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Thermal Management of Solar Photovoltaic Systems

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Abstract: *Due to their eco-friendliness, photovoltaic panels to produce electricity have recently gained popularity worldwide. Depending on the characteristics and configuration of the solar cells, photovoltaic cells manufactured of semiconductors can have an electrical efficiency between 4% and 47%. Photovoltaic (PV) panels that are not used to generate electricity experience some of the sun spectrum as incident light, which increases their operating temperature and shortens their lifespan. This study examines several methods that could be used to lessen the negative impacts of high temperatures. It describes how to bring down the surface temperature of the PV module. The goal, significance, and type of technology used to cool solar panels in various research are evaluated and categorized. The conclusions have been considered considering each technology's advantages, disadvantages, potential applications, and techno-economic character. The primary focus of the inquiry will be the range of surface temperature reductions bound by each cooling technology. Additionally, the effectiveness of each cooling technology will be highlighted in this review. The effectiveness of each cooling strategy will also be compared in this review. The findings of the study are fully described in the conclusion section. It is demonstrated that any effective method for cooling PV panels should be utilized to keep the temperature of the working surface at a low and stable level, be simple and trustworthy, and, if possible, allow for the utilization of extracted thermal heat to increase the overall conversion efficiency. The detailed review is helpful for PV system theory, design, and application engineers.*

Keywords: Solar photovoltaics system, cooling technologies, efficiency, review

1. Introduction

Using PV systems, which transform sunlight into usable electrical energy, is one of the most widely used methods of producing renewable energy (RE) (Hu et al., 2016). The benefits of solar PV energy are highlighted by this sort of renewable energy technology, which is pollution-free while in operation, reduces global warming concerns, has lower operational costs, requires little maintenance, and has the highest power density compared to other RE technologies (Wang et al., 2014). Aside from the many benefits that PV technology offers, this conversion system has more widespread issues, such as dust, surface operating temperatures, and hail, which can impair the conversion system's efficiency (Da Silva & Fernandes, 2010). The most frequent external environmental variables that affect a PV module's surface temperature are wind velocity, the surrounding temperature, humidity level, built-up dust, and solar radiation (Elbreki et al., 2016). The PV module's surface temperature rises by 1°C, which results in a 0.5% drop in efficiency. Therefore, not all the solar energy the PV cells take gets transformed into electrical energy due to the temperature increase. The remainder of solar energy is transformed into heat to comply with the law of energy conversion. The total conversion efficiency is decreased because of this wasted heat.

Solar energy conversion equipment must be made more efficient for this RE technology to be a practical alternative. Finding other ways to address the temperature issue is necessary to make it a workable option, which must improve total conversion efficiency.

Few writers have attempted to compile and carry out a thorough analysis of various cooling methods that may be applied to the working surface of solar panels to boost the overall efficiency of the solar conversion system. Sahay et al. (2015) have briefly covered the different solar PV panel cooling techniques. The paper's primary emphasis, however, was on the testing and performance of a created Ground-Coupled Central Panel Cooling System (GC-CPCS), while just a few innovations were introduced. Royne et al. (2005) summarized the many techniques that may be used to cool solar cells. However, upon closer inspection, it becomes clear that the paper's main objective was to examine the various solar concentrator systems' use of forced air, liquid-driven convection, and passive cooling techniques.

While attempting to improve the performance of a PV panel operating above the recommended Standard Test Conditions (STC) temperature, this paper thoroughly reviews how various technologies can minimize the adverse effects of increased temperature. This contrasts with the review studies mentioned above. To accomplish the goals of the current study, a sizable number of research publications from various authors are employed. Various tools (schematic diagrams, images, tables, and figures) enhance the information and provide a clear and straightforward presentation.

In this study, the following technologies will be examined and discussed:

- Floating tracking concentrating cooling system (FTCC).
- Hybrid solar Photovoltaic/Thermoelectric (PV/TE) system cooled by heat sink.
- Hybrid solar Photovoltaic/Thermal (PV/T) system cooled by water spraying.
- PV panel with Phase-Change Materials (PCM) cooling.
- Hybrid solar Photovoltaic/Thermal (PV/T) system cooled by forced water circulation.
- Hybrid solar Photovoltaic/Thermal (PV/T) system cooled by forced air circulation.
- PV panel with water-immersion cooling.
- PV panel with transparent coating (photonic crystal) cooling.

The paper is structured as follows: **Section 2** presents the fundamental workings of a PV cell. The issue brought on by a rise in temperature is addressed in detail using graphs and calculations. According to their operational principles, the various cooling systems are discussed in **Section 3** utilizing an appropriate graphic presentation. A lengthy tabular list of the examined books is provided in **Section 4**. This table contains details on the authors, the research topic, the review's contribution, and the technology employed to handle the temperature issue. **Section 5** discusses the key conclusions of this study about the various technologies examined, and **Section 6** provides the conclusion.

2. Effect of temperature on the performance of the solar cell

The electron transitions from the valence band to the conduction band when a photon with energy $E = h.v$ **equal** to the bandgap energy E_G strikes it. *Thermalization loss*, the release of surplus energy = E - E_G as heat to the material, occurs when photon energy $E = h.v$ is **larger than** E_G. The electron excites from the valence band to the conduction band and then promptly returns to the valence band when photon energy $E = h.v$ is **less than** E_G. *Bandgap losses* are the release of an electron's energy in the form of heat (Häberlin, 2012; Solanki, 2015)

Solar cell efficiency temperature dependence derived from V_{OC} temperature dependence (Goswami, 2022), as provided in the equation, Eq. (1):

$$\frac{d(V_{oc})}{d_t} = \frac{1}{T_{PV}} \left(V_{oc} - \frac{E_g}{q}\right) \tag{1}$$

The change in open-circuit voltage (V_{OC}) caused by a rise in temperature will always be negative since E_g/q is higher than V_{OC}. The open-circuit voltage of the solar cell drops with the rise in its operating temperature (Kaldellis et al., 2014). The characteristics curve (*I-V* curve) of a solar cell or module is shown in **Fig. 1** as a function of temperature and a drop-in open-circuit voltage (V_{OC}) and power output of the PV panel with the temperature rise as shown in **Fig. 2**. However, short circuit current (I_{SC}) barely rises as temperature rises (Bagienski & Gupta, 2011).

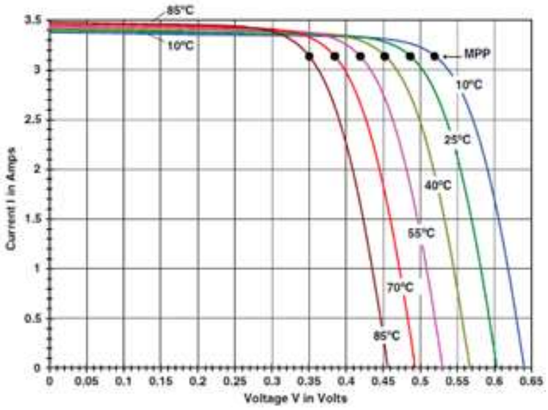

Figure 1: Characteristics curve (I-V) for a solar cell with cell temperature as a

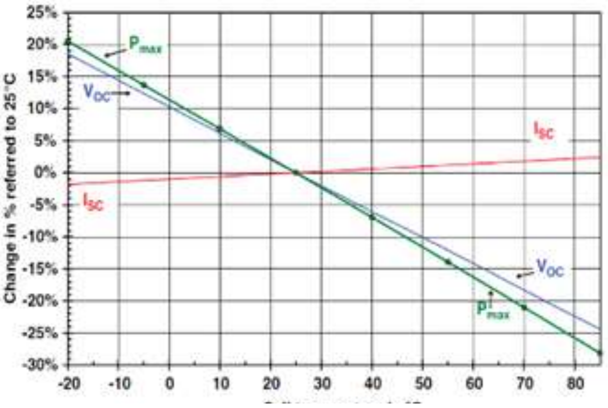

Figure 2: VOC, ISC, and Pmax as a function of cell temperature

3. Technologies that address the temperature issue and boost the PV's efficiency

In order to comprehend the pertinent research from various authors gathered, reviewed, and summarized in Section 4, as well as the discussion in Section 5, the general operational principle of the various technologies that can be used to minimize the effect of the increased temperature while attempting to improve the performance of a PV panel operating beyond the recommended temperature of the Standard Test Conditions (STC), will be explained technically in this section.

3.1 Floating tracking concentrating cooling system (FTCC)

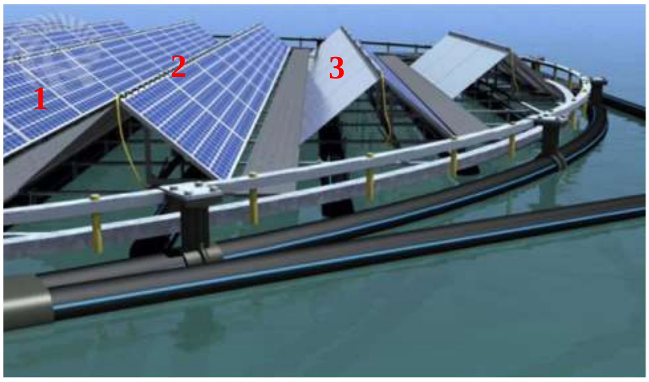

Figure 3: FTCC

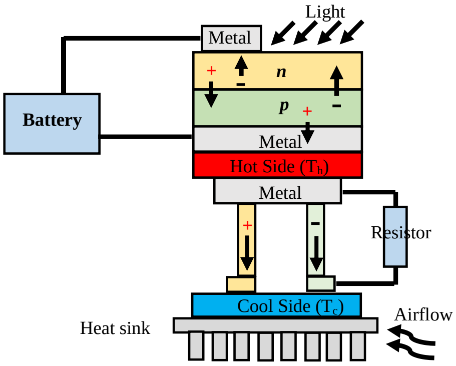

Figure 4: Hybrid PV/TE with heat sink

One technique for enhancing a PV module's output power involves putting floating PV plants in artificial basins. These floating plants comprise a platform with PV modules, some reflectors, and a sun-tracking system. Making use of water sprinklers, the PV module is cooled. To enhance energy harvesting, reflectors are employed to focus sun radiation. The floating platform enables the placement of reflectors and increases solar radiation on the PV modules using a one-axis tracking system. The abbreviation for these facilities is FTCC, which stands for Floating, Tracking, Concentrating, and Cooling. The essential parts of an FTCC system are seen in **Fig. 3** (Cazzaniga et al., 2012), and they are numbered as follows: (1) PV modules, (2) Sprinklers, and (3) Solar reflectors.

3.2 Hybrid solar Photovoltaic/Thermoelectric (PV/TE) system cooled by heat sink

PV conversion systems have advanced by including a thermoelectric module (TE) and heat sink. The TE module absorbs the heat produced by the thermalization loss of low-energy photons from the PV module's surface. The thermoelectric module is positioned in the middle of the PV module's back. The TE module has one thermal resistor on top and other thermal resistors in the remaining spaces around it. The temperature rises over time when the PV/TE system is exposed to solar light. The dispersion of charge carriers inside the thermoelectric materials causes a minor temperature differential between the thermal resistors on top and below when the top and bottom surfaces differ. The resistor and battery disperse the PV module's gathered energy. The PV module's surface is cooled down by the heat sink, which is employed to dissipate heat from the PV module, as can be seen in **Fig. 4** (Pang et al., 2015).

3.3 Hybrid solar Photovoltaic/Thermal (PV/T) system cooled by water spraying

The water in this system is forced through the spraying nozzles by a centrifugal pump through a suction hose from the tank. To prevent a massive particle from being sucked in and to safeguard the centrifugal pump, the suction pipe has a non-return valve and strainer. To cool the PV module using an industrial clear water filter, water is transmitted from the strainer to the spraying nozzles beyond it. A PV module and a cooling system comprise a hybrid photovoltaic/thermal (PV/T) system. A fan is spraying the cooling agent, water, over the PV panel's surface. The PV module's surface temperature drops, and its electrical efficiency rises when water is sprayed on it. The essential parts of the system are seen in **Fig. 5** (Nižetić et al., 2016), and they are numbered as follows: (1) PV modules, (2) Aluminium water tank, (3) Centrifugal pump, (4) Industrial transparent water filter, and (5) spraying nozzles.

3.4 PV panel with Phase-Change Materials (PCM) cooling

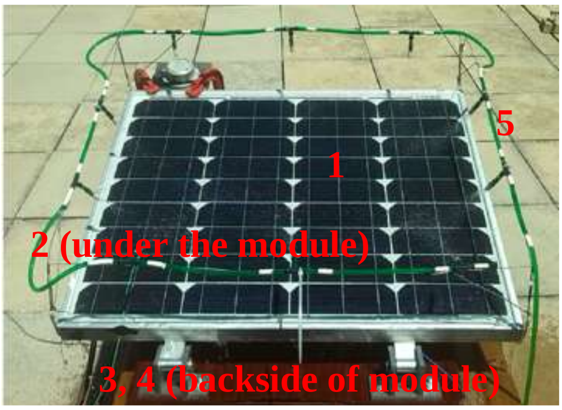

Figure 5: Hybrid PV/T with water spraying

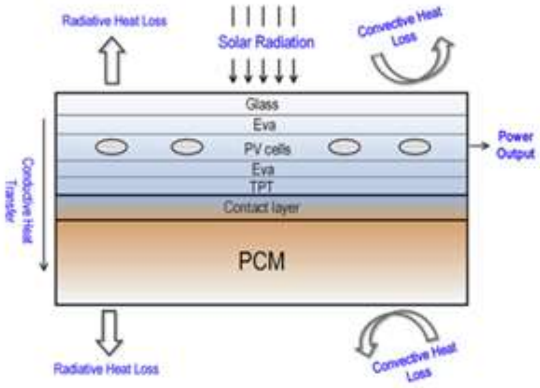

Figure 6: Typical PV-PCM system configuration

Incorporating Phase-Change Materials (PCM), such as tungsten photonic crystals, is one method that may be implemented to lower the surface operating temperature of a PV panel to achieve greater electrical efficiency. On the back of the PV panel is a latent heat storage substance called PCM, as seen in **Fig. 6** (Li et al., 2019). The chemical bonds in the PCM break apart as the temperature rises, altering the material's phase from solid to liquid. Due to the phase change being an endothermic process, the PCM absorbs heat. The substance melts when the heat within the storage material reaches the phase-change temperature. After that, the temperature remains stable until the melting is finished. Because the heat is stored throughout the melting process (phase-change process), it is known as a latent heat storage material.

3.5 Hybrid solar Photovoltaic/Thermal (PV/T) system cooled by forced water circulation

A hybrid photovoltaic/thermal (PV/T) system concurrently produces electrical and thermal energy to raise the PV system's efficiency (Good, 2016). As shown in **Fig. 7** (Alzaabi et al., 2014), the system comprises a PV module and heat-collecting pipes installed on the module's rear. The contact area between the PV module and the thermal collecting pipes is increased using rectangular collecting pipes. The circulating fluid is water, and a DC pump supplied by the PV module or other sources circulates water through the paired thermal collecting pipes. Waste heat is transferred to the circulating water flowing via the thermal collecting pipes when the hybrid system is exposed to solar radiation. To use the heated water for residential or other purposes, the heated water returns to the hot water insulated tank. The essential parts of the system are numbered as follows: (1) PV modules, (2) Circulation pump, and (3) Water storage tank.

Figure 7: Hybrid PV/T with forced water circulation

Figure 8: Hybrid PV/T with forced air circulation

3.6 Hybrid solar Photovoltaic/Thermal (PV/T) system cooled by forced air circulation

Forced air circulation is yet another method that may be applied to lower a PV panel's surface working temperature to increase electrical efficiency. The PV module that makes up this system is set on top of a steel plate with an air passage below it. The working fluid is air, which is pushed through the channels by a fan equipped with a nozzle. The fan is powered by a photovoltaic (PV) module, whose energy consumption rises as the cavity velocity, channel width, and heat-exchanging surface increase. Convection transfers heat from the PV panel to the air in the channels, lowering the surface working temperature and increasing electrical efficiency. The essential parts of the system are seen in **Fig. 8** (Mazón-Hernández et al., 2013), and they are numbered as follows: (1) PV modules, (2) Forced air circulation, and (3) Air channel.

3.7 PV panel with water-immersion cooling

Using the water immersion cooling method is another method that may be used to lower a PV panel's temperature. A PV module is submerged in vast amounts of water, such as rivers, seas, lakes, and canals, to cool it. The immersing fluid is water, which maintains the PV module's surface temperature by absorbing heat from the PV module. As a result, electrical efficiency rises when the water absorbs the heat from the PV module. The essential parts of the system are seen in **Fig. 9** (Mehrotra et al., 2014) and are numbered as follows: (1) PV modules, (2) Plastic containers, and (3) Water.

3.8 PV panel with transparent coating (photonic crystal) cooling

Transparent coating (photonic crystal cooling) is a method that may be used to lower the surface operating temperature of a PV panel to achieve greater electrical efficiency. On the top surface of the PV cells, this visible transparent thermal blackbody, which is based on silica photonic crystals, can reflect heat produced by the PV cells in the form of infrared light (thermal long infrared transparency window, which is in the 8-30 µm range) under solar irradiance back into space (Zhu et al., 2015), as seen in **Fig. 10** (Cracker, 2015). Likewise, anti-reflection and light-trapping actions marginally improve the PV cells. By allowing the PV module to absorb more photons, the PV cells are cooled as a result.

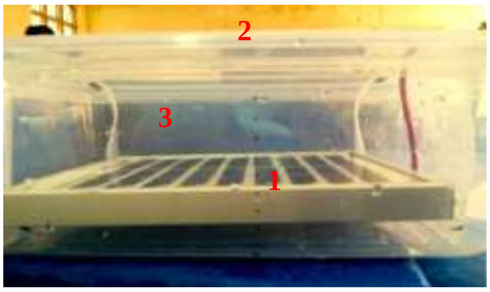

Figure 9: Water immersion cooling

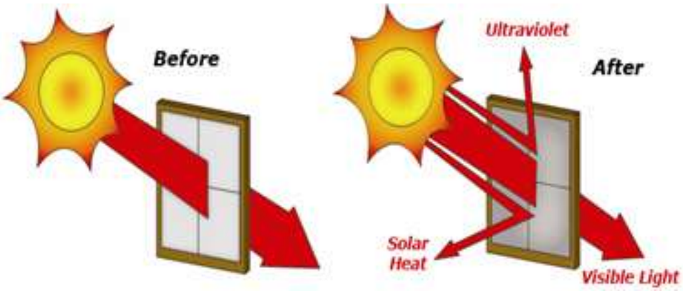

Figure 10: Photonic crystal cooling

4. Analyses of the relevant literature

By addressing the issue related to the operating temperature of the PV surface, several writers have attempted to increase the efficiency of solar panels. The several studies by various authors that have attempted to boost the PV module's effectiveness by utilizing the strategies detailed below are summarized in **Table 1**. The source authors, the study's area of focus, a summary of the review's contribution, and the technology employed to solve the temperature problem are all listed in this table.

Table 1: Highlight a few research on the technology and contributions of cooling PV modules

Technology	Authors	Contribution/Highlights
FTCC	Carlotti et al. (2016)	• Studies have been conducted to enhance the optical performance of solar concentrators. • PMMA layers effectively increased light concentration.
	Vishwanathan et al. (2015)	• The performance of PMMA light guide sheets that were flat and bent into cylinders was compared, and the results showed that cylindrically bent PMMA performed better.
	Andrade et al. (2016)	• The study looked at dynamic heating in solar dish concentrators, and the results show that sizeable thermal energy needs may be met.
	Parel et al. (2015)	• It is possible to use the established model, which illustrates the angular distribution of light emanating from the luminescent solar concentrator (LSC) edge-to-PV modules to increase efficiency.
	Wu et al. (2016)	• Lightweight, inexpensive, innovative solar concentrators that may also generate electricity; analysis of ideal optical performance using 3-D tracing technology; enhanced output power because of the approach.
Hybrid PV/TE with heat sink	Hashim et al. (2016)	• The outcomes of the simulation of the model developed for thermoelectric module geometry optimization point to a rise in electricity efficiency.
	Popovici et al. (2016)	• To assess performance, the heat sink's angle between the ribs and the base plate was adjusted, and the output showed a reduction of 10 °c.
	Verma et al. (2016)	• A dynamic model was created to excite TEM material's thermal and electrical properties. According to the simulation, hybrid systems exposed to dynamic disturbance and solar radiation may gather the most energy.
	Ali et al. (2016)	• Analysis of the thermoelectric generator's performance in pin shape. According to simulation studies, the output power of a PV module increases when airflow is used more effectively.
	Soprani et al. (2016)	• A model was created for integrated hybrid PV/Thermoelectric modules, including the requirements for the heat sink design. The findings of the simulation and experiment show good compatibility.
Hybrid PV/T with water spraying	Akbarzadeh and Wadowski (1996)	• A PV module's output power may be increased by around 50% via cooling, plus the results reveal that a PV panel's surface temperature cannot rise over 46°c.
	García and Balenzategui (2004)	• Nominal Operation Cell Temperature (NOCT) is an excellent way to gauge the efficiency of PV modules. Applied to determine the temperature and performance of several types of PV modules.
	Dubey and Tiwari (2008)	• Model for PV/Flat Plate Collector derived. As a result, thermal efficiency has been enhanced.
PV-PCM	Su et al. (2017)	• The improvement of PCM materials' thermal conductivity for thermal energy storage is discussed. Models created to increase PCM thermal conductivity and detailed analysis were described.
	Hachem et al. (2017)	• PV panel electrical performance is improved by pure and mixed PCM, with transient energy balance given to study thermal behavior. Electrical efficiency was improved by an average of 5.8% using combined PCM.
	Hasan et al. (2017)	• Presenting the PV/PCM system's annual energy efficiency results based on paraffin. The model's cost-effectiveness and electrical energy output created to anticipate melting and solidification fractions rose by 5.9%.
	Chandel and Agarwal (2017)	• Only high insolation levels throughout the year are commercially viable for inorganic PCM research. Further study is required due to the expensive cost and little gain in electricity efficiency of just 5%.
	Su et al. (2017)	• A dynamic model was created to compare the performance of PV/PCM. The higher phase-change material guaranteed better performance.
Hybrid PV/T with forced water circulation	Salameh et al. (2021) Lebbi et al. (2021)	• It uses symmetric-convection boundary conditions for the right and left sides plus symmetric-symmetric boundary conditions for the middle cooling channels, with the results of thermal efficiency being 60% at 0.4 L/min and 68% at 5.4 L/min.

	Yildirim et al. (2022)	• Bi-fluid combines active cooling and self-cleaning techniques, showing a reduction of 15ºc of the average temperature and an improvement of about 5.7% in electrical efficiency.
	Chiang et al. (2022)	• The PV module reaches an electrical conversion efficiency of 17.79% with 76.13% thermal efficiency when the mass flow rate is 0.014kg/s and the inlet flow temperature is 15ºc.
	Hattam et al. (2021)	• The passive loop thermosyphon system was used to extract heat from panels and then transfer it to the water shell and tube with a reduction of about 17% compared to ordinary temperature.
		• The system consists of two sides of a rectangular channel made of insulating material, producing 14.2% maximum electrical efficiency and a maximum thermal efficiency of 82%.
Hybrid PV/T with forced air circulation	Singh (2021)	• By increasing the thermal contact area of the fin with changes in the design of the fin, the result shows a cooling of up to 60 ºc to 65ºc at the surface temperature of 120ºc has been achieved, plus the highest thermal efficiency reading was 81%.
	Patil et al. (2023)	• With different mass flow rates of air, the results showed a substantial decrease in the operating temperature of the PV panel to 9ºc and an increase in its electrical performance from 7% to 12.6%.
	Zaite et al. (2021)	• The night radiative cooling technology has proven to lower the daily temperature of the PV cells by 3-5, improving their monthly gain of electrical energy by 5.5% to 6.15% compared to a conventional PV thermal collector.
	Sajjad et al. (2019)	• Installing PV modules on the duct of cooled air of air-conditioners in most buildings showed 7.2% and 6% higher electrical efficiency and performance ratio, respectively, compared to the module without cooling.
	Fterich et al. (2021)	• An experimental device modified with an arrangement of square aluminum tubes shows a maximum temperature difference of around 20ºc, and the best thermal average efficiency was 42.5%.
Water immersion cooling	Abdulgafar et al. (2014)	• Submerging PV panels in distilled water at different depths shows an increasing efficiency of 11% at a water depth of 6cm.
	Sun et al. (2014)	• Dimethyl silicon oil is used as an immersing fluid, with results showing controllable temperature from 20ºc to 31ºc at 920W/m2 irradiance, with Reynolds number varying between 13,602 and 2,720.
	Han et al. (2013)	• The presence of a thin liquid layer (1.5mm) results in an increase in the silicon CPV solar cell's efficiency by 8.5-15.2% from the reference value.
	Zhu et al. (2011)	• CPV immersion using de-ionized water is favorable as the module can be cooled to 45ºc at 540 W/m^2 direct normal irradiance, 17ºc ambient temperature, and 30ºc water inlet temperature.
	Clot et al. (2017)	• There is an efficiency increase if the water layer is below 5 cm, and for a thin water layer, the gain can be around 20% concerning a dry panel without a cooling system.
Photonic crystal cooling	Arpin et al. (2013)	• 3-D metallic photonic crystals have been altered to fit the emission spectrum for practical solar thermo-photovoltaics. The result shows that high-quality tungsten photonic crystals maintain stability to 1,400ºc.
	Zhu et al. (2014)	• A micro-photonic architecture that approaches optimal performance is employed to cool PV panels radiatively. The micro-photonic design successfully cools PV cells, according to the results.
	Li et al. (2017)	• 1-D photonic films can radiate heat through thermal emission and reflect the solar spectrum in the sub-bandgap and ultraviolet regimes. The result shows that the PV panel's temperature is lowered by 5.7ºc.
	Zhu et al. (2015)	• A silica photonic crystal blackbody preserves or even slightly enhances sunlight absorption but reduces the temperature of the underlying silicon absorber by as much as 13 ºc due to radiative cooling.
	Chen et al. (2016)	• Using a selective thermal emitter and eliminating parasitic thermal load shows an ultra-large temperature reduction of 60ºc.

5. Discussion

It is essential to summarize the findings straightforwardly and understandably for any party interested in these technologies after analyzing the various methods used to address the temperature problem to enhance efficiency. **Table 2** below does this. The benefits, drawbacks, and justifications for these technologies are listed in the table below.

This table's analysis concludes that any cooling system should be employed to maintain a constant, low PV cell temperature to increase electrical efficiency. If at all feasible, it should also permit the use of thermal energy that has been extracted for other beneficial reasons.

Table 2: Technical discussion of different PV module cooling technologies

Technology/Discussion	Disadvantages	Advantages
FTCC - The systems function effectively. However, the entire surface area is only partly cooled when water is sprayed. Evaporation results in the loss of water.	• High capital cost. • Evaporation causes water wastage. • Sprinklers cannot spray the whole surface of the PV module.	• Operates highly efficiently. • Avoid energy dispersion problems. • Avoid electric grid stress when using a pumping scheme.
Hybrid PV/TE with heat sink – It has been shown to experimentally lower surface temperature. However, a heat sink becomes extremely unstable in turbulent airflow. It is preferable to use the lost heat to improve electrical efficiency.	• Turbulent airflow with pin fin heat sink. • Heat conduction loss between hot and cold parts through semiconductors. • Heat is wasted.	• Alleviates hot spotting. • The average temperature with the heat sink lowered to 8.29%. • Electrical efficiency improved.
Hybrid PV/T with water spraying - Results from experiments indicate enhanced effectiveness. However, the heat might gather additional solar radiation while water is wasted.	• Heat wastage. • The whole surface area of the PV panel is partially cooled.	• More efficient than air cooling. • Increased energy yield.
PV-PCM - PCM functions appropriately. When the PCM is melting, the mechanism stores the heat. The ability of a substance to absorb, however, deteriorates over time. Plus, it has more excellent performance in hot weather circumstances.	• Less efficient in cold areas. • Paraffin has a low thermal conductivity in its solid state. • Segregation reduces the active volume available for heat storage.	• Heat absorbed can be used to heat buildings. • Able to store large amounts of heat with small temperature changes. • Phase change occurs at a constant temperature.
Hybrid PV/T with forced water circulation – Increases electrical efficiency effectively. Due to the continuous flow rate, it cannot attain its ideal state. Modifying the flow rate in response to the temperature changes is desirable.	• Subsidies are needed for these systems. • Cannot achieve optimal efficiency due to constant flow rate. • High initial cost.	• More efficient when combined than separated. • Electrical efficiency increased. • Supplied hot water for domestic applications.
Hybrid PV/T with forced air circulation – The system is quite adequate, although it performs best in cold weather. Additionally, it is less effective than forced water circulation.	• In hot weather, water cooling is more efficient than air cooling. • Air cooling is less efficient than water cooling.	• Buildings may be heated with heated air, increasing efficiency overall. • Financially feasible.
Water immersion cooling – Efficiency rose as the temperature dropped. However, during cloudy days, efficiency is poor. Additionally, prolonged contact with ionized water reduces electrical efficiency.	• Over time, ionized water has an impact on electrical efficiency. • Efficiency suffers on cloudy days.	• No need to acquire land. • On clear days, electrical efficiency rose. • Ecologically responsible. • Very effective. • Economic.

	• Efficiency is influenced by submersion depth.	
Photonic crystal cooling – Eliminating temperature issues improves the effectiveness of PV panels. Heat, however, is wasted and may be used for home purposes.	• The heat deflected into space is wasted energy that might be used at home.	• The temperature of PV cells significantly dropped. • An economical answer. • No specific area is required.

6. Conclusion

An in-depth discussion of several cooling methods used to improve the performance of a PV system is covered in this study. The thermal, electrical, and overall efficiency of PV systems is increased by proper cooling, which also lowers the cell deterioration rate and lengthens the PV module's lifespan (Ghadikolaei, 2021; Verma et al., 2021). To clearly illustrate, analyze, and compare these technologies used to address the unfavorable influence of temperature on PV efficiency in terms of their advantages and disadvantages, as well as their techno-economic and environmental implications, a variety of tools, such as equations, schematic diagrams, and pictures, have been used.

To improve the panel's effectiveness, several articles from many scientific topics have been evaluated and categorized based on their emphasis, contributions, and technology utilized to achieve cooling. Future studies should concentrate on efficiently gathering heat from a PV module's surface and stabilizing and controlling its cooling. Furthermore, the authors of this research determined that engineers working on solar system theory, design, or application may benefit from the offered complete overview.

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