to the PV cooling under the forced convection.
8.	Catalin George Popovici et. al	Air (heat sink)	The reduction in PV Panel temperature is observed by using the air cooled heat sinks. The heat sink is conceived as a ribbed wall, realized of a high thermal conductivity material. The cooling efficiency is studied for different configurations of the heat sink, obtained by modifying the angle between the ribs and the base plate.	A 10°C reduction in panel temperature values is obtained in the basic case and 90% power is achieved. For this configuration, the rise of maximum power produced by PV panel is from 6.97% to 7.55% comparing to the base case, for angles of the ribs from 90° to 45° respectively.
9.	Fahad Al-Amri et. al	Air	The solar cell was attached to the cover glass and rear aluminium plate via an adhesive material. Air was forced to flow within the ducts behind the back plate, The two walls of the duct were assumed to be gray, opaque, and diffuse.	As the emissivity of the walls increases, the effect of the surface radiation increases. The interaction of surface radiation and air convection could adequately cool the solar cell at medium concentration ratios.

S.No:	Author	Fluid Type	Observations	Remarks
10.	Ilhan Ceylan et. Al	Air	It was observed that he module placed on the front of the solar collector decreased the collector efficiency but increased the system efficiency. The module temperature was changed according to solar radiation and set temperature. As the solar radiation increased, the module temperature decreased in this system.	The result of experimental research shown that the module efficiencies with cooling were 13%, the module efficiencies without cooling were about 10%. The efficiency of the module with a cooling was higher at a rate of 3% than that of the one without a cooling. Also cooling the panel increased electrical efficiency.
11.	Mohd Nazari Abu Bakar et al	Air and water(bi-fluid)	The design of a simple unglazed and bi-fluid photovoltaic thermal (PV/T) solar collector was integrated with conventional serpentine-shaped copper tube flat plate water solar collector with a single pass air solar collector is experimented.	At optimum mass flow of air and water the total thermal efficiency was found to be as high as 76%. The rise in temperature of both fluids in either independent or simultaneous mode have shown that the latter is efficient than that of the former.

CONCLUSION:

The various methods discussed have their own advantages and disadvantages which differ in each case discussed earlier. It is necessary to identify the circumstances before utilizing each method to improve conversion efficiency of the solar cells. In region with medium ambient temperature, it is recommended to use PCM for cooling [14] which will be economic also. But in tropical regions where ambient temperature shuts up as high as possible, it becomes a necessary to have air cooling [2-3].

Water cooling of the solar cells will have will have greater participation in operating the solar cells at optimum than that of air as water has high heat transfer co-efficient[6, 11]. But in water cooling system, effect of corrosion should be considered before implementation.

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