Review of Various Cooling Techniques to Improve the Performance of the Solar Photovoltaic Panel

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Abstract:

With limited Non Renewable resources and considering Environmental pollution concerns due to Non-renewable energy sources, Solar Panels will play a vital role in satisfying global energy demands in the upcoming future. While evaluating the performance of Solar Photovoltaic Panel, various parameters are required to be taken into consideration. Apart from External parameters, various internal parameters also affect the efficiency of PV Panels. Several external and internal parameters like Weather Conditions, Shading, Panel Orientation, Wind Velocity, Location, Angular inclination of Solar Panel Cleanliness of Solar Panel surface, Ageing of Solar panel mainly affect the performance of Solar Panel Output. Researchers came to know the fact that the efficiency of Solar Panels decreases as the temperature of the back surface of Solar PV Panels increases due to the accumulation of heat inside the PV panels. This paper enlists various techniques used to cool down the operating temperature of a photovoltaic system.

***Key Words*: Photovoltaic Module, Conversion Efficiency, Cooling Techniques, Operating Cell Temperature, PCM, Forced Water Cooling, Air Cooling, Heat Transfer**

1. INTRODUCTION

The global energy landscape is witnessing a significant shift from traditional to non-conventional energy sources, triggering the need to reduce environmental pollution and promote sustainable development. Conventional energy sources, such as coal and fossil fuels, lead to various environmental issues, including air pollution, acid rain and greenhouse gas emissions. In contrast, non-conventional energy sources like solar, wind, hydro and biomass offer cleaner and more sustainable alternatives. Solar energy, in particular, has emerged as a promising green energy source due to its abundant availability and minimal environmental impact. Solar power generation systems harness sunlight to produce electricity without emitting harmful pollutants. Moreover, solar energy is renewable, meaning it can be replenished naturally and will not run out, unlike fossil fuels.

However, one challenge faced by solar PV panels is the reduction in efficiency caused by an increase in ambient temperature. As the temperature rises, the output power of the PV panel decreases, leading to lower overall efficiency. To address this issue, researchers have developed various cooling methods for PV panels, which can be classified into active and passive techniques. Active cooling methods involve the use of moving parts, such as fans or pumps, to dissipate heat from the solar panels. Examples include air cooling, water cooling, and a combination of both. On the other hand, passive cooling techniques do not require any moving parts and rely on natural processes like convection and radiation to remove heat. Some examples of passive cooling methods are phase change materials (PCMs), heat sinks, and nanofluids. Additionally, integrating thermo-electric generators (TEGs) with solar PV panels can help extract energy from waste heat, further enhancing the overall efficiency of the system.

1.1 Effect of environmental factors on the efficiency of PV module:

Manas Ranjan Das (2019) worked on the effects of temperature, humidity, wind velocity, light intensity, altitude and atmospheric pressure on the efficiency and performance of the panel. He found the temperature being inversely proportional to I-V characteristics decreases the performance of solar panel with an increase in temperature. Presence of humidity surrounding solar panel results in reflecting the sun's rays affecting the overall output of the panel and rusting of metal used in the panel and thus decreasing its performance. The wind velocity positively impacts the performance of the panel thereby improving efficiency. His results also showed that voltage and current decrease as the light intensity decreases with the direct proportionality of the two. Thus he included different environmental factors affecting the efficiency and performance of Solar PV panels.

2. ACTIVE COOLING TECHNIQUES

Active Cooling techniques mainly includes Forced Air Cooling, Forced water cooling & PV/T thermal systems to cool down the operating temperature of PV module.

2.1 Forced Air Cooling

Sajjad et al. (2019) performed research on two photovoltaic modules in which one was air-cooled and the other was without cooling. The module which was cooled showed 7.5% electrical efficiency and a 6.4% higher performance ratio when compared to the photo voltaic module without cooling.

Y.Tripanagnostopoulos et al. (2017) studied PV air cooling in several modes whose objective was to create a practical and efficient system configuration for its application in PV installations of buildings. They used two reference systems, one was a commercial PC-Si PV module which was used as a reference and the second was a fabricated PC-Si PV module with transparent tedlar on the front and normal glass on the back surface. These systems were tested in two conditions, first with forced air circulation and second with natural air circulation. The results of the experiment showed that the modifications done on the PV module contributed to satisfactory PV cooling.

Figure 1: Experimental Setup (Y.Tripanagnostopoulos et. al.(2017))
Left panel is a reference & Right panel is above a steel plate, creating an air channel underneath it.
a) First setup Natural convection b) Second setup Forced convection

J. R. García-Cascales et al. (2013) conducted research to modify the design of PV modules that are placed on roofs to ensure low operating cell temperatures. The experiment was conducted at the Universidad Politécnica de Cartagena in Spain. The setup consists of two similar solar panels in which one was taken as it is and the other was modified and mounted on different channels to allow the passage of air. The results show that there must be considerable air space between the photovoltaic panels and the roof for cooling the panel thereby increasing its efficiency.

Y. Tripanagnostopoulos and P. Themelis (2010) performed cooling of solar panels with natural air flow with the objective of the improvement of electrical efficiency of solar panel Installation on buildings through cooling of solar panels with natural airflow. The experiments were performed in daylight for several days with the addition of thin metal sheet (TMS) or metal fins in the middle of air channel and readings were observed. It was found that there was a significant improvement in the efficiency of solar photo voltaic cells which was due to the flow of natural air.

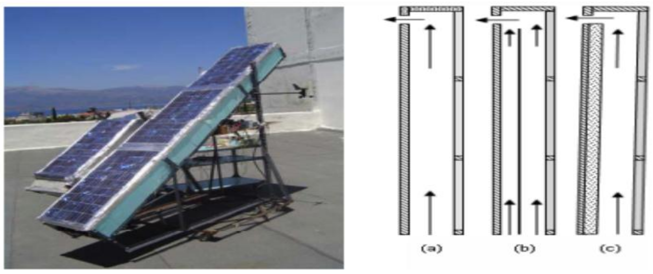

Figure 2 : Arrangement of PVT/AIR tested systems (left) and cross-section of the three models indicating the airflow along the air channel (right)

Y. Tripanagnostopoulos and P. Themelis (2010)

Ahmer A.B. Baloch et al. (2015) conducted research on an innovative cooling technique of solar PV panels which is known as the converging channel cooling technique which was applied to achieve low and uniform temperatures on the surface of solar PV panels. The experiment was conducted in Saudi Arabia in the month of June and December. The temperature readings were recorded in both the months of uncooled solar PV panels and cooled solar PV panel by applying the converging cooling technique. The temperature for the uncooled PV panel was 71.2°C and 48.2°C for the months of June and December respectively and for the cooled PV panel it was 41.6°C and 36.4°C for June and December respectively. Due to this significant drop in temperature, there was a rise in both the power output and electrical efficiency. The output power and electrical efficiency were increased by 35.5% and 36.4% respectively, hence making it economically viable.

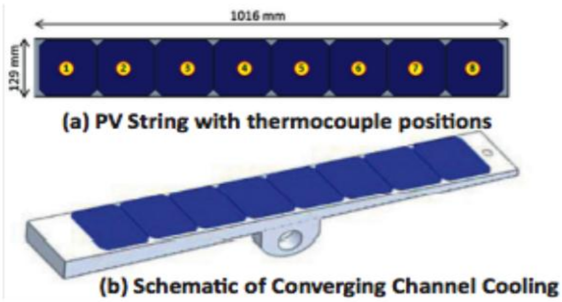

Figure: 3 (a) PV string with thermocouples' position, (b) Schematic of the converging channel

(Ahmer A.B. Baloch et. al. (2015))

2.2 Forced Water Cooling:

H. Bahaidarah et al.(2013) used a water jacket at the back of the panel to improve the efficiency of the panel by controlling the water temperature They analyzed the module temperature vs wind speed and variation of irradiance vs ambient temperature.

They also developed and tested a numerical model comprising the Thermal and Electrical models predicting the performance of thermal and electrical parameters on the efficiency of PV panel. After experimenting and analysis they found out the numerical results were in coordination with experimental results and using a water cooling technique the panel temperature dropped significantly to nearly 20% thereby increasing the PV panel efficiency by 9%.

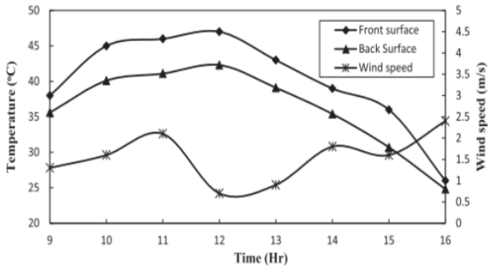

Figure 4 : Graph of Front And Back Surface Temperatures and wind speed at different time intervals (H.Bahaidarah et al. 2013).

Guilherme Zanlorenzi et al. (2017) conducted an experiment for cooling of solar photovoltaic modules by deploying water cooling system to increase the conversion efficiency of solar PV panels. The researchers worked on the model which comprised of a Photovoltaic hybrid module that consists of a traditional photovoltaic system and an automatic water cooling system.

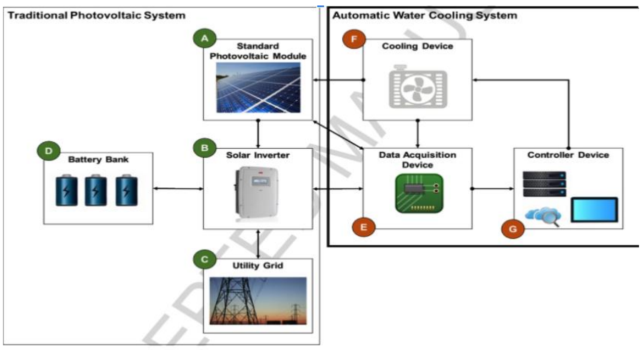

Figure 5: Conceptual Model of the Photovoltaic Hybrid Module

Guilherme Zanlorenzi et al. (2017)

The water cooling system used by researchers consisted of serpentine tubes which covered each and every cell of solar PV panel. For serpentine formation, copper tubes were used with a 3/8'' diameter such that 96% of the solar PV panel backside surface gets covered and only 3% of it was left due to the compulsory placing of junction box.

Researchers conducted experiments on the prototype in an area of the state of Parana, Brazil in the month of December during day times for 23 days. The data was collected for different time batches and the collected data such as temperature, voltage and current was analyzed and synthesized properly using graphs and statistics. The results showed a drop in 11.42% of the average operating temperature of the solar PV panel and the energy produced by the water-cooled PV panel was increased by 8.22% than the conventional PV module and also the average conversion efficiency was increased by 33.28%.

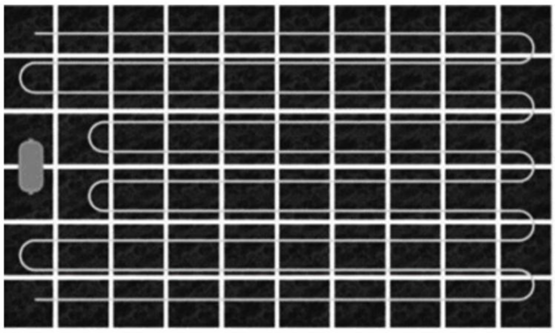

Figure 6 : Serpentine pattern on the photovoltaic module

Guilherme Zanlorenzi et al. (2017)

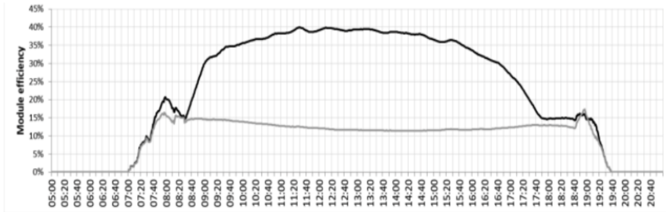

Figure 7 : Graph of efficiency comparison between the hybrid module and the standard module on 13/01/2017

Black line – hybrid module electrical efficiency; Grey line - standard module electrical efficiency

Guilherme Zanlorenzi et al. (2017)

Saad Odeh and Masud Behnia (2013) conducted an experiment for improving Solar PV panel efficiency which is to be done by reducing the average operating temperature of the solar PV module through surface cooling of the front side of the PV panel using water dripping technique. An experimental setup was organized to investigate the results and performance of solar panels which were to be cooled using the surface cooling technique. Due to surface cooling the heat was lost due to convection between the water and the front side of PV panel which resulted in 15% increase in the output power of the panel and the electrical efficiency was increased by 5%.

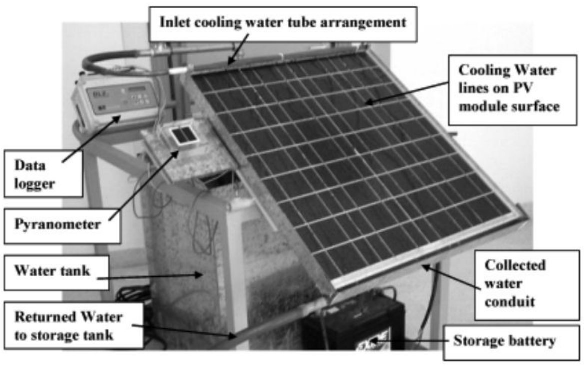

Figure 8 : PV water cooling Test Rig (Saad Odeh and Masud Behnia (2013))

Colt G. used active water cooling on the back surface to cool down the cell temperature and also performed numerical as well as experimental study and analysis. He used an Aluminum cooling radiator with Silicon thermal conducting paste for heat transfer between the panel and the radiator. Using COMSOL simulation he performed analysis regarding water temperature distribution in the flow channel and temperature distribution of the PV cell.

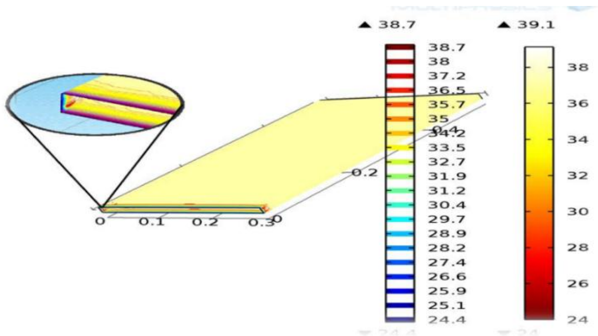

Figure 9 : Photovoltaic Cell Temperature Distribution (Colt G. et al. (2016))

With the use of PV panel with a forced cooling system he maintained the temperature of the PV panel and of the radiator decreased when the pump is started determining the rise in water temperature at the outlet of the radiator. With this analysis, he found a compelling temperature drop from 50°C to 34°C about 32% giving an increase to panel efficiency by 57% from 7W to 11W.Thus having a total increase in the energy produced by about 25%.

2.3 Research on PV/T Thermal Systems

H. Fayez et al. (2019) carried out numerical as well as experimental investigations for impacts on the performance of PVT and PVT-PCM panels. They used a thermal collector of serpentine design with an aluminum pipe being used as the passive flow passage for working fluid by an overhead water tank. Firstly, they attached a thermal collector with a PV module without PCM for preparation of PVT and in the second system; PCM was added along with a collector to prepare PVT-PCM for numerical assessment. For the conduction of experimental analysis, Polyethylene was used as an insulating material for both configurations with maximum care.

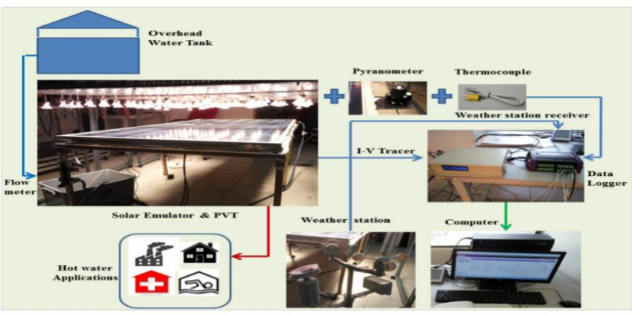

Figure 10: Schematic of Experimental Setup (H. Fayaz et al. 2019)

With controlled parameters and passive cooling of the system numerical and experimental electrical efficiencies for both (i) PVT and (ii) PVT-PCM were (i) 12.4% and 12.28% and (ii) 12.75% and 12.59% respectively. The electrical performances were improved at 10.13 & 9.2% for PVT and 12.91 & 12.75% for PVT-PCM.

3. PASSIVE COOLING

Unlike Active cooling systems, Passive cooling techniques are mainly dependent on conduction, convection and radiation-assisted heat transfer without consuming energy. Natural air convection using surrounding air as a working fluid and thermosyphon cooling using liquid coolants are the simplest and most commonly implemented techniques.

Juan Duan (2021) conducted a numerical study on a novel heat sink to analyze the effects of PCM porous systems with different porosities and different heights on the electrical efficiency of CPV Modules. With the decrease in porosity, solar cell electrical efficiency increases. For the same porosity, increase in the enclosure height of PCM porous cavity could improve electric efficiency. But, CPV cooled by pure PCM will have a prolonged duration than PCM porous for the same cavity volume due to the slow heat absorption and low thermal conductivity of PCM.

Hernandez- Parez et al. (2019) proposed a series of 3D models of the heat sink and evaluated the newly designed model using CFD Software. They used a segmented Al sheet to allow better airflow. Numerical Analysis showed a reduction of about 9.4°C. When the length of fin is increased, due to the reduced extent of heat transmission from the base fin, results depicted an exponential fall in the thermal efficiency of a fin. They also experimented with the effect of the direction of airflow on the performance of the heat sink. The lowest temperature was registered when the airflow was perpendicular to the fins and the higher temperature was registered when the air flows parallel to the fins.

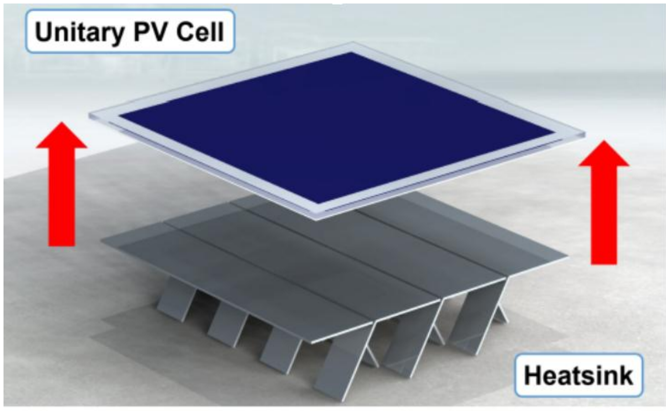

Figure 11: Unitary PV Cell with Heat Sink (Hernandez- Parez et al.2019)

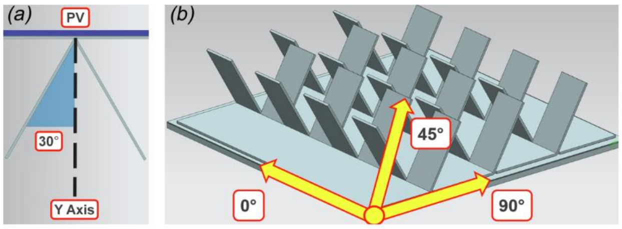

Figure 12: Orientation in Newly Proposed Heat Sink Design Hernandez- Parez et al.(2019)

Erdem Cuce et al.(2011) performed studies regarding the effects of passive cooling on solar photo voltaic cells. In this experiment heat sink made of aluminum was used to dissipate waste heat from a photovoltaic (PV) cell. A solar simulator was used in this experiment to simulate the different conditions of ambient temperature. In the results, it was seen that a 20% increase in power output of PV cell was achieved which shows a considerable increase in conversion efficiency. Maximum efficiency in operating conditions was achieved at 800 W/m^2.

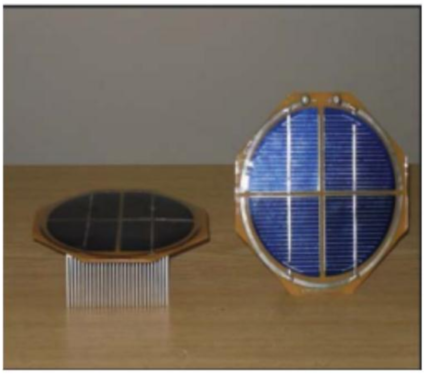

Figure 13: Photovoltaic cells equipped with fins and without fins (a) and straight fins of uniform cross-section (Erdem Cuce et al.(2011))

Filip Grubisic-Cabo et al. (2018) conducted research on passive cooling technique consisting of aluminum fins mounted with epoxy glue on the backside surface of PV panels to reduce its temperature thereby increasing its conversion efficiency. There were two approaches for cooling, in first approach the aluminum fins were positioned parallel to each other in L-profile while in second approach the aluminum fins were positioned arbitrarily.

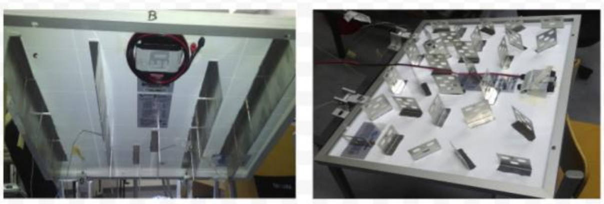

Figure 14: First approach
Parallelly placed fins arrangement

Figure 15: Second approach
Randomly oriented fins arrangement

Filip Grubisic-Cabo et al. (2018)

The second approach was found to be more efficient than the first one, so the second one was analyzed further. The first approach was dropped since it resulted in only 2% efficiency improvement. The research was performed in city of split, Croatia in month of November. The results of the research were positive i.e. the cooling technique employed resulted in increasing the overall conversion efficiency of PV panel by lowering their operating temperature.

4. PCM COOLING

The use of Water-based Cooling systems may face constraints like Water availability issues, and the requirement of pumping power to maintain a continuous or periodic water supply. Also, water being recirculated for PV Panel Cooling requires a Cooling mechanism to control the temperature of coolant water. Owing to all these practical limitations, researchers are working use of Phase Change Material for Solar PV Module Cooling.

Salem et al. (2019) used $Al2O3$/PCM mixture with various concentrations of Alumina Nanoparticles for cooling PV modules and compared outcomes with Water-based Cooling Alternatives. They fabricate a setup consisting of twenty parallel channels with a common inlet and a common outlet with a flow rate adjusted by the required number of ball valves. Silicon oil was used on the top and bottom of the channels to maintain thermal contact between contact surfaces. Higher concentrations of Alumina nanoparticles result in more heat-storing capacity at comparatively lower melting point temperatures. Alumina nano-particle addition of concentration of $\varphi = 1$ % showed better results than pure water-based cooling. But, results also depicted that, in general, solely water cooling provides more conversion efficiency and more exergy and thereby more power. Despite this, PCM-based PV Module cooling is used widely due to the fact that PCM does not utilize additional power or expenditure during routine operation.

S.A.Nada et al. performed an experiment on three polycrystalline Silicon PV Modules; one without PCM, one with PCM and one with PCM impregnated with $Al2O3$ nanoparticles to investigate the effects of the addition of nanoparticles in PCM. For Peak Solar radiation between 12 PM to 1 PM, peak temperatures registered were 75°C, 61°C and 57°C respectively. The addition of nanoparticles benefited in increased. Results of the experiment showed temperature drops of 8.1°C and 10.6 °C and an increase of 5.7% and 13.2% for pure PCM and enhanced PCM-based PV modules.

M. Rajvikram et al. (2019) experimented with the cooling of a solar module using PCM entrenched with aluminium attached to the back side of the solar panel. Paraffinic Organic PCM was used for this experiment. The maximum temperature of the PV-PCM entrenched aluminum panel was reduced to 47.7°C as compared to 55.4°C temperature the corresponding temperature of a naturally ventilated panel which gave 4% more electrical efficiency.

Leila Siahkamari et al. worked to postpone the melting point of PCM material. For this, they used sheep fat + CuO nanoparticles. The results of pure sheep fat and paraffin wax as PCM material exhibited better cooling performance. Maximum power generation increased by 24.6 % to 26.2 % using Sheep Fat+CuO nanoparticles in comparison with naturally ventilated cooling systems and 5.3% to 12 % in comparison with paraffin wax.

Ahmadi R. et al. (2021) studied passive and active cooling systems and the power efficiency of PV cell systems with the use of solar simulators as an artificial source of solar irradiation. All these experiments were conducted in the solar radiation range of 800-1700 Wm^{-1}. The passive coolant used was Phase change Material (PCM) and to overcome the disadvantage of low thermal conductivity of PCM, special material called PS-CNT heat conductive foam was also used for analyzing the impacts on the power performance. According to the results, PCM material can lessen cell temperature by up to 6.8% with increments of up to 14%.

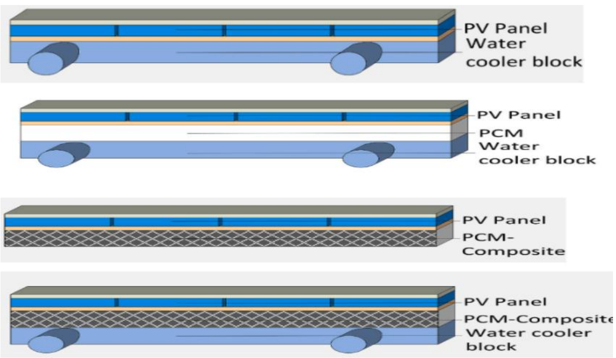

Figure 16 : Experimental Setup Diagram for Active & Passive Cooling (Ahmadi R. et al. (2021))

They also performed the setup of an active cooling system installed on the backside surface of the system. On performing the results depict that the performance of the active cooling system was superior to the passive PVT system. The system of PV-PCM Composite was also inspected in the study and found to be the best system with energy efficiency in active cooling being 66.8 to 82.6%.

Adeel Waqas and Mie Ji (2017) used Organic PCM RT44 to cool Solar PV Module Cell temperature. Movable Rotatatable shutters were deployed to encapsulate PCM. To ensure complete solidification of PCM, Shutters are kept open during non-sunshine hours and kept closed otherwise. The maximum fall observed in temperature when PCM is used was from 90 C to 55 C.

To analyze the effect of the melting point of PCM on Solar PV panel temperature and efficiency, they altered PCM melting temperatures from 30°C to 40°C. For Tm = 30°C, PV temperature was found to be even more than naturally ventilated PV panels. This occurred due to the fact that the ambient temperature of air surrounding rarely falls below 30°C during non-sunshine hours which keeps melted PCM in liquid state only prohibiting the Solidification of PCM. Further, the PCM enclosure reduced the ability of the Panel to be cooled naturally. For Tm =35°C, incomplete solidification resulted in a very low heat storage capacity 45 % of the total capacity. For Tm = 40°C, complete solidification of PCM helped to maintain PV Cell Temperature below 45°C. Considering the average PV panel cell temperature of 63°C, the use of PCM enclosed in Shutters reduced cell temperature to 42.1°C using PCM which is having melting point at 35°C.

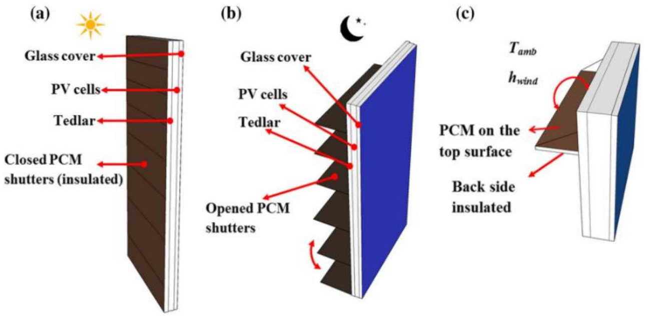

Figure 17 : Use of movable shutters for PCM-based cooling (Adeel Waqas et al. (2017))

Table -1: Comparison of various cooling methods

Cooling Methods	Advantages	Disadvantages
Natural Convection of air	Longer Life Easy integration Noiseless No power supply Passive Heat Exchange	Dust accumulation at inlet hampers Heat transfer rate Low heat transfer rate Limited temperature drop
Forced Convection of air	Higher heat transfer rate, mass flow rate & temperature reduction compared to natural convection	Extra Power Requirement Noisy operation High Investment & Maintenance cost due to use of fans and ducts
Water cooling	High heat capacity, Higher heat transfer compared to both previous methods	Less life due to corrosion High Investment & Maintenance cost due to use of pumps
PCM Cooling	Higher heat transfer and higher heat storage capacity due to latent heat No power supply requirement Noiseless	High Cost of PCM Selection of PCM material for application is difficult task Careful Disposal required

5. CONCLUSIONS

After studying various research papers, we came to conclusion that the operating cell temperature of solar photovoltaic module has significant impact on the conversion efficiency of solar panels. Hence it is necessary to bring down the cell temperature to optimum level for increasing electrical efficiency of solar cells. For this researchers have implemented various cooling techniques such as Forced air convection, forced water cooling, PCM based cooling, PV/T Thermal cooling, Thermosyphon cooling, water dripping techniques to cool down operating temperature. From all these studies we can conclude that all above mentioned techniques results in improved performance of Photovoltaic module. Water cooling is found to be most reliable and cost effective technique and PCM cooling is widely researched due to its compact structural requirements.

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