# A REVIEW STUDY ON COOLING TECHNIQUES FOR PHOTOVOLTAIC/THERMAL (PV/T) AND A COMPARISON BETWEEN THEM

by

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*This paper provides a detailed review of PV/T systems and their related cooling technologies. It identifies and systematically classifies several methods, including active techniques of forced air and pumped water with or without nanofluids, passive cooling by heat sinks, phase change materials, and hybrid cooling techniques, and presents a critical evaluation. Thermal management in photovoltaics is highly effective in counteracting the efficiency loss due to operational overheating. The comparison between theoretical, experimental, and numerical studies from 2013 to 2026 evidences the research included in the Clarivate database. The key temperature reductions and efficiency gains were obtained through various cooling strategies. It also integrates strategic strengths, weaknesses, opportunities, and threats (SWOT) analyses for the most used air- and water-based working systems. The results are intended as a point of reference, which gives clear indications of the optimal selection and further development of cooling solutions for increasing the energy yield and economic viability of solar energy systems in several applications and various climatic conditions.*

Keywords: *PV/T, solar energy, PV cooling, active cooling, passive cooling*

## Introduction

The world's growing population, along with a sharp rise in energy needs, has made shifting to sustainable power sources more pressing. Right now, depending mostly on fossil fuels does not work long-term because they won't last forever and are being used up too fast [1]. Besides this, burning these high-carbon fuels has caused serious harm to nature, triggering climate shifts, rising global temperatures, and thinning of the ozone layer in the upper atmosphere. Because of that, creating and rolling out strong, cleaner energy options is now a top priority for scientists and engineers worldwide [2, 3]. The range of green energy tools is not about sunlight, where they work best depends on local natural features. Solar power hits peak performance where sunshine is strong and steady, so places like Africa, parts of Asia, and sunny zones in North America use it a lot. Wind energy comes in two types: land-based and sea-based it thrives where winds

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blow reliably, such as across Northern Europe, parts of North America, and East Asia, thanks to wide-open coasts and flat terrain. Water-driven electricity plays a key role where rivers are powerful and landscapes are steep, especially in South America, North America, and large areas of Asia. Heat from deep underground powers some regions, but only where tectonic plates shift actively, limiting their use to certain geologically restless zones [4], notably along the Pacific Ring of Fire in regions of Asia, North America, and Oceania. The biomass energy [5], coming from plant and animal waste, is used widely, especially where farming or wood are common throughout Asia, Europe, and the Americas - providing electricity along.

A solar PV/T system is a smart device that collects sunlight to make both electricity and heat together all in one piece. The PV/T systems are primarily classified based on the heat transfer fluid used: Liquid-based PV/T Systems, Air-based PV/T Systems. The dual-output nature of PV/T systems makes them suitable for a wide range of residential, commercial, and industrial applications. Cooling technologies for PV cells can be systematically classified into three primary categories, as shown in fig. 1. Active cooling methods ,passive cooling methods and hybrid cooling methods.

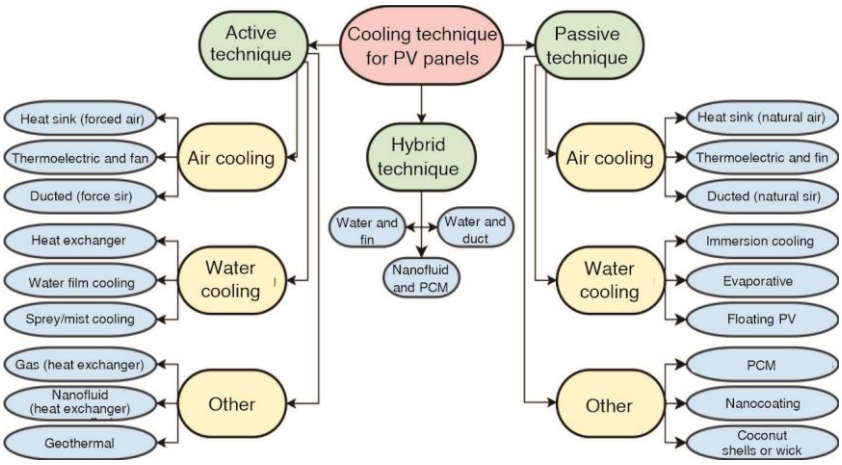


**Figure 1. Classification of PV panel cooling methods**

This review study is an in-depth analysis and correct classification of the most widespread cooling methodologies employed for enhancing the thermal and electrical performance of PV solar panels. The research work is based on a regular survey of research works published in the Clarivate databases and for international publishers like Elsevier, IEEE, MDPI, and Wiley, for the period covering 2013-2026. The main goal, therefore, is to pursue the following focus on key aspects:

- *Detailed Classification*: Categorization of various cooling techniques into active, passive, and hybrid, systematically, with evaluation methodology employed in research study, experimental, theoretical, or numerical.
- *Identifying a Research Gap*: Although many review studies have been carried out, this study is unique in that it provides a comparative, focused, and up-to-date analysis based on very recent research from several indexed international publishers and journals.
- *SWOT Analysis*: Strategic Evaluation - the study area was enriched by the SWOT analysis of water cooling and air cooling, which are the most common and at-hand cooling technologies. It gives a very clear strategic evaluation of the feasibility of those technologies.

## Overview of published research on photovoltaic cooling technologies

To map the new research area of PV cooling, a bibliometric overview was performed, surveying a broad range of scientific literature from 2013-2026. The evidence, as reported in fig. 2, is unambiguous: there is a sharp peak of scholarly activity circa 2018, and a clearly growing upward trend in 2022-2024. This trend represents a reflection of growing recognition of thermal management as a critical PV system performance and life driver. The research also points towards increasing use of CFD [6]. This trend is a sharp shift from experimental studies of single cooling technologies to the development of complex, multi-mode thermal management systems for optimum energy co-generation.

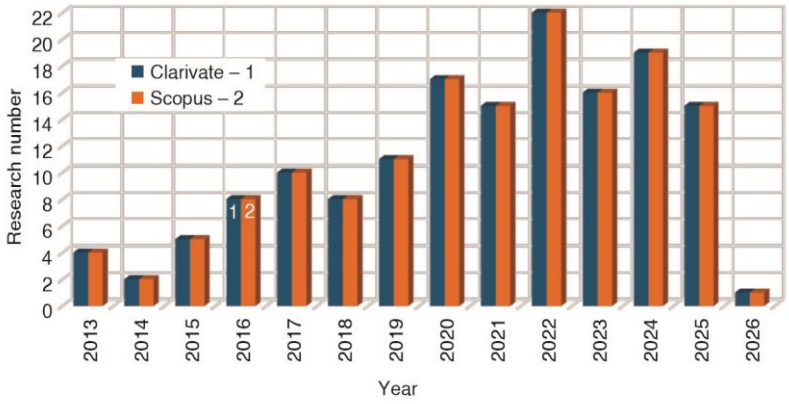


**Figure 2. Research published research on PV cooling (2013-2026)**

## Methodology of photovoltaic cell cooling types

### *Air-based cooling for photovoltaic cells*

The operational efficiency of photovoltaic cells is closely related to their operating temperature, by way of a negative temperature coefficient, which means electrical output decreases with an increase in thermal energy. A part of incident solar radiation is converted into wasted heat, elevating the cell temperature and inflicting overall performance degradation and problems in the long term. Therefore, effective thermal control isn't simply a development but an essential requirement for improved electricity production. Among the types of cooling techniques, air cooling offers a technically easy and economical solution. This technique utilizes air because it is the number one heat switch fluid to dissipate undesirable thermal energy from the PV modules. Implementation is achieved through two main types: passive and active cooling. Passive air cooling is predicated on natural convection air-flow throughout the panel floor, supplying no energy consumption. In contrast, active air-cooling uses an external approach, which includes fans or blowers, to force air throughout the back surface of the PV panel, extensively improving the heat removal charge by forced convection. The main benefits of air-cooling systems are their simplicity, minimal renovation requirements, and avoidance of the fluid leakage risks related to water-based systems. However, the effectiveness of this method is restricted by means of the low thermal conductivity and air conductivity, which can also restrict its cooling ability as compared to water alternatives. Despite this problem, air cooling remains an important

approach and a broadly researched topic. Several researchers have reported that using air increases the cooling rate of solar cells [7, 8]. Initially, research by Mazon-Hernandez *et al*. [9] has shown that forced air convection can significantly enhance electricity generation by lowering the operating temperatures of the units. Based on this principle of active air cooling, Mojumder *et al*. [10] research explored surfaces equipped with integrated fins to increase the heat transfer area, thereby developing a more efficient air-based PV/T system, resulting in improved thermal and electrical output simultaneously. More recently, the work of da Silva *et al*. [11] showed that the coil design made of sheets and tubes with a bending diameter of 85 mm is the most efficient and practical for large-scale photovoltaic power plants. Idoko *et al*. [12] study applied a multi-idea cooling method: rear-aspect conductive cooling through an aluminum heat sink and natural air convection. This method correctly decreased the module surface temperature to 20 °C and increased the power output by 20.96 W and the thermal performance by 49.56%.

Building on the topic of active air cooling, the configuration of the cooling system itself is a critical factor. Therefore, Wu *et al*. [13] presented a numerical investigation of air-cooled solar PV/T, comparing thermal and electrical performance with the cooling channel located either above or below the PV panel. They showed that the position of the cooling channel affects the internal distribution of radiative heat transfer and the flow characteristics. They pointed out that although the configuration with the channel below the panel offers superior cooling of the cells, the configuration with the channel above may yield higher overall energy efficiency, highlighting a key design trade-off. Elmenshawy *et al*. [14, 15] extensively investigated the active geothermal cooling approach, the use of a buried floor-to-air warmness exchanger to pre-cool the ambient air before circulating it in the back of the PV panel. Their experimental consequences continuously confirmed the high effectiveness of this technique in warm climates, decreasing panel temperatures by up to 16 °C and enhancing electrical efficiency by up to 29% compared to uncooled panels. Research in this place has highlighted the use of attached fins and heat sinks. On passive fin cooling, Elbreki *et al*. [16] researchers proposed a hybrid system combining *lapping fins* with a planar reflector. Using CFD and experimental validation, they optimized fin parameters, including top, pitch, and range, resulting in a net gain in power performance despite the increased thermal load.

Research related to the cooling of PV cells shows a clear advancement in the development of technologies and performance. Elbreki *et al*. [17] established the high potential of optimized passive fin heat sinks, with lapping fins reducing temperature by 24.6 °C. Building on this, Hernandez-Perez *et al*. [18] and AlAmri *et al*. [19] advanced fin design through segmentation and analytical modeling, demonstrating improved cooling and economic viability even in harsh climates.

Other research focuses on modifying existing components for passive cooling. Al-Amri *et al*. [20] innovated a dual-function racking structure, where the support purlins were thermally connected to the panel to act as a heat sink, offering a simple and cost-effective passive cooling solution. In contrast, Praveenkumar *et al*. [21] found that active thermoelectric cooling could reduce PV temperature by 12.2 °C, boosting electrical efficiency by 5.1%. Hudisteanu *et al*. [22] used a CFD model to reveal that passive cooling with perforated heat sinks is highly dependent on air direction, with optimized designs increasing power output by up to 7.7%. In active systems, Manasrah *et al*. [23] an algorithm is developed for PV panel cooling by adaptive fan control. They found over 97% accuracy while efficiently adapting to environmental changes. Hussien *et al*. [24] active air-cooling methods were compared experimentally and through CFD. They found that distributed rear fans were more effective than a single central

fan, reducing the temperature by 9.9 °C and improving electrical efficiency by 2.1%. Ataman and Arslanoglu [25] showed that wind direction and speed critically affect rooftop PV cooling. Side winds at higher speeds (Δ1 m/s) provided up to 7 °C cooling. Mahdi *et al*. [26] used CFD to model a semi-active ground-source cooling system. Air cooled by underground pipes reduced PV temperature by 28% and increased power by 6.5%. Selimefendigil *et al*. [27] modeled an advanced active system combining thermoelectric generators (TEG) and multiple slot jet impingement. The system achieved a temperature drop of 69.55 °C. Aktas *et al*. [28] developed PV/T collectors with smart air-flow control, they found electrical (17.62%) and thermal (76.75%) efficiency. Hamed *et al*. [29] validated a passive, moisture-driven approach using silica gel and heat sinks, which improved power by 29.8%. Al Hasan *et al*. [30] optimized passive air-cooling by finned heat sinks (FHS), identifying an 11-fin design as optimal. Yang *et al*. [31] investigated dew-point evaporative cooling to enhance PV panels. Bashir and Ali [32] optimized passive-fin heat radiators, finding that rectangular pin-fins were the most effective. Hamida *et al*. [33] also optimized active cooling for PV/T, identifying a 60° barrier angle for thermal efficiency of 53.15% and electrical efficiency of ~16.9%. Abdul Mohsen *et al*. [34] experimentally compared active methods; the water jacket finished better, lowering the temperature by 30°C and increasing production by 9.8%.

Abdel-Aziz *et al*. [35] enhanced PV/T efficiency by a passive air-gap cooling technique, improving thermal and electrical output. Cornago *et al*. [36] modeled a BAPV-T system with ventilated channels, using an optimized control strategy to increase net energy gain, reducing operating temperatures. The experimental comparison by Farzan *et al*. [37] they directly contrasted TEC with the simpler, passive FHS, finding comparable electrical efficiency but superior cost-effectiveness for FHS.

### *The SWOT analysis: air-based cooling for photovoltaic cells*

This SWOT analysis in fig. 3 effectively outlines the critical aspects of the air-based cooling method system. The strengths highlight their structural simplicity, low cost, and operational safety, important factors that enhance reliability and are easy to apply. The weaknesses accurately emphasize inherent thermophysical limitations of air, which restrict thermal efficiency and make system performance sensitive to the environment. The opportunities section reflects a strong improvement through hybridization with passive or PCM technologies, with current research trends in energy efficiency and thermal management. Finally, the threats part realistically note the growing competition from water cooling technologies and scalability issues, which means the need for innovation to maintain competitiveness in high performance applications.

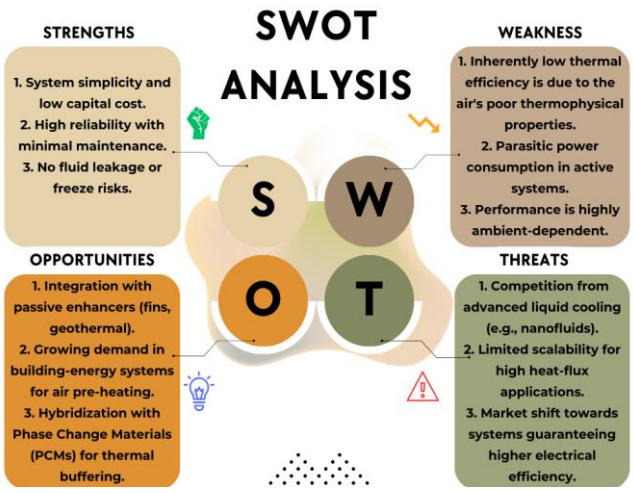


**Figure 3. The SWOT analysis of air-based cooling systems for photovoltaic cells**

### *Water-based cooling for photovoltaic cells*

A big portion of solar energy is transformed into heat, mainly to multiply cellular temperatures and a consequent lowering in electrical power output. To mitigate this strength loss, water-based cooling has emerged as a realistic and effective thermal control strategy. This method leverages the high thermal capacity of water to actively extract waste heat from the PV modules. By keeping a decreased operating temperature, the electric performance of the PV is greater. Furthermore, this method may be incorporated into hybrid PV/T systems, which simultaneously generate energy and usable thermal energy, thereby enhancing the general electricity yield and economic viability of the solar conversion gadget [38]. This development of studies explores a spectrum of PV cooling solutions: from the simplicity of passive wick Chandrasekar *et al* [39] to the higher performance of active heat exchangers Bahaidarah *et al*. [40] Elnozahy *et al*. [41] developed an automated cooling/cleaning system to boost efficiency in hot climates. Irwana *et al*. [42] experimentally validated front-side water cooling. Ali *et al*. [43] introduced advanced micro-channel cooling for maximum efficiency.

Mathias [44] demonstrated that water cooling at the front surface is a feasible approach, they showed that a flow charge of 2 Lpm presents a great balance, lowering the panel temperature from 70-50 °C, and reaching a net performance increase of 16.66%. Based on the principle of lively warmth extraction, Colt [45] investigated cooling the rear surface using an aluminum heat exchanger. This approach achieved a further 32% temperature reduction (from 50-34 °C), resulting in a significant 57% increase in electrical power. Peng *et al*. [46] experimentally demonstrated that cooling a PV panel with ice reduced its surface temperature, resulting in a 47% increase in electrical efficiency. They proposed a residential cooling system using water channels, projecting a 35% annual electrical efficiency gain and a reduction in cost payback time from 15-12.1 years when combined with hot water recovery.

Some studies together illustrate the evolution of photovoltaic cooling research from a basic numerical verification of a new passive device by Alizadeh *et al*. [47]. To the practical implementation and economic optimization of an active system for existing realistic infrastructure based on Castanheira *et al*. [48], and to the advanced thermodynamic analysis of an unconventional integrated hybrid system aiming to maximize total energy utilization designed by Wu *et al*. [49]. To further optimize the system design for practical applications, Saada *et al*. [50] studied a closed-loop cooling system. Their numerical model for a hot climate showed that a low flow rate of 50 g/s could homogenize the panel temperature and maintain it at 34.9 °C, preventing it from reaching 87.24 °C, providing a maximum efficiency improvement of 25%. Research on PV cooling has evolved from single-function methods to multi-functional systems. Gomaa *et al*. [51] demonstrated that active water-cooling and passive fin-cooling significantly reduce PV module temperature and boost energy output. Advanced this concept, Hu *et al*. [52] developed a hybrid photovoltaic-photothermic-radiative cooling system that generates electricity and heat during the day and provides cooling at night, enabling 24 hour energy harvesting and improved overall efficiency.

Kianifard *et al*. [53] designed a novel PV/T system using a half-pipe absorber, improving thermal and electrical efficiency by reducing thermal resistance. Osma-Pinto and Ordonez-Plata [54] developed a dynamic thermal model to accurately predict PV panel temperature during intermittent water cooling, enabling better system simulation. Guo *et al*. [55] created an integrated system combining PV/T collectors with ground-source pre-cooling and desiccant cooling, achieving high performance with low temperature heat. Lubon *et al*. [56] experimentally demonstrated that a continuous water film on the front surface significantly increases

power output (up to 22%) by maintaining a lower module temperature. Maleki *et al*. [57] conducted a comprehensive numerical analysis, revealing that cooling by meandering channels on the panel's rear is particularly advantageous under high solar irradiance and ambient temperature, with electrical efficiency enhancements of up to 17.12%. Complementing this theoretical work, Taqwa *et al*. [58] implemented an experimental, automated cooling system that used a thermostat to trigger water flow only when necessary. For high-stress environments, Atwan *et al*. [59] implemented active geothermal cooling, showing that circulating well water could recover over 85% of power losses in hot climates.

Shen *et al*. [60] found that the optimized parallel channel design (Type I, 10 subchannels, diameter ratio 4) maximized heat transfer and minimized pressure drop. Wang *et al*. [61] used an integrated waste heat system for desalination, cooling the PV cells to increase power by 8% and producing fresh water without any fluid discharge Gomaa *et al*. [62] conducted a CFD study. The study showed that a 15 mm thick cross-finned cooling box, with a flow rate of 3 Lpm, optimally reduced the PV temperature to 30.8 °C. Shalaby *et al*. [63] enhanced electrical efficiency from 17.4%-19.8% with a simple backwater cooling system, resulting in a 14.1% power gain. Shalaby *et al*. [64] experimentally validated that direct back surface cooling with $H_2O$/CuO nanofluid enhances electrical efficiency.

Building on this, Yildirim *et al*. [65] numerically designed a high performance PV/T system, achieving superior combined efficiency through an innovative multi-channel cooling box, highlighting the potential for simultaneous electrical and thermal energy harvest. Recent studies consistently demonstrate the efficacy of active cooling in enhancing PV performance. Abdullah *et al*. [66] achieved an 11.69% electrical efficiency in a PV/T rombe wall using combined air-water cooling. Mahmood and Aljubury [67] reported 11.2% efficiency gain via evaporative cooling, reducing panel temperature by ~20 °C. Bhat *et al*. [68] confirmed a 9.35% efficiency improvement using front water cooling, validated through MATLAB modeling. Collectively, these findings establish water-based cooling as a superior method for mitigating PV efficiency losses under high temperature operations. Initial studies, such as that by Ahmed *et al*. [69], established foundational benefits of active water cooling and quantified severe efficiency losses from dust deposition in tropical climates. Ohnus *et al*. [70] demonstrated the viability of using water cooled PV/T units to power an entire desiccant air-conditioning system, achieving seasonal energy self-sufficiency.

Terashima *et al*. [71] developed a compact, high-efficiency panel using a CIS module and an integrated decompression-boiling collector, achieving superior combined efficiencies while minimizing environmental heat rejection. Further integrating multiple enhancement strategies, Kabeel *et al*. [72] combined active bi-fluid cooling with a self-cleaning concave cover and reflectors, significantly boosting both electrical and overall energy performance in arid environments. Panda *et al*. [73] established the efficacy of a basic passive system using water-retaining dry grass, reporting a 47% electrical efficiency increase. Advancing passive design, Kaneesamkandi *et al*. [74] engineered a heat pipe thermosiphon, achieving a 10 °C temperature drop and providing a validated predictive model for such systems. Finally, Kaplanis *et al*. [75] quantified the inherent advantages of floating PV, developing a model that attributes a 4%-11.5% efficiency gain to the combined effects of elevated humidity and evaporative cooling from seawater. Mansour *et al*. [76] showed that evaporative cooling with concentrators boosts power increment by 1.7 times in winter. Kabakus *et al*. [77] introduced electrospray cooling, achieving a 56.6% power increase with minimal water consumption (80 ml per hours), highlighting a leap in resource-efficient thermal control, while Bhatnagar *et al*. [78] achieved a 12.7 °C temperature drop using gravity-fed *V*-channels, enhancing both electrical and exergy

efficiency. Concurrently, advanced active cooling methods focus on efficiency. Research into active water-cooling for photovoltaics demonstrates its efficacy in reversing efficiency losses from overheating. Building on this, more recently, Amr *et al*. [79] supplied a direct comparison of evaporative methods: water misting and a continuous water movie. Their paintings confirmed the superiority of the nozzle-based movie approach and crucially established that intermittent cooling ought to attain similar performance gains while lowering water consumption by 50%.

Concurrently, Shaban *et al*. [80] optimized the system's techno-economics, finding that the cooling rate remains constant once the panel is fully wetted. They concluded that a minimal flow rate of 1.25 Lpm is optimal, as higher rates do not yield faster cooling, thereby maximizing energy gain and economic viability. Zureigat and Qawasmeh [81] pioneered a passive cooling system using a copper heat exchanger with forced water circulation, establishing a foundation for simple and effective thermal management. Satpute *et al*. [82] advanced this field by optimizing thermal absorber geometry, demonstrating through CFD and experiments that a spiral rectangular design significantly outperforms traditional circular absorbers.

*The SWOT analysis: water-based cooling for photovoltaic cells*

This SWOT analysis in fig.4 is a general, concise overview of water-based cooling systems. The strengths part are their superior cooling efficiency and the resulting enhancement in electrical power output, which means that it is highly effective for cogeneration applications. The weaknesses reveal practical challenges, including structural complexity, additional power requirements, and an opportunity for leakage or corrosion, all of which can raise maintenance requirements. The opportunities emphasize the suitability of these systems for deployment in hot regions, and there can be improvement through integration with other technologies or the inclusion of things such as nanofluids. Conversely, the threats identify key limitations related to high initial costs, water scarcity, and frost issues in cold environments, which may restrict large-scale or all-season adoption.

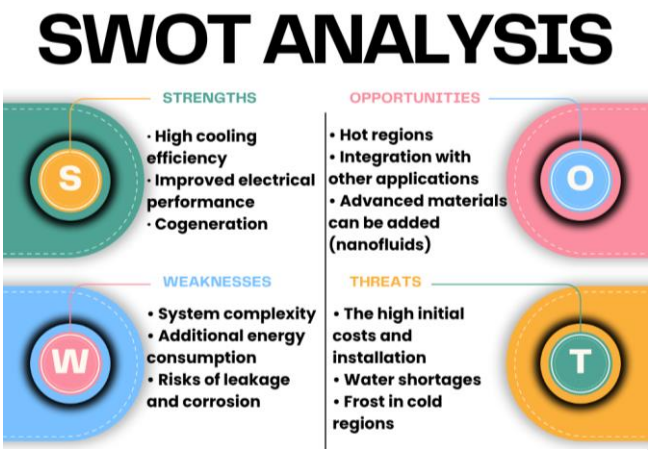


**Figure 4. The SWOT analysis of water-based cooling systems for photovoltaic cells**

### *Coating-based cooling for photovoltaic cells*

A novel approach has been found to utilize passive radiative cooling for commercial photovoltaic modules using polyethylene terephthalate (PET) and polydimethylsiloxane (PDMS) polymer coatings, focusing specifically on hot and humid climates such as Jeddah, Saudi Arabia. The researchers identified 200 μm as the optimal coating thickness for both PDMS and PET. At this thickness, the coatings achieve an excellent balance: they enhance the

transmission of useful solar radiation (0.3-1.1 μm) to the solar cell while maximizing the thermal emissivity in the main atmospheric windows (8-13 μm and 16-22 μm). Specifically, as compared to an uncoated glass cover, the PDMS and PET coatings increased the surface emissivity of those windows by 7.5%-8.32% and 3.43%-8.52%, respectively. Parametric analysis revealed vital insights into how environmental factors, which include sun radiation, wind velocity, and relative humidity, affect cooling overall performance. In immediate comparison, PDMS constantly completed slightly higher than PET, albeit by a small margin. They additionally mounted a performance benchmark to compare the use of a "best" coating against which practical polymers have been compared [83].

### *Comparative analysis of PV/T heat pump system configurations for heating and cooling applications*

Ammar *et al*. [84] and Fan *et al*. [85] present two innovative but distinct pathways for PV/T heat pump integration. Fan *et al*. [85] developed a system optimized for cooling, where the PV/T acts as an enhanced condenser, excelling particularly at night. In contrast, Ammar *et al*. [84] developed a system for heating, where the PV/T acts as an efficient evaporator, performing best under high solar irradiance. Their common findings powerfully validate that PV/T heat pump systems, regardless of configuration, successfully enhance PV electrical output through active cooling and can achieve high overall performance coefficients. The choice between these configurations ultimately depends on the primary application, cooling or heating, and the specific climatic conditions in which the system is intended to operate.

### *Eco-friendly passive cooling solutions for enhanced photovoltaic performance*

A study used passive cooling techniques to improve the performance of a 50 W polycrystalline PV module under tropical climatic conditions. The study focused on temperature regulation and power optimization using sustainable methods, including vegetative cooling, copra, greenhouse shading with netting, combined methods, and PCM. Module temperature, output voltage, current, and power were systematically measured and compared to a baseline uncooled module. Coir cooling was the highest power improvement, achieving an 11.34% increase in output power compared to the uncooled module. Plant cooling provided a significant 7.34% power improvement and reduced module temperature by 6.3 °C, delivering balanced performance. Although cooling the greenhouse grid resulted in the largest temperature drop of 14 °C, it caused a sharp decrease in energy production of 66.88% due to the significant blockage of solar radiation. The PCM cooling technique showed energy improvement of only 1.49%, indicating the limited effectiveness of the material used in this study. The important findings reveal that the decrease in temperature is not closely related to energy gains. Underscoring the importance of choosing cooling strategies that optimize thermal and electrical performance [86].

### *Comparative analysis of nanofluid-based photovoltaic cooling strategies*

The distinct strategic approaches to PV cooling using nanofluids, Abed *et al*. [87] investigated experimentally a hybrid PV/Trombe wall system. Their research on a glass cover enhances thermal energy output for heating, but at the cost of reduced electrical efficiency due to higher PV temperatures. Using a low-concentration $Al_2O_3$ nanofluid helped optimize the overall energy balance. Al Aboushi *et al*. [88] studied a passive cooling solution experimentally

by attaching a finned radiator coated with $TiO_2$ nanofluid. This low-complexity approach achieved modest but valuable efficiency gains without requiring pumps or external power. Ebaid *et al*. [89] focused on high performance active cooling, directly comparing nanofluids. They conclusively experimentally showed that $Fe_3O_4$ nanofluid, with its superior thermal conductivity, provided the highest electrical power and efficiency enhancement, establishing a performance benchmark for active cooling systems.

### *Hybrid of advanced thermal management techniques for photovoltaic efficiency enhancement*

The pursuit of higher PV efficiency has led to extensive research into thermal management. Khan *et al*. [90] tested reflectors and cooling. Al-foil + water sprinkling is best, boosting power by 22.75%-38.55%. While Rajput and Yang[91] compared passive cooling. Water PV/T collectors beat pin-fin heat sink (41.5% *vs*. 30% heat flux gain). Abdollahi *et al*. [92] used a hybrid PV-cooling tower. Evaporative cooling increased in electrical efficiency by 44.83% (no wind). Research into diverse cooling strategies reveals several advanced solutions. Lebbi *et al*. [93] developed a high-efficiency hybrid PV/T system that uses air and water for active cooling while simultaneously cleaning the panel surface. Fabbri and Greppi [94] designed an innovative system that integrates a TEG into a heat exchanger, uniquely enabling it to generate surplus electricity from waste heat.

Dewi *et al*. [95] demonstrated that in tropical climates, active water-cooling yields higher power, while passive heat sinks offer a better efficiency-complexity trade-off. Mahmood and Aljubury [67] demonstrated that a hybrid PV/evaporative cooling system, using a cellulose pad, simultaneously boosts electrical output and provides conditioned air, with performance improving with pad thickness and water flow. Advancing further, Aydin *et al*. [96] combined passive fins with active $Al_2O_3$-water nanofluid cooling. Their *collective cooling* approach found an optimal nanoparticle concentration of 0.4%, beyond which performance diminished due to increased viscosity, yet it significantly outperformed water cooling alone. Building nano-enhancement, Kazem *et al*. [97] implemented a dual-nanomaterial system using both nano-PCM (SiC-paraffin) and a SiC-water nanofluid energy co-generation, representing the leading edge for enhancing PV performance and energy yield.

Building on the theme of passive cooling, Hamed *et al*. [98] numerically investigated a hybrid system using a silica gel layer for simultaneous PV/T regulation and atmospheric water harvesting. This approach eliminated the need for an external water supply, leveraging desorption cooling to reduce cell temperature and enhance electrical output, while also producing harvestable water.

### *Phase change material cooling method*

Research on PV passive cooling using PCM. Nehari *et al*. [99] systematically demonstrated that system inclination below 45° maximizes cooling by enhancing natural convection. Sellami *et al*. [100] further refined this by proving that advanced numerical models accounting for fluid-flow are crucial for accurately predicting enhanced thermal performance due to this convention. Kawtharani *et al*. [101] provided fundamental experimental and numerical proof, demonstrating that a simple organic PCM (decanoic acid) can achieve significant immediate energy savings.

Hasbou *et al*.[102] determined an optimal PCM thickness and demonstrated that PCM matrix absorbers can effectively reduce peak temperatures, with a subsequent numerical model predicting even greater performance gains. Meanwhile, Sopian *et al*.[103] studied advanced

active hybrid systems through nanotechnologies. Their work on grid-tie solar PV systems showed that the single use of nanofluids improved the performance, however, maximum electrical and thermal energy efficiencies were achieved when both nano-PCM and nanofluidic cooling were employed together, leading to an unprecedented level of thermal management. Bayrak *et al*.[104] compared three distinct passive cooling methods: aluminum fins, PCM, and thermoelectric modules. Their work highlighted the importance of choosing the right PCM, as an incorrectly selected PCM (with a melting point higher than the panel's operating temperature) can act as an insulator and reduce performance. Of the methods tested, the PV+Fin3 system proved to be the most effective and cost-effective, yielding the highest power output and energy efficiency. Abdollahi and Rahimi [105] studied combining natural water circulation with nanotechnology-enhanced PCM. The researchers used composite oil (coconut and sunflower oils) as a PCM additive, further enhancing this system by adding boehmite nanoparticles to increase thermal conductivity. This highlights the significant potential of nanofluids in the thermal management of PV systems. Studies on PCM-integrated PV cooling show an evolution from structural improvements to material and climate optimization. Abdullah and Rahimi [106] presented an active hybrid cooling system combining PCM and nanofluids, achieving a 58.8% increase in electrical power. Sadeghian *et al*. [107] parametrically demonstrated that internal fins (ribs) significantly enhance performance, especially with low-melting-point PCM, by increasing the heat transfer area and delaying complete melting.

## Conclusions

The following are the conclusions from this review study.

- Heat regulation is important for the highest PV/T efficiency, and it works directly counter in opposition to maximum overall performance losses from high operating temperatures.
- There is not any unmarried advanced cooling technique, as the whole thing relies on application, local weather, and energy demand profile; consequently, the choice thereof strongly depends on the context.
- The hybrid cooling systems, in which a few methods are combined synergistically, have invariably shown more potential to enhance electrical and thermal energy yield compared to any single method.
- In general, active cooling achieves higher performances and bears an economic cost for parasitic energy consumption. Properly designed passive systems are generally associated with a good cost/benefit ratio, and they can be considered as a reliable per zero-energy source.
- Advanced materials like nanofluids and nano-enhanced PCM will represent a promising frontier in view of the much-needed enhancement both in the heat transfer efficiency and thermal storage capability of photo-thermal conversion systems.
- Further development should be directed at the most promising intelligent, climate-adaptive cooling methods, which will be able to provide a dynamic response to changing environmental conditions and will emphasize long-term reliability, economic viability, and environmental acceptability necessary for wider proliferation.

## References

[1] Satpute, J., Rajan, J., Analysis of Energy, Exergy, Environmental, and Economics (4E) on Photovoltaic-Thermal Collector System, *Thermal Science, 26* (2022), 5B, pp. 4233-4247
[2] Shakir, A., *et al*., Numerical Investigation for Y-Shaped Twisted Inserts with Trapezoidal Perforations in Heat Exchangers, *Heat Transfer, 54* (2025), 8, pp. 5219-5237

[3] Mohammed, A., *et al*., A Review on the Effect of Y-Shaped Twisted Tape on Heat Exchanger Performance, *Al-Nahrain Journal for Engineering Sciences, 28* (2025), 1, pp. 138-151
[4] Abbas, M., Geothermal Energy Development in Türkiye: A Review, *Al-Nahrain Journal for Engineering Sciences, 27* (2024), 2, pp. 207-255
[5] Mohammed, A., *et al*., Study of Prototypes for Biofuel Production Extraction from Biodegradation in Oxygen-Free Environments Processing Wastewater, *Solar Energy and Sustainable Development, 14* (2025), 1, pp. 522-539
[6] Abed, R., *et al*., Experimentally and Numerically Investigation of the Effect of Cuo:$Cr_2O_3$ Nanoparticles in a Carbon Ash Coating on Flat Plate Col-lectors, Enhancing the Absorption of Solar Energy Collection, *International Journal of Thermal Sciences, 220* (2026), 110347
[7] Zhang, R., *et al*., Numerical Model and Efficiency Analysis of Finned Staggered Solar PV/T Air Collector, *Thermal Science, 28* (2024), 1B, pp. 941-960
[8] Alshibil, A., *et al*., Evaluation of Fin Configurations for an Air-Cooled Hybrid Photovoltaic-Thermal Solar Collector, *Thermal Science, 28* (2024), 1A, pp. 39-49
[9] Mazon-Hernandez, R., *et al*., Improving the Electrical Parameters of a Photovoltaic Panel by Means of an Induced or Forced Air Stream, *International Journal of Photoenergy, 2013* (2013), 830968
[10] Mojumder, J., *et al*., An Experimental Investigation on Performance Analysis of Air Type Photovoltaic Thermal Collector System Integrated with Cooling Fins Design, *Energy Build, 130* (2016), Oct., pp. 272-285
[11] Da Silva, V., *et al*., Development of a Real-Scale Cooling Module for A PV Power Plant, *IET Renewable Power Generation, 12* (2018) , 4, pp. 450-455
[12] Idoko, L., *et al*., Enhancing PV Modules Efficiency and Power Output Using Multi-Concept Cooling Technique, *Energy Reports, 4* (2018), Nov., pp. 357-369
[13] Wu, S., *et al*., Effect of Cooling Channel Position on Heat Transfer Characteristics and Thermoelectric Performance of Air-Cooled PV/T System, *Solar Energy, 180* (2019), Mar., pp. 489-500
[14] Elminshawy, N., *et al*., Performance of PV Panel Coupled with Geothermal Air Cooling System Subjected to Hot Climatic, *Applied Thermal Engi-neering, 148* (2019), Feb., pp. 1-9
[15] Elminshawy, N., *et al*., The Performance of a Buried Heat Exchanger System for PV Panel Cooling Under Elevated Air Temperatures, *Geothermics, 82* (2019), Nov., pp. 7-15
[16] Elbreki A., *et al*., An Innovative Technique of Passive Cooling PV Module Using Lapping Fins and Planner Reflector, *Case Studies in Thermal Engineering, 19* (2020), 100607
[17] Elbreki A., *et al*., Experimental and Economic Analysis of Passive Cooling PV Module Using Fins and Planar Reflector, *Case Studies in Thermal Engi-neering, 23* (2021), 100801
[18] Hernandez-Perez, J., *et al*., Thermal Performance of a Discontinu-ous Finned Heatsink Profile For PV Passive Cooling, *Applied Thermal Engineering, 184* (2021), 116238
[19] AlAmri, F., *et al*., Analytical Modeling and Optimization of a Heat Sink Design for Passive Cooling of Solar PV Panel, *Sustainability, 13* (2021), 6, 3490
[20] Al-Amri, F., *et al*., Novel Dual-Function Racking Structure for Passive Cooling of Solar PV Panels – Thermal Performance Analysis, *Renewable En-ergy, 198* (2022), Oct., pp. 100-113
[21] Praveenkumar S., *et al*., Experimental Assessment of Thermoelectric Cooling on the Efficiency of PV Module, *International Journal of Renewable Energy Research, 12* (2022), 3, pp. 1670-1681
[22] Hudișteanu S., *et al*., Effect of Wind Direction and Velocity on PV Panels Cooling with Perforated Heat Sinks, *Applied Sciences, 12* (2022), 19, 9665
[23] Manasrah, A. *et al*., Investigation of a Real-Time Dynamic Model for a PV Cooling System, *Energies, 15* (2022), 5, 1836
[24] Hussien, A., *et al*., Experimental and Numerical Investigation for PV Cooling by Forced Convection, *Alexandria Engineering Journal, 64* (2023), Feb., pp. 427-440
[25] Ataman, A., Arslanoglu, N., Investigation of the Cooling Effect of Wind on Rooftop PV Power Plants, *Case Studies in Thermal Engineering, 63* (2024), 105295
[26] Mahdi, E., *et al*., Photovoltaic Panel Cooling Using Ground Source Energy: CFD Simulation, *Results in Engineering, 22* (2024), 102144
[27] Selimefendigil, F., *et al*., Three Dimensional Numerical Study of PV Module Cooling by Using Thermoelectric Effects and Nano-Enhanced Confined Multiple Slot Jet Impingement, *International Journal of Heat and Mass Transfer, 221* (2024), 125093
[28] Aktas, A., *et al*., Numerical and Experimental Investigation of a Single-Body PVT Using a Variable Air Volume Control Algorithm, *Energy, 307* (2024), 132793

[29] Hamed, M., *et al*., Performance Comparative Study on Passively Cooled Concentrated Photovoltaic (PV) Using Adsorption/Desorption and Heat Sink Cooling Methods: Experimental Investigations, *Energy, 307* (2024), 132700
[30] Al Hasan, A., *et al*., A Computational Analysis of Air-Cooled Heat Sinks Designs for PV Solar Panel Cooling With Different Fin Numbers, *Heat Transfer, 54* (2025), 2, pp. 1462-1475
[31] Yang, C., *et al*., Dew-Point Evaporative Cooling of PV Panels for Improved Performance, *Applied Thermal Engineering, 236* (2024), 121695
[32] Bashir, M., Ali, H., *et al*., Numerical Investigation of Passive Cooling of the PV Module Using Extended Fin Heat Sinks: A Parametric Analysis, *Process Safety and Environmental Protection, 195* (2025), 106749
[33] Hamida, M., *et al*., Optimizing Baffle Plate Inclination in PV Cooling Systems for Maximum Heat Dissipation, *Applied Thermal Engineering, 278* (2025), 127387
[34] Abdelmohsen, H., *et al*., Enhancing PV Performance Using a Novel Water Jacket and Humidified Air-Cooling Systems in Arid Climates, *Applied Thermal Engineering, 278* (2025), 127259
[35] Abdel-Aziz, M., *et al*., Enhancing PV/T Thermal Efficiency via Passive Air-Gap Cooling with Stagnant Water Heat Sink, *Heat Transfer, 54* (2025), 7, pp. 4650-4667
[36] Cornago, I., *et al*., New Approach of PV and Thermal Modeling to Develop Feasible Cooling Solutions for PV in Buildings, *EPJ Photovoltaics, 16* (2025), 19
[37] Farzan, H., *et al*., Comparative Study on Electrical Performance of Photovoltaic Panels Integrated with Thermoelectric Coolers and Finned Heat Sinks: An Experimental Study, International Journal of Engineering, *Transactions B: Applications, 39* (2026), 4, pp. 925-935
[38] Alous, S., *et al*., Experimental Study about Utilization of MWCNTS and Graphene Nanoplatelets Water-Based Nanofluids in Flat Non-Concentrating PVT Systems, *Thermal Science, 25* (2021), 1B, pp. 477-489
[39] Chandrasekar, M., *et al*., Passive Cooling of Standalone Flat PV Module with Cotton Wick Structures, *Energy Conversion and Management, 71* (2013), July, pp. 43-50
[40] Bahaidarah, H., *et al*., Performance Evaluation of a PV (Photovoltaic) Module by Back Surface Water Cooling for Hot Climatic Conditions, *Energy, 59* (2013), Sept., pp. 445-453
[41] Elnozahy, A., *et al*., Performance of a PV Module Integrated with Standalone Building in Hot Arid Areas as Enhanced by Surface Cooling and Cleaning, *Energy and Buildings, 88* (2015), Feb., pp. 100-109
[42] Irwan, Y., *et al*., Indoor Test Performance of PV Panel Through Water Cooling Method, *Energy Procedia, 79* (2015), Nov., pp. 604-611
[43] Ali, M., *et al*., Performance Enhancement of PV Cells Through Micro-Channel Cooling, *AIMS Energy, 3* (2015), 4, pp. 699-710
[44] Matias, C., Electrical Performance Evaluation of PV Panel through Water Cooling Technique, *Proceedings*, IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, Italy, 2016, pp. 1-5
[45] Colt, G., Performance Evaluation of a PV Panel by Rear Surface Water Active Cooling, *Proceedings*, Int. Conference on Applied and Theoretical Electricity (ICATE), Craiova, Romania, 2016, pp. 1-5
[46] Peng, Z., *et al*., Cooled Solar PV Panels for Output Energy Efficiency Optimization, *Energy Conversion and Management, 150* (2017), Oct., pp. 949-955
[47] Alizadeh, H., *et al*., Numerical Simulation of PV Cooling by Using Single Turn Pulsating Heat Pipe, *International Journal of Heat and Mass Transfer, 127* (2018), Part A, pp. 203-208
[48] Castanheira, A., *et al*., Demonstration Project of a Cooling System for Existing PV Power Plants in Portugal, *Applied Energy, 211* (2018), Feb., pp. 1297-1307
[49] Wu, S., *et al*., Heat Transfer Characteristics and Performance Evaluation of Water-Cooled PV/T System with Cooling Channel above PV Panel, *Renewable Energy, 125* (2018), Sept., pp. 936-946
[50] Saada, S., Preliminary Study of a Water Cooled PV System, *Proceedings*, International Conference on Communications and Electrical Engineering, El Oued, Algeria, 2018
[51] Gomaa, M., *et al*., Performance Enhancement of Grid-Tied PV System Through Proposed Design Cooling Techniques: An Experimental Study and Comparative Analysis, *Solar Energy, 211* (2020), Nov., pp. 1110-1127
[52] Hu, M., *et al*., Performance Assessment of a Trifunctional System Integrating Solar PV, Solar Thermal, and Radiative Sky Cooling, *Applied Energy, 260* (2020), 114167
[53] Kianifard, S., *et al*., Modeling, Designing and Fabrication of a Novel PV/T Cooling System Using Half Pipe, *Journal of Cleaner Production, 253* (2020), 119972

[54] Osma-Pinto, G., Ordonez-Plata, G., Dynamic Thermal Modelling for the Prediction of the Operating Temperature of a PV Panel with an Integrated Cooling System, *Renewable Energy, 152* (2020), June, pp. 1041-1054
[55] Guo, J., *et al*., A Novel Solar Cooling Cycle – A Ground Coupled PV/T Desiccant Cooling (GPVTDC) System with Low Heat Source Temperatures, *Renewable Energy, 162* (2020), Dec., pp. 1273-1284
[56] Lubon, W., *et al*., Assessing the Impact of Water Cooling on PV Modules Efficiency, *Energies, 13* (2020), 10, 2414
[57] Maleki, A., *et al*., Energy and Exergy Analysis of a PV Module Cooled by an Active Cooling Approach, *Journal of Thermal Analysis and Calorimetry, 141* (2020), 6, pp. 2475–2485
[58] Taqwa., A., *et al*., Automatic Cooling of a PV System to Overcome Overheated PV Surface in Palembang, *Proceedings*, 3rd Forum in Research, Science, and Technology (FIRST 2019) International Conference, South Sumatera, Indonesia, 2020
[59] Atwan, A., *et al*., Improvement the PV Solar Module Cooling Systems by Using Shallow Geothermal, *AIP Conference Proceedings, 2290* (2020), 1, 012014
[60] Shen, C., *et al*., Numerical Study on the Thermal Performance of Photovoltaic Thermal (PV/T) Collector with Different Parallel Cooling Channels, *Sustainable Energy Technologies and Assessments, 45* (2021), 101101
[61] Wang, W., *et al*., Integrated Solar-Driven PV Cooling and Sea-Water Desalination with Zero Liquid Discharge, *Joule, 5* (2021), 7, pp. 1873-1887
[62] Gomaa, M., *et al*., Temperature Distribution Modeling of PV and Cooling Water PV/T Collectors through Thin and Thick Cooling Cross-Fined Channel Box, *Energy Reports, 8* (2022), Suppl. 1, pp. 1144-1153
[63] Shalaby, S., *et al*., Experimental Study on the Performance of PV with Water Cooling, *Energy Reports, 8* (2022), Suppl. 1, pp. 957-961
[64] Shalaby, S., *et al*., Development of an Efficient Nano-Fluid Cooling/Preheating System for PV-RO Water Desalination Pilot Plant, *Energy Conversion and Management, 268* (2022), 115960
[65] Yildirim, M., *et al*., A Cooling Design for Photovoltaic Panels – Water-Based PV/T System, *Energy, 256* (2022), 12465
[66] Abdullah, A., *et al*., Effect of Cooling Method on The Performance of PV/Trombe Wall: Experimental Assessment, *Thermal Science and Engineering Progress, 30* (2022), 101273
[67] Mahmood, D., Aljubury, I., Experimental Investigation of a Hybrid Photovoltaic Evaporative Cooling (PV/EC) System Performance Under Arid Conditions, *Results in Engineering, 15* (2022), 100618
[68] Bhat, P., *et al*., Experimental Investigation and Validation of Solar PV Cooling for Enhanced Energy Conversion Efficiency for Indian Climatic Conditions, *Journal of Thermal Engineering, 8* (2022), 6, pp. 711-718
[69] Ahmed, M., *et al*., Experimental Investigation of Cooling, Wind Velocity, and Dust Deposition Effects on Solar PV Performance in a Tropical Climate in Bangladesh, *Case Studies in Thermal Engineering, 50* (2023), 103409
[70] Olmus, U., *et al*., Seasonal Analysis of a Desiccant Air-Conditioning System Supported by Water-Cooled PV/T Units, *Energy and Buildings, 291* (2023), 113101
[71] Terashima, K., *et al*., PV/T Solar Panel for Supplying Residential Demands of Heating/Cooling and Hot Water with a Lower Environmental Thermal Load, *Energy and Buildings, 297* (2023), 113408
[72] Kabeel, A., *et al*., Experimental Study on Energy and Exergy Assessments of a New PV System with a Concave Cover for Active Cooling and Self-Cleaning, *Renewable Energy Focus , 47* (2023), 100512
[73] Panda, B., *et al*., Energy & Exergy Analysis of a PV Panel with Passive Cooling Mechanism, Suranaree *Journal of Science and Technology, 30* (2023), 6, 010260
[74] Kaneesamkandi, Z., *et al*., Passive Cooling of PV Modules Using Heat Pipe Thermosiphon with Acetone: Experimental and Theoretical Study, *Applied Sciences, 13* (2023), 3, 1457
[75] Kaplanis, S., *et al*., PV Temperature Prediction Incorporating the Effect of Humidity and Cooling Due to Seawater Flow and Evaporation on Modules Simulating Floating PV Conditions, *Energies, 16* (2023), 12, 4756
[76] Mansour, M., *et al*., Enhancement of PV and Concentered PV Panels Using Evaporative Cooling During Summer and Winter Seasons: A Case Study in Egypt, *Case Studies in Thermal Engineering, 63* (2024), 105354
[77] Kabakus, A., *et al*., A New Approach to Cooling Photovoltaic Panels: Electrospray Cooling, *Case Studies in Thermal Engineering, 64* (2024), 105545

[78] Bhatnagar, A., *et al*., Innovative Cooling for PV Panels: Energy and Exergy Assessments of Water-Induced V-Shaped Channels, *Results in Engineering, 24* (2024), 103100
[79] Amr, A., *et al*., Theoretical-Experimental Investigation of Performance Enhancement of a PV System Using Evaporative Cooling, *International Journal of Emerging Electric Power Systems, 26* (2025), 5
[80] Shaaban, A., *et al*., Techno-Economic PV Evaluation Depending on Surface Water Cooling, *Polityka Energetyczna, 27* (2024), 3, pp. 53-70
[81] Zureigat, H., Qawasmeh, B., Enhancing the Productivity of PV Module Using Cooling Method: Experimental and Simulation Investigation in Jordan, *Solar Energy, 287* (2025), 113238
[82] Satpute, J., *et al*., Parametric Influence and Efficiency Assessment of Water-Cooled Photovoltaic Thermal PV/T Absorber Designs, *Energy, 320* (2025), 135218
[83] Alshammari, A., *et al*., Polymeric Coatings for Passive Radiative Cooling of PV Modules in Hot and Humid Weather: Design, Optimization, and Performance Evaluation, *Case Studies in Thermal Engineering, 57* (2024), 104341
[84] Ammar, A., *et al*., Performance Study on Photovoltaic/Thermal Solar-Assisted Heat Pump System, *Journal of Thermal Analysis and Calorimetry, 136* (2019), 1, pp. 79-87
[85] Fan, M., *et al*., Simulation of Air-Cooled PV/T Air Conditioning System for Cooling and Power Cogeneration, *Applied Thermal Engineering, 224* (2023), 119971
[86] Ramkiran, B., *et al*., Sustainable Passive Cooling Strategy for PV Module: A Comparative Analysis, *Case Studies in Thermal Engineering, 27* (2021), 101317
[87] Abed, A., *et al*., Influence of Glass Cover on the Characteristics of PV/Trombe Wall with BI-Fluid Cooling, *Case Studies in Thermal Engineering, 27* (2021), 101273
[88] Al Aboushi, A., *et al*., Finned PV Natural Cooling Using Water-Based $TiO_2$ Nanofluid, *Sustainability, 14* (2022), 20, 12987
[89] Ebaid, M., *et al*., Exploring Cooling of PV Panels Based on Metallic and Nonmetallic Nanofluids: An Experimental Study, *Advances in Mechanical Engineering, 16* (2024), 1
[90] Khan, M., *et al*., Performance Evaluation of Photovoltaic Solar System with Different Cooling Methods and a Bi-Reflector PV System (BRPVS): An Experimental Study and Comparative Analysis, *Energies, 10* (2017), 6, 826
[91] Rajput, U., Yang, J., Comparison of Heat Sink and Water Type PV/T Collector for Polycrystalline Photovoltaic Panel Cooling, *Renewable Energy, 116* (2018), Part A, pp. 479-491
[92] Abdollahi, N., *et al*., Heat Transfer Enhancement in a Hybrid PV Cell-Cooling Tower, *Heat and Mass Transfer, 55* (2019), Feb., pp. 2355-2363
[93] Lebbi, M., *et al*., Energy Performance Improvement of a New Hybrid PV/T Bi-Fluid System Using Active Cooling and Self-Cleaning: Experimental Study, *Applied Thermal Engineering, 182* (2021), 116033
[94] Fabbri, G., Greppi, M., Numerical Modeling of a New Integrated PV-TE Cooling System and Support, *Results in Engineering, 11* (2021), 100240
[95] Dewi, T., *et al*., Active and Passive Cooling Comparison of PV Panels Applied in Tropical City: Case Study Palembang, South Sumatra, *Proceedings*, IOP Conference Series: Earth and Environmental Science, 7th International Conference on Sustainable Agriculture, Food and Energy, Phuket, Thailand. 2021, 709
[96] Aydın, A., *et al*., Determination of the Performance Improvement of a PV/T Hybrid System with a Novel Inner Plate-Finned Collective Cooling with $Al_2O_3$ Nanofluid, Energy Sources, Part A: Recovery, *Utilization and Environmental Effects, 44* (2022), 4, pp. 9663-9681
[97] Kazem, H., *et al*., Design and Experimental Evaluation of a PV/T System Cooled by Advanced Methods, *International Journal of Energy Research, 46* (2022), 7, pp. 9684-9709
[98] Hamed, M., *et al*., PV Thermal Regulation and Water Harvesting Hybrid System Using Evaporative Cooling of Silica Gel Layer, *Process Safety and Environmental Protection, 181* (2024), Jan., pp. 243-265
[99] Nehari, T., *et al*., The Effect of Inclination on the Passive Cooling of the Solar PV Panel By Using Phase Change Material, *International Journal of Renewable Energy Research, 6* (2016), 1, pp. 1445-1452
[100] Sellami, A., *et al*., Temperature Regulation of PV Solar Cell Under PCM Cooling System, *Proceedings*, International Renewable and Sustainable Energy Conference (IRSEC), Marrakech, Morocco, 2016
[101] Kawtharani, F., *et al*., Cooling PV Modules Using Phase Change Material, *Proceedings*, 29th International Conference on Microelectronics (ICM), Beirut, Lebanon, 2017
[102] Hassabou, A., *et al*., Passive Cooling of Photovoltaic Modules in Qatar by Utilizing PCM-Matrix Absorbers, *Proceedings*, ISES Solar World Congress 2019 and IEA SHC International Conference on Solar Heating and Cooling for Buildings and Industry 2019, Santiago, Chile, 2019, pp. 795-803

[103] Sopian, K., *et al*., Thermodynamic Analysis of New Concepts for Enhancing Cooling of PV Panels for Grid-Connected PV Systems, *Journal of Thermal Analysis and Calorimetry, 136* (2019), 1, pp. 147-157
[104] Bayrak, F., *et al*., Experimental Study for the Application of Different Cooling Techniques in Photovoltaic (PV) Panels, *Energy Conversion and Management, 212* (2020), 112789
[105] Abdollahi, N., Rahimi, M., Potential of Water Natural Circulation Coupled with Nano-Enhanced PCM for PV Module Cooling, *Renewable Energy, 147* (2020), Part 1, pp. 302-309
[106] Abdollahi, N., Rahimi, M., Heat Transfer Enhancement in a Hybrid PV/PCM Based Cooling Tower Using Boehmite Nanofluid, *Heat and Mass Transfer, 56* (2020), Oct., pp. 859-869
[107] Sadeghian, A., *et al*., Effects of Rib on Cooling Performance of Photovoltaic Modules (PV/PCM-Rib), *Journal of Central South University, 28* (2021), 11, pp. 3449-3465

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