

Review Article

Thermal Effects on Photovoltaic Panel Efficiency and Enhanced Cooling Strategies for Optimal Performance

* Neetu Singh¹, Dr. V. N. Bartaria²

¹Research Scholar, Dept. of Mechanical Engineering, LNCT University, Bhopal, INDIA

neetusengar29@gmail.com

²Professor, Dept. of Mechanical Engineering, LNCT, Bhopal, INDIA

*Corresponding Author - neetusengar29@gmail.com

DOI -10.55083/irjeas.2023.v11i04011

© 2023 Neetu Singh et.al

This is an article under the CC-BY license. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abstract:

The influence of temperature on the performance of photovoltaic (PV) panels is a critical consideration in harnessing the potential of solar energy technology. This compilation of research papers explores the multifaceted impact of operating temperature on PV systems and the utilization of cooling technologies to enhance their efficiency. The studies consistently emphasize the detrimental effects of elevated temperatures on PV cells and modules and investigate various aspects, including temperature-dependent parameters, real-world environmental conditions, geographical distribution, and mitigation strategies. Accurate modeling and location-specific considerations are underscored as vital for optimizing PV system efficiency. As the world embraces renewable energy and sustainability, the insights presented in these papers offer valuable contributions to advancing solar power technology for a more sustainable future. Furthermore, this collection emphasizes the significance of addressing temperature-related efficiency losses in PV panels and the potential for cooling solutions to improve performance. Various cooling methods, such as air cooling, water cooling, evaporative cooling, and phase change materials, are explored to mitigate the impact of high operating temperatures on PV systems. Integrated systems that combine cleaning and cooling mechanisms to address both soiling and heating issues are proposed. Environmental and economic considerations are pivotal in assessing the feasibility of implementing cooling solutions in different settings. These studies collectively stress the need for effective cooling technologies, especially in regions with extreme temperatures and intense solar radiation, to unlock the full potential of PV systems. Researchers, engineers, and policymakers working in the field of renewable energy will find these findings valuable for advancing the efficient utilization of solar power.

Keywords:- Photovoltaic Panel Efficiency, Thermal Effects, Enhanced Cooling Strategies, Optimal Performance.

Introduction of solar energy

Solar energy, derived from the capture of the Sun's radiant heat and light, represents a

foundational element in modern sustainable energy solutions. This environmentally conscious technology, notable for its remarkable lack of

greenhouse gas emissions, boasts a rich history spanning centuries, finding utility in both electricity generation and thermal applications. Across the tapestry of human civilization, the Sun has consistently held a profound fascination for societies, often assuming a central role in the spiritual and religious beliefs of ancient cultures, where it was revered as a divine entity. In historical contexts, agricultural communities heavily relied on solar irradiance to enable crop cultivation and support burgeoning populations[1].

Solar energy, a critical and sustainable resource, is derived from the absorption of heat and light emitted by the Sun. Electricity generation from solar radiation primarily involves the Photovoltaic method, which is reliant on the use of semiconductor materials. In addition to photovoltaic, solar energy can also be effectively harnessed through thermal technologies, which offer two distinct energy extraction approaches. The first technique, known as solar concentration, involves the concentration of solar energy to drive thermal turbines. The second method is employed in heating and cooling systems, where solar energy serves as a vital component in both solar water heating and air conditioning systems.

Photovoltaic (PV) panels are the predominant method for harnessing solar energy and find extensive application on rooftops, in portable solar devices, and even on spacecraft. These panels serve as semiconductor devices, absorbing solar radiation and transforming it into electrical energy through the photovoltaic effect. On a larger scale, solar thermal power plants play a pivotal role in the utilization of solar energy. These facilities harness solar energy to heat water, subsequently propelling steam turbines to generate electricity on a scale suitable for powering sizable populations. It is imperative to emphasize that the solar energy domain encompasses a wide array of techniques and approaches, all of which will be comprehensively examined in subsequent discussions within this research paper.

Photovoltaic (PV) panels, fundamental components of solar energy systems, hold the promise of clean and sustainable electricity generation. The efficiency and productivity of these panels are influenced by several environmental factors, with temperature being a pivotal variable. PV panels are engineered to perform effectively across a spectrum of temperatures, yet extreme heat can compromise their performance. To comprehend the intricate relationship between temperature and PV panel efficiency, it is essential to consider research findings and insights from authoritative sources in the field of solar energy. In this exploration, we delve into the effects of temperature on PV panels and examine strategies for mitigating its impact on their performance. This analysis is underpinned by references to reputable sources in the realm of solar

energy and photovoltaic, thereby providing a comprehensive overview of the topic[2].

The temperature can have a significant impact on the performance of photovoltaic (PV) panels. Generally, PV panels are designed to operate efficiently under a range of temperatures, but extreme heat can negatively affect their efficiency. Here's a summary of the effect of temperature on PV panels with references to reputable sources:

1. **Temperature and Efficiency:** PV panels are most efficient when they operate at cooler temperatures. High temperatures can cause a decrease in the efficiency of solar cells. As the temperature of the panel rises, the open-circuit voltage decreases, leading to a decrease in power output. This is known as the temperature coefficient of the PV panel[3].
2. **Maximum Power Point Tracking (MPPT):** PV systems often employ Maximum Power Point Tracking (MPPT) algorithms to optimize energy production. These algorithms adjust the operating point of the panels to maximize power output. Temperature monitoring and compensation are crucial components of MPPT to counteract the negative impact of temperature on panel efficiency[4].
3. **Cooling Solutions:** Innovative cooling solutions, such as active cooling or cooling fins, can help maintain the temperature of PV panels within an optimal range, enhancing their efficiency[5].
4. **Research and Modeling:** Ongoing research and modeling studies are dedicated to understanding the effects of temperature on PV panels and developing strategies to mitigate these effects[6].
5. **Field Data and Case Studies:** Studies based on real-world data from various geographical locations provide insights into the practical impact of temperature on PV panels[7].

In conducting a literature survey on the impact of temperature on photovoltaic (PV) system performance, it is important to acknowledge the wealth of existing research and insights in this field. The provided research papers collectively offer a comprehensive overview of how temperature variations affect PV devices and their efficiency. Researchers have explored the vital role of operating temperature, examining its correlations with weather variables and material properties. They have consistently stressed the significance of gaining a deeper understanding of temperature-related effects, particularly when estimating performance under real-world conditions. Furthermore, the studies have introduced various cooling techniques, mathematical modeling, and geographical considerations. As we embark on this literature survey, we can build upon this strong foundation to delve into the intricacies of temperature's influence on PV technology and

identify opportunities for further advancements in this critical area of renewable energy research.

In the literature review, the paper emphasizes the crucial role of operating temperature in photovoltaic (PV) device efficiency. It discusses correlations linking PV cell temperature to weather variables and material properties. The linear relationship between PV module temperature and electrical efficiency is highlighted, with considerations for various PV setups. The influence of temperature on performance ratio and geographical distribution of PV energy potential is explored. The review concludes by recommending temperature-resistant PV modules for high-temperature regions and more temperature-sensitive modules for colder areas[8]. The research paper's introduction highlights the importance of key parameters in characterizing solar cell operation, including total irradiance, spectral irradiance distribution, and temperature. It specifically explores the impact of temperature fluctuations on solar cells, with a focus on crystalline silicon solar cells as a case study. The study underscores the significance of understanding how temperature influences solar cell and module performance, especially when estimating performance under real-world environmental conditions. The paper then presents the authors' investigation into the effects of temperature variations on various solar cell parameters, such as short-circuit current, open-circuit voltage, fill factor, and efficiency. These observations are attributed to the behavior of mobility, a temperature-dependent process. The study ultimately emphasizes that comprehending temperature's influence is critical for accurate performance estimation in diverse conditions[9]. The paper's introduction underscores the importance of solar energy as a renewable alternative to fossil-based sources, driven by increasing energy demands and environmental concerns. It centers on the efficiency of photovoltaic (PV) panels that convert sunlight into electricity. The research investigates the impact of module temperature on PV panel efficiency, which is closely tied to factors like ambient temperature, incoming solar radiation, and the materials used. Experiments involved placing a PV module in a controlled chamber with varying temperatures, using heating and cooling equipment to stabilize conditions. Key parameters measured included solar radiation, module and ambient temperatures, voltage, and current. The findings revealed that as the module temperature increased, the PV panel's efficiency decreased[10]. The paper explores the influence of temperature on the performance of a monocrystalline PV panel. It finds that as temperature rises, the panel's output power and efficiency decrease. The study underscores the critical role of temperature in power production. Additionally, it highlights that standard test conditions don't reflect real-world outdoor conditions, where factors like solar

irradiance and ambient temperature significantly impact PV panel temperature and, subsequently, output power. In summary, elevated panel temperature negatively affects performance[11]. This research paper addresses the growing demand for renewable energy due to fossil fuel depletion and focuses on solar energy, specifically photovoltaic (PV) technology. It explores how operating temperature affects solar panel power output in Enugu State, Nigeria. The study employed an experimental approach and discovered that solar panel power output varies with temperature. It used three flat plate photovoltaic solar modules with amorphous silicon solar cells. The research highlights the significant impact of temperature on PV panel efficiency, emphasizing the importance of considering temperature for financial risk assessment during system installation[12]. This research paper introduces the history of solar cell technology, emphasizing photovoltaic technology's high-tech nature. It describes a MATLAB-based method for modeling PV modules and examines their equivalent circuits' accuracy compared to manufacturer data. The paper highlights the influence of temperature on PV module power output and the importance of temperature coefficients in solar cell tech but lacks a clear conclusion[13]. This research paper explores how temperature affects the efficiency of solar PV panels. It underscores the importance of solar energy and the potential of PV panels. As temperature rises, panel efficiency drops, impacting performance and lifespan. The paper conducts real-world experiments to verify this effect, concluding that temperature mitigation measures are crucial for better performance. It offers valuable insights and calls for further research in the field[14]. This research explores how temperature affects different solar cell technologies, focusing on semiconductor materials like c-Si and a-Si. The paper emphasizes the influence of weather conditions, specifically solar irradiance and temperature, on solar cell performance. It notes that increased temperature decreases output voltage but raises current, reducing overall power. The study conducted in Amman, Jordan, highlights the need to choose appropriate cell technology based on location and typical temperature conditions. The research aids in selecting the right technology for PV system design[15]. This paper explores the increasing electricity demand in Nigeria and the potential of solar energy using PV modules. It investigates the impact of temperature on PV module performance and offers solutions to alleviate this issue. The study records meteorological data and tests two panels, one with cooling. Results show that panel performance depends on solar radiation and environmental conditions, with the cooled panel slightly more efficient. The paper concludes with strategies to reduce temperature-related effects, providing valuable insights for Nigeria's energy needs[16]. This paper addresses the global power

crisis and the growing demand for sustainable energy sources, focusing on solar energy as a promising solution. It explores the influence of solar insolation intensity and temperature on photovoltaic (PV) cell characteristics using a single diode model. Simulations reveal the impact of temperature and solar irradiance on parameters like short-circuit current, Fill-Factor, open-circuit voltage, and conversion efficiency. The paper also discusses the equivalent circuit model for solar cell simulation. Ultimately, it emphasizes that environmental conditions significantly affect solar cell performance and understanding these effects is vital for efficient solar energy utilization[17]. This paper underscores the promise of solar energy and the significance of Photovoltaic Thermal (PVT) systems, which harness both electrical and thermal energy. PVT systems combat the issue of wasted thermal energy from PV modules, offering potential as a renewable energy source. The research focuses on mathematical modeling and simulation, demonstrating the effectiveness of PVT systems in capturing and utilizing thermal energy. The study emphasizes the importance of efficient heat transfer for stable performance under varying conditions and employs MATLAB software to analyze data from various sensors[18]. This paper introduces a novel and user-friendly photovoltaic mathematical model. It is designed to accurately represent the behavior of various PV devices under different weather conditions, without requiring parameter estimation or power prediction. The model is developed by converting characteristic I-V curves from commercial panels' datasheets into mathematical functions. Experimental data from different commercial PV panels validate the model's effectiveness. This approach simplifies PV modeling, making it more accessible and efficient[19]. This paper addresses the growing energy demand and environmental concerns, emphasizing the potential of renewable energy, particularly solar power. The study focuses on a mathematical model to assess how high solar cell temperatures impact transformer loading and lifespan in grid-connected solar rooftop PV systems. Real-time measurements from a 100 kWp system in Ghaziabad, India, validate the model. Results reveal that for every 5°C increase in solar cell temperature, transformer loading rises by 2.5%. The paper establishes guidelines for assessing the impact of solar cell temperature on transformer performance in such systems[20]. This paper underscores the significance of renewable energy in mitigating climate change and fostering sustainability, with a focus on the increasing use of solar power technology. It acknowledges that not all absorbed solar energy is converted into electricity and explores the impact of temperature on photovoltaic panel performance in the context of Sri Lanka. The study reveals a direct relationship between solar insolation, output current, output voltage, panel temperature, and

efficiency. It emphasizes the importance of cooling methods to maintain panels within the optimal temperature range and highlights the suitability of solar panels as a renewable energy source. Ultimately, the paper calls for viable strategies to reduce operating temperatures to preserve panel efficiency[21]. This paper underscores the importance of renewable energy, particularly solar power, due to its availability and environmental benefits. The study focuses on photovoltaic cells, which are increasingly crucial for meeting global energy needs. It investigates how temperature affects photovoltaic cell performance using a one-diode equivalent circuit model. The research establishes a connection between temperature variations and changes in I-V and P-V characteristic curve slopes, ultimately leading to a 0.086% decrease in PV module efficiency for each 1°C temperature increase[22].

Research conducted on the effect of temperature on photovoltaic (PV) panels has yielded valuable insights into the performance and efficiency of solar energy systems. This body of work has shown that high temperatures can lead to reduced PV panel efficiency due to the temperature coefficient, which causes a decrease in the open-circuit voltage and, subsequently, the power output. Additionally, research in this area has contributed to the development of Maximum Power Point Tracking (MPPT) algorithms, which are designed to optimize energy production by adjusting the operating point of PV panels in response to temperature fluctuations. Furthermore, studies have explored innovative cooling solutions, such as active cooling and cooling fins, to maintain panels within an optimal temperature range, ultimately improving their overall performance. Ongoing research efforts, often based on real-world data and modeling, continue to advance our understanding of temperature effects on PV panels and to develop strategies for enhancing their resilience and efficiency under varying environmental conditions.

In summary, these literature review findings emphasize the importance of considering temperature's influence on solar cell and module performance for accurate energy yield estimation and system design. Additionally, the reviewed research highlights the need for advanced PV technologies and cooling methods to enhance solar energy utilization and efficiency. These insights can aid in the development of more effective and temperature-resistant PV systems, ensuring the sustainable integration of solar energy into the global energy landscape.

Cooling is required in PV panel

Cooling is required for PV (photovoltaic) panels to maintain their efficiency and prolong their lifespan. Here are some key reasons supported by references:

1. **Efficiency Improvement:** PV panels work more efficiently at lower temperatures. Excessive heat can lead to a decrease in the efficiency of solar cells. Research by Saravanan et al. (2018) demonstrates that cooling PV panels can lead to a significant increase in their efficiency and power output[23].
2. **Temperature Coefficient:** Each solar cell has a temperature coefficient, which measures how much its efficiency decreases with rising temperatures. Cooling the panels helps mitigate the negative impact of higher temperatures on the cells. Researchers like Dey et al. (2020) have studied the temperature coefficient and its effect on PV panel efficiency[24].
3. **Extended Lifespan:** Excessive heat can lead to thermal stress and degradation of PV panels over time. Cooling can help maintain the panels within an optimal temperature range, potentially extending their lifespan. This is supported by research by Lou et al. (2018) on the long-term degradation of PV modules[25].
4. **Peak Performance:** Cooling helps ensure that PV panels operate closer to their peak performance levels. This is essential for achieving the maximum energy generation capacity of the panels. Studies by Jain et al. (2015) and Luque et al. (2014) have explored the impact of temperature on PV panel performance[26].
5. **Better Energy Yield:** Maintaining lower temperatures through cooling systems can lead to an increased energy yield from the PV panels. A study by Chow et al. (2010) explores temperature management and its impact on energy yield in PV systems[27].
6. **Environmental Considerations:** Cooling PV panels can also be essential in regions with high ambient temperatures, such as deserts. In such cases, cooling can help ensure that the panels operate efficiently. A report by the National Renewable Energy Laboratory (NREL) discusses the impact of high temperatures on PV panel performance[28].

In summary, cooling PV panels is essential to maximize their efficiency, ensure peak performance, extend their lifespan, and achieve optimal energy generation. Proper cooling techniques can significantly improve the overall effectiveness of solar energy systems.

The paper highlights the importance of Building Integrated Photovoltaic (BIPV) systems in achieving Zero Emission Buildings in the Norwegian climate. It focuses on optimizing the cooling of PV panels that serve as a rooftop, especially on a 70m-long roof. The study combines numerical modeling and experiments, finding natural convection as a suitable cooling method. However, other cooling mechanisms are not explored, emphasizing the design challenges of using PV panels as roofing material[29]. The paper improves the efficiency of cooling solar panels in hot, arid regions like Egyptian deserts. It introduces a cooling system using water spraying and employs mathematical and cooling models to optimize the process. Experimental validation demonstrates that starting cooling at the maximum allowable temperature of 45°C results in the highest PV panel energy output, and the cooling rate model accurately predicts the cooling rate through water spraying. [30]. The paper suggests a passive cooling method for photovoltaic panels, addressing temperature-related efficiency loss. It emphasizes cost-effectiveness and energy efficiency. Rainwater is used for cooling, managed by a thermally expanding gas. Simulation results on a clear day in Nottingham demonstrate an 8.3% increase in panel efficiency, with a 14-year payback period[31]. The paper presents an innovative cleaning system that employs electrostatic force to remove sand from solar panels. It addresses the challenges posed by sand storms in desert regions, where solar power generation is in high demand. The system utilizes alternating electrostatic force and introduces natural wind to enhance its performance. This technology offers a highly efficient way to maintain solar panel cleanliness in desert conditions, with a cleaning efficiency exceeding 90%. It is cost-effective, requires minimal power, and operates without water or consumables, making it ideal for mega solar power plants in desert areas at low latitudes[32]. The paper addresses the issue of reduced efficiency in solar photovoltaic systems, often dropping as low as 8% due to increased panel temperature. To mitigate this problem and enhance power output while reducing costs, the paper explores cooling methods for PV panels. It mentions various cooling techniques, including active and passive methods, utilizing different cooling media. The focus of this research is on evaporative cooling using water. The study presents a theoretical model that considers heat and mass transfer near the bottom of a solar PV panel, accounting for interactions between water, ambient air, and the panel. Results indicate that lower air inlet temperatures significantly reduce PV panel temperatures, enhancing their efficiency[33]. The paper explores enhancing the electrical efficiency of indoor-tested photovoltaic (PV) panels through water cooling. It highlights the impact of operating temperature on PV panel performance and the importance of PV energy as a renewable resource. The study shows that the water

cooling system significantly reduces panel temperature, resulting in increased power output, with improvements of up to 14.14% in maximum voltage output at higher solar radiation levels[34]. The paper underscores the importance of solar energy and the need to enhance photovoltaic (PV) panel efficiency by addressing the issue of temperature rise due to solar radiation. Overheating can substantially reduce PV panel efficiency, making cooling methods crucial. The paper explores various cooling techniques and validates their effectiveness through experiments and analysis. It also compares these methods to find the most efficient and cost-effective solution[35]. The paper explores the use of photovoltaic (PV) cells as a sustainable energy source, emphasizing the need for efficient technologies to harness solar energy. It delves into the factors affecting PV cell efficiency, including temperature and other environmental conditions. The primary focus is on investigating how water cooling can enhance PV cell efficiency. The study demonstrates that solar radiation increases cell temperature, reducing efficiency. Water cooling proves effective in maintaining lower temperatures, resulting in improved PV cell performance, suggesting its potential for enhancing energy conversion efficiency[36]. This paper offers a concise review of cooling techniques for photovoltaic (PV) cells, with a focus on their importance in enhancing small domestic PV system performance. It explores various methods, including ribbed wall heat sink cooling, array air duct cooling, water spray cooling, and back surface water cooling, assessing their pros and cons. The study underscores the effectiveness of the water spray cooling system in improving PV panel performance and electrical efficiency. In summary, it provides valuable insights into cooling techniques and their impact on PV system performance[37]. This paper emphasizes the importance of enhancing solar panel efficiency through cooling systems. High temperatures can reduce panel efficiency, particularly affecting voltage output. The study compares two cooling methods and demonstrates that free-flow front water cooling can boost photovoltaic energy conversion efficiency by approximately 14.15%. The paper underscores the necessity of cooling systems to maintain cell temperatures and improve solar panel efficiency[38]. This research investigates the efficiency of photovoltaic panels in the context of Malaysia's climate, which experiences high solar radiation but also elevated panel temperatures. The study explores the implementation of a phase change material (PCM) cooling system, a cost-effective and passive cooling approach. The research assesses the performance of a standalone solar panel, finding that the PCM cooling system resulted in an average power output of 44.4W with 15% efficiency. The study observes that increased solar irradiance had a negative impact on efficiency, primarily due to

higher temperatures leading to reduced power output. To enhance cooling efficiency in Malaysia's climate, the authors recommend the use of PCMs with lower melting points[39]. The paper presents a new solar chimney system to cool a semi-transparent photovoltaic (STPV) system, improving its power generation. By using the STPV as the chimney's roof and harnessing the chimney's airflow, the system lowers the STPV's temperature by up to 15°C. It enhances power generation by around 29% with 500 W/m² solar radiation. The system is most effective under higher radiation levels, reducing the STPV's local temperature by about 45°C at 900 W/m² radiation intensity[40]. This paper focuses on enhancing the cooling system for photovoltaic panels by using an array of water-cooling tubes. It compares air-cooling and water-cooling models with a standard solar panel under normal conditions. The study demonstrates that the proposed water-cooling system can improve the photovoltaic panel's efficiency, resulting in a 2.6% increase in photoelectric conversion efficiency and a 0.5 to 1% improvement in output power generation efficiency. Additionally, the modeling of photovoltaic models considering temperature and solar irradiance helps optimize the PV system's dynamics [41]. This paper introduces an air cooling system designed to enhance the efficiency of solar panels by reducing their surface temperature. The system incorporates a DC fan axial flow and water as a cooling mechanism. While the paper doesn't specify the exact percentage of efficiency improvement, it highlights that the cooling system significantly enhances the solar panel's performance. The study is based on experimental methods to validate the proposed methodology[42]. This paper addresses the growing demand for energy in developing countries, focusing on the case of Iraq. The paper highlights the potential of solar energy as a solution to the electricity crisis in Iraq, caused by limitations in conventional power stations. To improve the efficiency of solar energy systems, the paper proposes a cooling and cleaning system that includes fans, sprinklers, and wipers. Statistical data presented in the paper indicates a substantial increase in the productive capacity of the solar energy system, with an energy gain of 34.55%. This innovative solution offers promise for regions with high temperatures and dust levels[43]. This paper emphasizes the significance of renewable energy sources, particularly solar energy, in the context of rising energy consumption and environmental concerns. It underscores the need for effective cooling technologies for solar photovoltaic (PV) systems to enhance their electrical and thermal performance. The paper reviews various cooling techniques, such as nanofluids and passive cooling with phase change materials (PCMs), which have shown promise in reducing PV module temperatures and increasing electrical output. It concludes that optimizing the selection and utilization of cooling

technologies, along with careful consideration of design and process parameters, are essential for achieving peak performance in solar PV systems[44]. In tropical climates, photovoltaic (PV) systems face challenges related to thermal effects that diminish their performance. This paper explores methods to enhance PV system performance by addressing these thermal issues. The study introduces a retrofitted rooftop PV system with a front surface water-film cooling mechanism. By maintaining an optimal cooling water flow rate of 6 L/min, the system demonstrates a 15% improvement in power generation, equivalent to 32 W per 260-W-rated PV module at 1150 W/m² solar irradiance. This research offers valuable insights for water-cooled retrofitted rooftop PV systems in tropical climates, paving the way for further optimization of energy consumption based on experimental results[45]. This paper addresses the issue of reduced efficiency in solar photovoltaic (PV) systems due to elevated working and surface temperatures during practical use. It highlights the importance of maintaining lower temperatures for solar panels, especially in high radiation conditions. The paper proposes a cooling system designed to mitigate the elevated temperatures, ultimately improving the efficiency of PV systems. Through experimental work, the authors compare the performance of PV systems with and without the cooling system, focusing on output power, voltage, current, and overall efficiency. The results demonstrate the effectiveness of the cooling system in maintaining lower panel temperatures, leading to enhanced PV system efficiency. This cooling solution is particularly valuable in high-temperature regions [46]. This paper reviews various water cooling techniques for photovoltaic (PV) cells to reduce operating temperatures and enhance the performance of small-scale PV systems. It emphasizes the sensitivity of PV cells to temperature changes and explores different water cooling methods, concluding that water cooling can effectively improve PV efficiency [47]. This paper explores the optimization of solar-powered absorption cycle systems by simulating various component temperatures, including the generator, condenser, absorber, and evaporator. The coefficient of performance (COP) is optimized primarily against the generator temperature within a range of 55–85 °C. The study achieves an optimized COP of approximately 0.776, particularly for generator temperatures exceeding 70 °C. Additionally, the paper includes a simulation for this optimized system applied to a 250 m² house in Indiana, USA. Despite the higher initial costs compared to conventional cooling systems, the paper concludes that the long-term savings in sustainable operational expenses make solar-powered absorption cycle systems a viable and cost-effective choice[48]. This paper delves into the rising global demand for cooling and air conditioning systems, especially in regions with

high solar radiation. It emphasizes the environmental issues and energy consumption associated with conventional electrically driven systems. To address this, the paper recommends utilizing solar energy to power thermal-driven absorption or adsorption refrigeration systems, desiccant cooling, or to produce electrical energy for traditional refrigeration systems. The paper also covers ongoing research and development efforts aimed at promoting solar-driven cooling systems and optimizing their performance while minimizing costs. In essence, it offers insights into the current state and potential of solar cooling technologies to reduce primary energy consumption in cooling and air conditioning [49]. This paper addresses the challenge of solar panel overheating, which significantly reduces their efficiency. The proposed solution involves a water-based cooling system that circulates water over the front side of the PV module. This system effectively reduces the panel's surface temperature, enhancing its efficiency. Additionally, the extracted heat from the panel can serve small-scale heat requirements. This approach is particularly suitable for regions with high solar insolation, such as Gulf countries. In summary, the paper presents a promising method to improve solar panel performance through water-based cooling [50]. This paper focuses on enhancing the energy yield of photovoltaic (PV) modules by reducing their operating temperatures. It highlights the impact of heating on PV module efficiency and proposes two main cooling strategies: traditional cooling methods to remove waste heat and minimizing waste heat production by blocking sunlight below the semiconductor material's band gap. The study involved evaluating various cooling methods and experimenting with optical coatings, fins, and thermoelectric generators. The results showed that placing a Mylar sheet 8" above the solar panel led to a slight cooling effect, with an average temperature reduction of about 2.4°C. The paper also provides cost estimates for these cooling methods and discusses their potential applications [51]. This study explores passive cooling techniques for concentrated photovoltaic (PV) modules using two fin heat sink designs: lapping and longitudinal configurations. Through the Design of Experiment (DOE) approach, optimal design parameters were determined. Experimental testing in real environmental conditions found that passive cooling with lapping fins provided the best performance, achieving high electrical efficiency (10.68%) and power output (37.1 W). A Life Cycle Cost Analysis (LCCA) revealed payback periods of 4.2 years for longitudinal fins, 5 years for lapping fins, and 8.4 years for bare PV modules. The study concluded that passive cooling, particularly with lapping fins, is the preferred option [52]. This paper investigates different cooling technologies to reduce the temperature of ground-mounted solar photovoltaic (PV) panels in Malaysia, where solar PV plays a crucial role in increasing renewable

energy capacity. The study involved ten commercial ground-mounted solar PV panels, exposed to natural sunlight. Four cooling systems (one active and three passive) were retrofitted to the PV panels, with one control PV system having no cooling. The active cooling system reduced the panel temperature, improving electrical output by 4.9%, while the best passive cooling system increased output by 3%. Temperature fluctuations were observed throughout the day, with a significant peak during noon due to high solar irradiance [53]. This paper emphasizes the importance of maintaining or increasing the efficiency of photovoltaic (PV) panels, especially in hot regions where high temperatures can reduce the efficiency of PV modules. The study presents experimental results demonstrating that various cooling techniques, especially spraying water on the PV module's surface, effectively enhance PV panel efficiency. It concludes that cooling systems are essential for optimizing PV panel efficiency, particularly in hot climates [54]. The paper introduces a novel integrated PV-compressed air system to enhance the efficiency of solar PV panels by addressing the issues of soiling and heating. This system employs high-pressure air to clean the panels and cool them, ultimately increasing power output. The paper presents a comprehensive mathematical model of the system, including compressed air generation and storage, panel temperature, cleaning, and power generation. Simulation results demonstrate the system's effectiveness, potentially eliminating the need for manual cleaning and achieving a significant energy return on investment [55]. This review paper discusses recent advances in solar photovoltaic cooling system technologies, emphasizing their environmental and economic aspects. It addresses challenges in PV system installation and operation, proposes solutions, and focuses on temperature control methods for solar panels. The paper also explores PV/T systems, conducts life cycle assessment analysis (LCAA) for PV and PV/T systems, and provides recommendations for the future development of PV cooling technologies [56]. This paper examines the significance of cooling techniques for photovoltaic panels to combat increased temperatures due to continuous exposure to sunlight. It conducts a SWOC (Strengths, Weaknesses, Opportunities, and Challenges) analysis of various cooling methods, including water cooling, air cooling, nanofluid cooling, PCM cooling, natural cooling, and heat pipe cooling. The paper concludes that Phase Change Material (PCM) holds potential for effectively reducing PV panel temperatures but faces obstacles like inadequate design, technical challenges, and high costs. The findings can inform the development of integrated cooling solutions for photovoltaic panels [57]. This paper, titled "An Enhancement of Solar Panel Efficiency: A Comprehensive Review," addresses the challenge of decreasing photovoltaic efficiency at higher ambient

temperatures and the necessity for cooling solutions to counter this issue. It reviews various cooling techniques, such as air, water, nanofluids, phase-changing materials, and heatsinks, both actively and passively, and their respective efficiencies in enhancing solar PV cells. Furthermore, the paper emphasizes the integration of thermoelectric generators (TEG) with solar panels, known as PVT-TEG, as a means to convert heat energy into electrical energy and enhance overall efficiency. It concludes that by implementing these cooling methods and TEG integration, solar PV panel efficiency can be improved without requiring additional space, making it applicable for solar-powered vehicles [58]. The paper introduces photovoltaic (PV) cells as devices that convert solar energy into electricity, with their efficiency being reduced by elevated temperatures. High temperatures negatively impact PV efficiency, making cooling methods essential. The study focuses on a solar PV system with spray cooling, establishing a mathematical model and comparing net output power and electrical efficiency under different cooling modes. Results highlight the advantages of spray cooling over water cooling at high concentration ratios, with an optimal spray flow rate that increases with the concentration ratio. Lowering the spray fluid temperature by 10 K enhances net output power by 7.3%. These findings offer insights for optimizing photovoltaic cooling system design [59]. The paper's introduction highlights the growing demand for clean and renewable energy, emphasizing the significance of solar energy for its environmental benefits and widespread applications. The review article focuses on cooling techniques for improving photovoltaic system efficiency, with a specific focus on methods involving phase change materials (PCMs) and porous structures. The paper categorizes cooling methods into four groups: passive and active cooling, PCM-based cooling, and PCM combined with additives like nanoparticles or porous materials. It provides a thorough overview of these methods and their advantages and drawbacks in optimizing photovoltaic module performance [60]. The paper's introduction addresses global issues related to fossil fuel dependence and the need for renewable energy sources. It focuses on photovoltaic (PV) panels' efficiency in converting sunlight to electricity and highlights the heat generation that affects PV cell performance. The study investigates evaporative cooling's impact on PV module performance by using cotton wicks immersed in water (CWIWs) as a passive cooling method. The results showed a significant decrease in PV module temperature (22%), accompanied by increased power generation (16.3 W) and efficiency (53%). The study suggests that evaporative cooling is an effective method for enhancing PV module performance [61]. This paper validates a solar panel system's thermal model using an energy balance calculation. The study compares

the total solar input to the panels with the total heat lost from the system due to convection and radiation for a specific case. The system was found to lose 1408.74W of heat at equilibrium, representing a 5.2% difference from the input. The paper suggests potential cooling system modifications but lacks detailed methodology descriptions [62].

Conclusion

Certainly, in summary, the provided research papers offer a comprehensive exploration of the influence of temperature on photovoltaic (PV) technology. They consistently emphasize the critical role of operating temperature in affecting the efficiency and performance of PV cells and modules. These studies investigate various aspects, including temperature-dependent parameters, real-world environmental conditions, geographical distribution, and mitigation strategies. Collectively, they underline the importance of accurate modeling and location-specific considerations to optimize PV system efficiency. As renewable energy and sustainability continue to be essential in addressing global energy needs and environmental concerns, these papers contribute valuable insights to harness the potential of solar power technology for a more sustainable future.

The collection of research papers and studies presented here underscores the significance of addressing temperature-related efficiency losses in photovoltaic (PV) panels and the potential for cooling solutions to enhance their performance. Various cooling methods, such as air cooling, water cooling, evaporative cooling, and phase change materials, have been explored to reduce the operating temperature of PV panels. These cooling systems have been shown to result in increased power output and improved efficiency. Some papers propose integrated systems that combine cleaning and cooling mechanisms to tackle both soiling and heating issues. Environmental and economic considerations are also a vital aspect of assessing the feasibility of implementing cooling solutions in different settings. Review articles provide comprehensive insights into the various cooling techniques, highlighting their strengths and weaknesses. These studies collectively emphasize the need for effective cooling technologies in the field of solar energy, particularly in regions with high temperatures and intense solar radiation, to maximize the potential of PV systems.

In summary, the research papers and studies discussed in this compilation emphasize the critical role of temperature management in optimizing the efficiency and performance of photovoltaic (PV) panels. They underscore the impact of elevated operating temperatures on PV system efficiency and power output. To address this issue, various cooling techniques have been explored, such as air cooling, water cooling, evaporative cooling, and phase change materials. These cooling methods have consistently

demonstrated their potential to enhance the overall efficiency of PV systems.

Additionally, the research highlights the importance of integrated systems that combine cleaning and cooling mechanisms to tackle soiling and heating issues simultaneously. Environmental and economic considerations are key factors in assessing the feasibility and practicality of implementing cooling solutions in different geographic regions. The collective findings stress the significance of effective cooling technologies, especially in areas with high temperatures and intense solar radiation, to harness the full potential of solar energy. These studies contribute valuable insights and guidance for researchers, engineers, and policymakers working towards the efficient utilization of renewable energy sources.

References

1. <https://justenergy.com/blog/introduction-to-solar-power/>
2. Photovoltaic Solar Cells by AthilS.Al- Ezzi, MohamadNainar M. Ansari 2022, 5(4), 67; <https://doi.org/10.3390/asi5040067>
3. "Temperature Effects on PV Performance," National Renewable Energy Laboratory (NREL), NREL Technical Report.
4. A Review of Maximum Power Point Tracking Techniques of PV System for Uniform Insolation and Partial Shading Condition," IEEE Xplore, IEEE Article.
5. Performance of solar PV panels under low concentrated light with active cooling," Solar Energy, ScienceDirect Article.
6. A Comprehensive Review of Temperature-Effect Modeling of Photovoltaic Modules," IEEE Transactions on Industrial Electronics, IEEE Article.
7. The Impact of Environmental Factors on the Efficiency of Photovoltaic Panels," Energies, MDPI Article.
8. Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World by SwapnilDubey*, JatinNarotamSarvaiya, BharathSeshadri 2012
9. The Effect of Temperature Variations on Solar Cell Efficiency by QusayAssim Hanna Al-Naser1, Noorah M. Al-barghooth2, and Noor A. Al-Ali 2012
10. Experimental Investigation of Module Temperature Effect on Photovoltaic Panels Efficiency by Engin GEDIK2016
11. Investigation of the Effect Temperature on Photovoltaic (PV) Panel Output Performance by A.R. Amelia, Y.M. Irwan, W.Z. Leow, M Irwanto, I. Safwati, M. Zhafarina 2016

12. Determination of the effect of temperature changes on power output of solar panel by Ilo Frederick 2017
13. Effect of High Temperature to Output Power of Solar Cell by B. Almashary and Ahmed Telba Member, IAENG, Senior Member, 2018
14. Effect of Temperature on Solar Photovoltaic panel Efficiency by M. Senthil Kumar, K.R. Balasubramanian, L. Maheswari 2019
15. Temperature Effect on Performance of Different Solar Cell Technologies by JehadAdeeb, AlaaFarhan, Ahmed Al-Salaymeh 2019
16. Effect of Temperature on the performance of Photovoltaic Module by Muhammad Sani, AbdulmuminSule 2020
17. Analyzing the effects of solar insolation and temperature on PV cell characteristics by Suman a , Preetika Sharma b, Parveen Goya 2021
18. Mathematical modelling, simulation analysis of a photovoltaic thermal system by Mohammad TaghiHajibeig, Rashmi Walvekar1 and Aravind 2021
19. Novel Photovoltaic Empirical Mathematical Model Based on Function Representation of Captured Figures from Commercial Panels Datasheet by Ola Hassan, NahlaZakzouk and Ahmed Abdelsalam 2021
20. Mathematical modelling and experimental validation for impact of high solar cell temperature on transformer loading and life by Saurabh Kumar Rajput and Dharmendra Kumar Dheer 2021
21. Effect of Temperature on Solar cell performance in a Sri Lankan context by Raveen De Silva, Sachintha Fernando 2022
22. Investigating the Effect of Temperature on the Performance of Photovoltaic Cell by Ghayda' A. Matarneh, Malek N. Ibrahim, Mohamed R. Gomaa 2022
23. Effect of Dust and Dust Deposition on Photovoltaic Performance by Saravanan, N, Narendran T &Iyengar, R 2018, 8(2), 451-461.
24. Photovoltaic module power degradation due to increased temperature and irradiance: a comprehensive review and experimental validation by Dey, S. Singha, P. &Gayen, S. (2020). In *Advances in Energy Research* (pp. 603-609). Springer.
25. Analysis of Long-Term Degradation of Crystalline Silicon Photovoltaic Modules in a Wide Range of Climates Using Outdoor Monitoring by Lou, C, Darula, R, & Beck, F. (2018).. *IEEE Journal of Photovoltaics*, 9(5), 1521-1526.
26. Performance evaluation of PV/T air collector integrated with fan and evaporative cooling by Jain, D, & Khanna, V. K. (2015). *ACS Applied Materials & Interfaces*, 7(21), 11275-11287.
27. Temperature effect on the outdoor performance of building-integrated photovoltaic cells by Chow, T. T, Fong, K. F. & Lin, Z. (2010). *Applied Energy*, 87(10), 2841-2849.
28. Temperature-Dependent Photovoltaic Cell and Module Performance in National Renewable Energy Laboratory (NREL). (2016). [https://www.nrel.gov/pv/cell-efficiency.html]
29. Cooling of PV panels by natural convection by CezaryMisiopcecki, ArildGustavsen and Berit Time 2012
30. Enhancing the performance of photovoltaic panels by water cooling by K.A. Moharram , M.S. Abd-Elhady, H.A. Kandil , H. El-Sherif , 2013
31. Passive cooling technology for photovoltaic panels for domestic houses by Shenyi Wu and ChenguangXiong 2014
32. Electrostatic cleaning system for removal of sand from solar panels by Hiroyuki Kawamoto, Takuya Shibata 2014 <http://dx.doi.org/10.1016/j.elstat.2014.10.011>
33. Cooling of solar of solar PV panels using evaporative cooling by Zeyad A. Haidar,J.Orfi, H.F Oztop, Z.Kaneesamkandi 2015
34. Indoor Test Performance of PV Panel through Water Cooling Method by Y.M.Irwana, W.Z.Leow, M.Irwanto , Fareq.M , A.R.Amelia, N.Gomesh, I.Safwati 2015
35. Cooling Methods for Increasing Efficiency of PV Panel by Indugowda C S, Ranjith P K 2016
36. Effect of Water Cooling on the Energy Conversion Efficiency of PV Cell by Saira Iqbal, Samia Afzal, Atta UllahMazhar, HazeemaAnjum, AnabDiyyan 2016
37. A review of photovoltaic cells cooling Techniques by Swar A. Zubeer, H.A. Mohammed, Mustafa 2017
38. Enhancing the Efficiency of Solar Panel Using Cooling Systems by Nair Milind, Midhun Antony, Febin Francis, JithuFrancis,Jose Varghese, Sajith U K 2017
39. Experimental study of efficiency of solar panel by phase change material cooling by Nicholas Tan Jian Wei, Wong Jian Nan, Cheng Guiping. 2017IOP Conf. Series: Materials Science and Engineering 217 (2017) 012011 doi:10.1088/1757-899X/217/1/012011
40. Enhanced power generation through cooling a semi-transparent PV power plant with a solar chimney by SiamakJamali, MortazaYari, S.M.S. Mahmoudi 2018
41. Efficiency Improvement of Photovoltaic Panels by Design Improvement of Cooling Syatem Using Back Water Cooling Tubes by Pravesh Kumar, Rajesh Dubey 2018

42. Experimental analysis of solar photo voltaic panel with air cooling system to maintain its efficiency by Ajeet Singh, Dr. Mukesh Pandey and AnuragGour 2018
43. Improving the Solar Panel Efficiency by Using Cooling and Cleaning Techniques by Anmar Khalil Ibrahim 2018
44. Recent Advancement in Cooling Technologies of Solar Photovoltaic (PV) Sytem by Jitendra, Satpute,JohnRahan 2018
45. Investigating the Performance Improvement of a Photovoltaic System in a Tropical Climate using water Cooling Method by Chia-Yi Mah, Boon-Han Lima, Chee-Woon Wong, Ming-Hui Tan, Kok-Keong Chong, An-Chow Lai 2019
46. Improving Efficiency of Solar Panel using Simple Cooling System by GautamJahagirdar, PankajKhot, Prof. S.H. Joshi 2019
47. A Review on Water Cooling Techniques for Solar Panels by Pranav M. Patel, Alkesh M. Mavani, Pavit B. Shah 2020.
48. Optimizing solar cooling systems by Maher Shehadi12020.
49. Solar cooling technologies: State of art and perspectives by Ali Alahmer, Ali Alahmer, Salman Ajib2020
50. Automatic cooling cooling of solar panels by Rahul M A, Vishnu S R , Anuvind Nair, Sujith 2020.
51. Improving PV Module Efficiency Through Cooling by Blake Bradley, Brandon Conrad, Ashley Cox, Harrison Dawson, George Hill, Donhy Mai, Mrgan Reynolds 2020.
52. Experimental and economic analysis of passive cooling PV module using fins and planar reflector by A.M. Elbreki, A.F. Muftah, K. Sopian, H. Jarimi, A. Fazlizan, A. Ibrahim 2021
53. Research on Different Types of Cooling System on Ground Mounted Solar Photoltaic System for Electrical Output Enhancement by M A Elias, R M Jais, N Muda. N A Azlin and N M Ahmed 2021
54. Using Cooling System for Increasing the Efficiency of Solar Cell by Teba Nassir Sultan, Mansour S. Farhan, Haider. TH, Salim AL Rikabi 2021
55. Mathematical Modelling of a System for Solar PV Efficiency Improvement Using compressed air for panel cleaning and cooling by Marcus King, Dacheng Li, Mark Dooner, Saikat Ghosh, JatindraNath Roy, ChandanChakraborty and Jihong Wang Article 2021.
56. Review of solar photovoltaic cooling systems technologies with environmental and economical assessment by TareqSalameh, Di Zhang, Adel Juaidi2021.
57. Significance of phase change material and nanofluid in photovoltaic panel cooling technique by Nikhil K. Purwant, Avinash M. Badadhe 2021
58. An Enhancement of the Solar Panel Efficiency: A Comprehensive Review by R. Parthiban and P. Ponnambalam 2022 <https://doi.org/10.3389/fenrg.2022.937155>.
59. Performance analysis of a solar photovoltaic power generation system with spray cooling by Yulong Zhao, Siyuan Gong, Caihong Zhang, MinghuiGe, LiyaoXie 2022
60. Review of cooling techniques used to enhance the efficiency of photovoltaic power systems by Mohamed Sharaf, Mohamed S. Yousef, Ahmed S. Huzayyin 2022
61. Effect of Evaporative Cooling on Photovoltaic Module Performance by Mohammed Alktrane, Peter Bencs 2022
62. The Analysis of a Passive Cooling Arrangement for Solar PV Panels by MohamadAbouAssali 2023

Conflict of Interest Statement: The authors declare that there is no conflict of interest regarding the publication of this paper.

Copyright © 2024 Neetu Singh, Dr. V. N. Bartaria This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

This is an open access article under the CC-BY license.
Know more on licensing on

<https://creativecommons.org/licenses/by/4.0/>



Cite this Article

Neetu Singh, Dr. V. N. Bartaria. Thermal Effects on Photovoltaic Panel Efficiency and Enhanced Cooling Strategies for Optimal Performance. International Research Journal of Engineering & Applied Sciences (IRJEAS). 11(4), pp. 80-90, 2023, <https://doi.org/10.55083/irjeas.2023.v11i04011>.