ISSN 2347 - 3983
Volume 9. No. 6, June 2021
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter07962021.pdf
https://doi.org/10.30534/ijeter/2021/07962021

Temperature on PV Module Performance and its Latest Mitigation Techniques: A Review

Mohsin Ali Koondhar[1], Muhammad Ismail Jamali[1], Imtiaz Ali Laghari[2], Abdul Khalique Junejo[1], Masood Rehman[1]

[1]Department of Electrical Engineering, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah, Sindh, Pakistan. [1]engr.mohsinkoondhar@quest.edu.pk, [1]engrimsail@quest.edu.pk, [1]ak.junejo@quest.edu.pk, [1]masood.rehman@hotmail.com

[2] Department of Electrical Engineering, Quaid-e-Awam University of Engineering, Science and Technology, Campus Larkana, Sindh, Pakistan. [2]laghari.imtiaz@quest.edu.pk

ABSTRACT

Photovoltaic modules (PVM) output power is sensitive to fluctuations in temperature and the concentration of solar insolation during sustained disclosure. The 20% of solar insolation will be converted into useful electrical energy, while the rest will be dissipated in the form of heat, which in rotate will increase the operating heat of the PVM and it negatively affects the open circuit voltage (Voc), resulting in a decrease in the power alteration productivity and an irreversible rate of cell deprivation. Appropriate cooling techniques are therefore crucial to preserve the operating temperature of the module under standard test conditions (STC). There are two different methods for cooling PVMs, namely active and passive these methods are subdivided into different techniques which are discussed one by one in literature review; in this paper the techniques for cooling PVMs are comprehensively reviewed.

Key words: PV module, temperature effect, cooling techniques, efficiency enhancing

1. INTRODUCTION

Most of the world's electricity consumption comes from fossil or nuclear fuels, which pollute too much and damage the environment. At the same time, the sun provides a huge quantity of energy in the usage of solar insolation, wind power and biomass. It is promising to be the main source of electricity as a renewable and sustainable energy. This energy could be obtained in two forms, thermal energy and electrical energy. The most valuable type of energy is the electric type because it is easy to transmit and convert into work. In addition, photovoltaic cells are the most efficient method of generating electrical energy directly from solar radiation. However, PV cells have a conversion efficiency of between 5 and 20%. This conversion rate is much higher than the ratio of wind and biomass technology. However, it decreases considerably as the surface temperature increases in the range of 0.45 to 0.5% / ° C for each degree Celsius [1-3], depending on the material used in PV fabrication. It has been found that the high operating temperature shortens the life of the photovoltaic module. Some cooling mechanisms have already been suggested [4-8].

The performance of PVM will decrease with increasing temperature. As a result, due to different or actual weather conditions, numerous panels will not work properly under perfect circumtances. Because photovoltaic modules are more efficient at lower temperatures, photovoltaic systems must be designed with active and passive cooling (PC) functions [9-12]. Extracting heat from water is more expensive than extracting heat from air, but in the above cases, since the water temperature in the grid is below 20°C for most of the year, it is considered feasible in practice. The most common type of PV water cooling is circulating by a heat transfer, which is in thermal touch with the back of the PVM to keep away from stress and electrical issues [13].

A right tendency between yield and heat can be observed without active cooling (AC), the heat of the module will be very high, and the efficiency of the Solar cell (SC) will only reach 8 to 9 pc. Though, while the device is operated under active chill conditions, the heat will drop expressively, thereby increasing the efficiency of the SC from 12% to 14% [14].

Various cooling methods have been studied to dissipate the heat produced by the PVM, thereby reducing its temperature. The temperature control of PVM can be categorized according to two techniques, passive method and the active method. For active cooling, other apparatuses (pumps / fans) need to be used to circulate the coolant. The main problems associated with this method are its applicability and economy [15, 16]. Recently, many researchers have studied the following active cooling methods, such as: geothermal heat exchanger [17-19], pulse heat pipe [20, 21], water cooling [22-24] and water cooling. Airflow [25-28]. Despite a significant reduction in the operating temperature of the module, the total initial investment cost remains significant. Different researchers have been working on a PC method. This technique is created on the standard of natural convection using the ambient air flow to decrease the heat of the PVM. The PCMs are extra smart because they do not require further mechanical power. Presently, the succeeding PCMs have been studied, such as: P.C.M [29-36], passive laminar flow heat sink [37-42] and radiant cooling [43-46].Understanding the advanced cooling techniques mentioned above is critical to improving electrical performance efficiency. Numerous researchers have showed in-depth analyses of different cooling methods attentions only on passive cooling approaches [47, 48].

The outcomes expression that the PC system lowers the temperature of the cells on the day it is designed and raises the electrical efficiency (EE) of the photovoltaic module by 8.3%. The return age for this system is 14 years [49].

2. RELATED WORK

In order to control issue of high heat on PVMs, the two cooling approaches are applied to reduce the PVM surface temperatures, thereby enhancing their efficiency , the two technique of cooling is applied namely Active cooling and passive cooling [21, 50].

2.1 Figures and Tables Active Cooling Techniques (ACT)

The ACT used in the PVM requires a method to increase the coolant flow rate to rise the heat transfer rate (HTR) from the PVM to the cooling medium. The motor is used to increase the cooling water flow of the AWC technology, and the fan is used to increase the air flow of the active air cooling (AAC) technology. In [51], the author studied the increase in EE and energy efficiency of photovoltaic modules obtained in active cooling technology, reaching 12.17% and 12.26%, respectively. In [52], the author studied the impact of water-cooling technology on photovoltaic panels through experiments. They found that the power generation and EE of the cooling technology increased by 16.3% and 14.1%, respectively. In [53], the author uses water spray technology to cool the front of the photovoltaic module. This leads to the fact that the performance of PV modules can be improved by using cooling water spray technology. In [54], the author conducted an experimental study on the behavior of PV/T hybrid power through hydrothermal cooling technology. The results illustrate that the cooling technology increases the EE and performance of photovoltaic modules by 37.5% and 30%, respectively.

In [14], the author revealed that for active cooling of PV cells, a parallel arrangement of ducts with inlet / outlet elbows was attached to the rear of the PV module for uniform distribution of air flow. . Experiments were carried out with and without active cooling. A proportional movement between EE and Heat are determined. Without AC, the PVM heat was high and the SCs can be gained only an EE of 8 to 9 percent (pc). Though, while the PVM was functioning under AC conditions, the heat decreases significantly, effecting the SC efficiency to increase between 12-14pc. A heat removal simulation model was prepared to equate with the actual heat curve of the PVM, and upright match was gained between the simulation and practical results.

An attempt to provide active cooling was discussed in [35, 55]. A tube used as a spiral exchanger was placed on the device. The results illustrated that the efficiency of the device was increased by 13% with this cooling method. In [56], an effort was made to cool photovoltaic modules by spraying water. Also try to determine the time required to decrease the temperature of the device to 35°C. The results show that when cooling starts at 450°C, the power output of the device is higher. Later, [57] tried to achieve 9% efficiency. In this research, an ac system is applied in which a heat exchanger is fixed on the back of PVM, which reduce the temperature significantly.

In [58], the focus is on the use of active water cooling (AWC) on the CPV system. The results show that when device heat drops under 60°C, the output power will increase. In order to overcome the challenges caused by the overheating of PV modules, various other efforts are being made. In order to use solar energy more effectively, an experiment was designed and implemented in [59], in which the energy obtained from a small amount of water used for cooling is directed to the other end. To avoid waste, it is usually more efficient than conventional arrangements.

Active cooling techniques have classifies as follows.

2.1.1 Air Cooling

2.1.1.1 Heat Sink (HS)

The device or an object which transfer temperature from device by thermal exchange is called HS. The heat is consumed in air, the induced draft air column or by the chill. The thermal good conductors are used in HS such as copper and aluminum alloys. The front of the HS should be plane and flat to decrease resistance heat with the device to be chill. Crosswise, V-shaped, arc model irregularity are used to increase the transfer thermal coefficient, because the chilling rate could be high [60-62]. Use shaped aluminum fins (L) and glue them to the backside of the PVM using the thermal conductive gum as illustrated in figure 1.

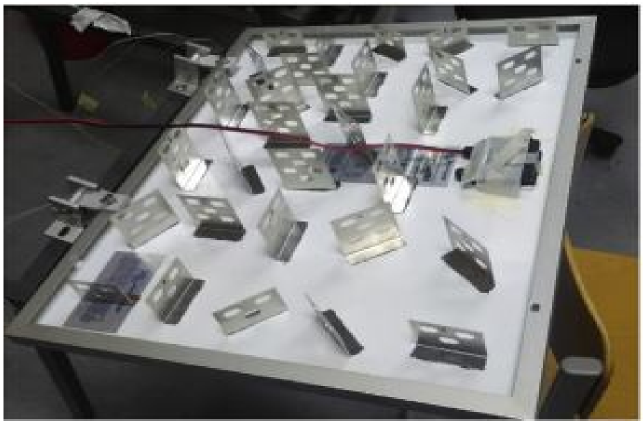

Figure 1: Backside of PV panel [63]

2.1.2 Water Cooling

The photoelectric water pump system is specially built for outdoor testing under various environmental circumstances. The key apparatuses of the system are shown in Figure 2.

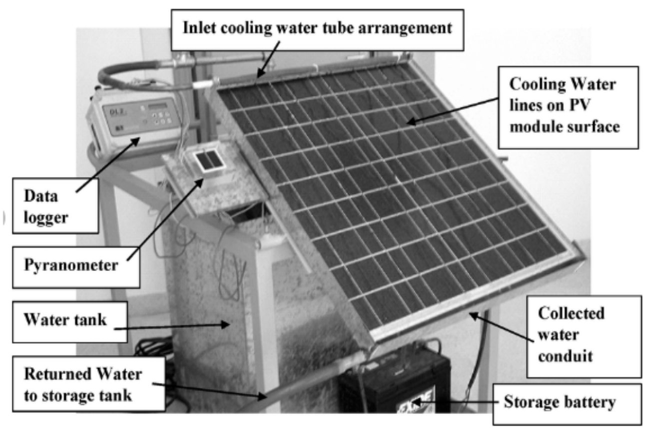

Figure 2: PV water cooling test rig

- Polycrystalline photovoltaic modules with a maximum power of 60 watts. The unit is jointed to a rehostate resistor to determine the I-V features of model.
- The solar protection sensor regulates the flow of voltage and current from the PV to the storage bank and then to the load.
- 12v DC motor submersible pump, approximate flow. 5 liters per minute, and the pumping height is 50 meter. The motor is injected into the water tank, which is irrigation well.
- A 12V battery to route the water motor by adjusting the internal cooling system and measuring the water flow.
- Cooling water drop configuration, including a distilled water pipe, D = 2.5 cm, L = 65 cm, connected to the top edge of the PVM, and a water pipe (L = 65 cm) located at the lower edge of the device, as well as pumping cooling water from the submersible pump Side channel. The dropper has 32 holes with a diameter of 5mm, which are evenly distributed.
- A thermometer installed on the PV front area to measure the input of solar insolation.
- Photovoltaic surface heat measurement arrangement.
- Entire system is collected on the installed front surface to analysis the performance of the system under dissimilar insolation circumstances [64-66].

2.1.2.1 Water Spray

In [52, 53], a water spray cooling method applied directly on the surface of the PVM was investigated and a significant improvement in EE was found. In [57], a method of cooling surface water for hot climatic conditions was investigated, in which an increase in EE of about 9% was recorded. Further, in [67, 58, 56, 4] alternative cooling techniques which contain water as a coolant have been investigated, in which the average increase in power output was between 10% and 20 % depending on the specific cooling technique used.

2.1.2.2 Heat Exchange

Heat exchanger technology is one of many popular cooling methods. Use heat exchanger technology to transfer heat from one liquid to another, or transfer one liquid to another. Get maximum efficiency at high temperatures. The best coolant flow rate can be obtained through CFD study to complete the highest efficiency. Microchannel cooling may be a possible way to improve the operation of photovoltaic cells inside their extreme capacity. Micropipes can also be used as hybrid systems for PV Thermal (PVT) System.

Aluminum fins can be used with wind current to maintain PV cell. Expanding pilot facilities and producing microchannels as competently as conceivable is the biggest contest in microchannel development. Table 1 summarizes various studies on microchannels [67, 68]. Active cooling techniques have been presented in table 2.

2.2 Passive Cooling Techniques (PCT)

This section reviews the latest survey on PCT. The key purpose is to briefly summarize useful information for further improvement. A thorough survey of the latest PCT of photovoltaic modules is vital for subsequent modification of existing PVM to improve electrical output efficiency [77].

2.2.1 Phase Change Material

Although this cannot be considered cooling in the strict sense, it does mean that the same temperature is maintained. It can still be considered a passive technique, mainly because no extra work is required to consume heat it is primarily dissipated in a conductive manner [78]. In [79-81], the authors illustrates that with the category of PCM, a decline of 15 ° C compared to the reference PV cell can be obtained over 5 hours with solar radiation of 1000 W / m2. PVM rated at 65W with 50mm PCM on the back and vertical aluminum fins were used to improve conduction.

Table 1: Cooling Techniques of Microchannel

Authors	Main Outcomes	Temperature Cell	Cooling mediator	Cooling System Types	Electrical performance
[69]	For simulation chaotic mixing theory has been applied	Improved heat transfer performance	Nano-liquid s	Micro conduit Heat sink with V-ribs	**N/A**
[70]	A congested ratio of h/H ¼ appears to supply overall best performance.	To decrease heating effect 6 ^{0}C on PV by increasing the channel height up to 20 mm.	Air	Micro channel with three-sided ribs	Efficiency of Electrical residues b/w 10 to 11.25%
[71]	Flow rate of 3 L/m. Accord noticed between experiment and CFD	Module temperature drop of 15 ^{0}C	Water	Micro channeled plate	14% improved Power

Table 2: Summary of Active cooling techniques

Authors	Cooling Methods	PV Technology	Efficiency Improvement	Economic aspect
[72]	Water	Si-poly (20W)	12% to 14.3%	N/A
[73]	Nanofluids (PV/T)	Si-mono (40W)	19.5%	N/A
[74]	PCM/water	Si-poly (40W)	1.3%	N/A
[75]	Air	Si-poly (240-280W)	6.3%	Yes
[14]	Air (PV/T)	Si-poly (50W)	50% to 55.5%	N/A
[76]	Water (PV/T)	Si-mono (n/a)	−10% to −23%	N/A
[58]	Water (CPV)	Si-mono (n/a)	−22%	N/A

2.2.2 Heat Pipe cooling (HPC)

HPC is considered a promising cooling technology [82-86]. In addition, there is a large thermal contact resistance between a conventional columnar heat pipe and a flat solar panel, resulting in poor heat transfer efficiency. The new network of micro-heat pipes proposed by the authors in [87-88] has good contact with the solar panel due to its flat shape. The heat pipe has higher heat transfer efficiency and even temperature distribution, which can solve the problem of cooling solar panels.

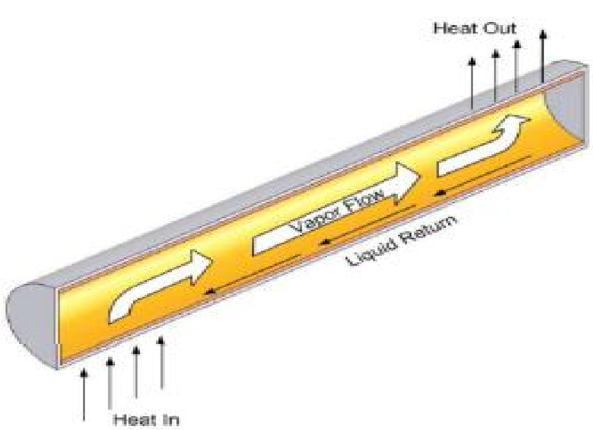

Figure 3: Heat pipe mechanisms [89]

2.2.3 Radioactive cooling (RC)

RC is constructed on an atmospheric window with high transparency in the wavelength range of 8-14 µm [90]. In [91], the author examined the HCM with PV and nocturnal radiant cooling. The main body consists of a transparent low density polyethylene shield, PVM, insulating factual and 6 copper tubes welded to the back of the PVM. The use of the TPT transparent layer has shown encouraging impacts due to its high heat emit and excellent insulating materials. The stipulated average energy effectiveness on clear days is about 14.9%, which is lower than in the morning and afternoon, and the net radiant cooling capacity is 72.94 W/m2. This situation shows the negative impact of increasing the operating heat of SCs. It has been create that the concert of radiant cooling depends to a large extent on the humidity in a particular location. The different passive cooling techniques illustrate in Table 3.

Table 3: Passive Cooling Techniques

Authors	Cooling Methods	PV Technology	Efficiency Improvement	Economic aspect
[29]	PCM (Palm Dirt)	Si-poly (20W)	5.3 %	N/A
[33]	PCM (PEG 1000)	Si-mono (40W)	8.0 %	N/A
[89]	Fin Heat sink (lapping, reflector)	Si-poly (40W)	11.2 %	N/A
[38]	Fin Heat sink (longitudinal)	Si-poly (250W)	5.0 %	Yes
[42]	Fin Heat sink (Perforated-L)	Si-poly (50W)	2.0 %	N/A
[39]	Radiative cooling (TE coupled)	Si-mono (n/a)	4.55 %	N/A
[45]	Radiative cooling (photonic)	Si-mono (n/a)	4.6 %	N/A

3. CONCLUSION

It is clear from Table one and two that active cooling result showing more efficiency than passive cooling.
It is also concluded that active cooling needed extra power source for cooling purpose but passive cooling is natural so, the major difference between that active cooling is uneconomic than passive cooling.
It reveals that from 50 to 55% efficiency is improved by active cooling techniques and in passive the maximum efficiency is improved 11.2%. So it is noticeably that active cooling by efficiency comparison is most effective than passive cooling. This research paper is very helpful for cooling technique selection and mostly for researchers.
Future recommendation the PV module must be provided cooling for enhancing the performance of PV.

REFERENCES

[1] R. Hussein, & M. H. K. Aboaltabooq, MHK. **Photovoltaic Panel Cooling: A Review of Methodologies and Technologies.** Al-Furat Journal of Innovation in Mechanical and Sustainable Energy Engineering, Vol. 1, no. 1, pp. 55-66, 2021.

[2] A. Siddique, et al. **Statistical Analysis of Renewable Energy Resources of Pakistan,** International Journal of Emerging Trends in Engineering Research, Vol. 9, no. 4, pp. 508-514, 2021.

[3] A. M. Alsayah, M. H. K. Aboaltabooq, M. H. Majeed, & A. A. Al-Najafy, **Multiple modern methods for improving photovoltaic cell efficiency by cooling: A review.** Journal Mech Eng Res Dev., Vol. 42, no. 4, pp. 71-78, 2019.

[4] S. Krauter, **Increased electrical yield via water flow over the front of photovoltaic panels.** Solar energy materials and SCs, Vol. 82, no. 1-2, pp. 131-137, 2004.

[5] A. Royne, C. J. Dey, & D. R. Mills, **Cooling of photovoltaic cells under concentrated illumination: a critical review.** Solar energy materials and SCs, Vol. 86, no. 4, pp. 451-483, 2005.

[6] P. Kumar, A. K. Shukla, K. Sudhakar, & R. Mamat, **Experimental exergy analysis of water-cooled PV module.** International Journal of Exergy, Vol. 23, no.3, pp. 197-209, 2017.

[7] R. Daghigh, M. H. Ruslan, & K. Sopian, **Advances in liquid based photovoltaic/thermal (PV/T) collectors.** Renewable and Sustainable Energy Reviews, Vol. 15, no. 8, pp. 4156-4170, 2011.

[8] M. H. K. Aboaltabooq, et al. **Effect of variable heat input on the heat transfer characteristics in an Organic Rankine Cycle system.** Renewable Energy and Environmental Sustainability, Vol. 1, no. 13, 2016.

[9] H. A. Hussien, A. H. Numan, & A. R. Abdul munem, **Improving of the photovoltaic/thermal system performance using water cooling technique.** In IOP Conference Series: Materials Science and Engineering, Vol. 78, no. 1, p. 012020, 2015.

[10] I. C. H. Cox & P. Raghuraman. **Design considerations for flat plate photovoltaic/thermal collectors.** Solar energy, Vol. 35, no. 3, pp. 227-241, 1985.

[11] L. Fedele, L. Colla, S. Bobbo, S. Barison, & F. Agresti. **Experimental stability analysis of different water-based nanofluids.** NanoSCale research letters, Vol. 6, no. 1, pp. 1-8, 2011.

[12] M. A. Koondhar, M. I. Jamali, A. S. Channa, and I. A. Laghari. **Partial Shading Effect on the Performance of PV Panel and its Different Circuit Topologies Based Mitigation Techniques: A Review.** International Journal of Advanced Research in Engineering and Technology, Vol. 12, no. 4, pp. 15-23, 2021.

[13] N. Rott. **Note on the history of the Reynolds number.** Annual review of fluid mechanics, Vol. 22, no. 1, pp. 1-12, 1990,

[14] T. G. Teo, P. S. Lee, & M. N. A. Hawlader. **An active cooling system for photovoltaic modules.** Applied Eenergy, Vol. 90, no. 1, pp. 309-315, 2012.

[15] E. Z. Ahmad, et al. **Recent advances in passive cooling**

methods for photovoltaic performance enhancement. International Journal of Electrical & Computer Engineering, Vol. 11, no. 1, 2021.

[16] S. Nižetić, E. Giama, & A. M. Papadopoulos. **Comprehensive analysis and general economic-environmental evaluation of cooling techniques for photovoltaic panels, Part II: Active cooling techniques.** Energy Conversion and Management, 155, pp. 301-323, 2018.

[17] A. Ibrahim, S. Mat, A. F. Abdullah, A. Fudholi, & K. Sopian. **Outdoor Performance Evaluation of Building Integrated Photovoltaic Thermal (BIPVT) Solar Collector with Spiral Flow Absorber Configurations.** International Journal of Power Electronics and Drive Systems, Vol. 9, no. 4, p. 1918, 2018.

[18] L. H. Yang, et al. **Enhanced efficiency of photovoltaic panels by integrating a spray cooling system with shallow geothermal energy heat exchanger.** Renewable Energy, 134, pp. 970-981, 2019.

[19] H. Alizadeh, et al. **Numerical simulation of PV cooling by using single turn pulsating heat pipe.** International Journal of Heat and Mass Transfer, 127, pp. 203-208, 2018.

[20] H. Wang, et al. **Thermal characteristic comparison of three-dimensional oscillating heat pipes with/without sintered copper particles inside flat-plate evaporator for concentrating photovoltaic cooling.** Applied Thermal Engineering, 167, p. 114815, 2020.

[21] A. E. Kabeel, M. Abdelgaied, & R. A. Sathyamurthy. C**omprehensive investigation of the optimization cooling technique for improving the performance of PV module with reflectors under Egyptian conditions.** Solar Energy, 186, pp. 257-263, 2019.

[22] F. Spertino, et al. **Thermal–electrical model for energy estimation of water cooled photovoltaic module.** Solar Energy, 133, pp. 119-140, 2016.

[23] S. Y. Wu, C. Chen, & L. Xiao. **Heat transfer characteristics and performance evaluation of water-cooled PV/T system with cooling channel above PV panel.** Renewable Energy, 125, pp. 936-946, 2018.

[24] S. Y. Wu, T. Wang, L. Xiao, & Z. G. Shen. **Effect of cooling channel position on heat transfer characteristics and thermoelectric performance of air-cooled PV/T system.** Solar Energy, 180, pp. 489-500, 2019.

[25] A. Fudholi, et al. **Energy and exergy analysis of air based photovoltaic thermal (PVT) collector: a review.** International Journal of Electrical & Computer Engineering, 2019, 9(1).

[26] Sajjad, U. et al. **Cost effective cooling of photovoltaic modules to improve efficiency.** Case Studies in Thermal Engineering, 14, p. 100420, 2019.

[27] T. Wongwuttanasatian, T. Sarikarin, & A. Suksri. **Performance enhancement of a photovoltaic module by passive cooling using phase change material in a finned container heat sink.** Solar Energy, 195, pp. 47-53, 2020.

[28] N. Choubineh, H. Jannesari, & A. Kasaeian. **Experimental study of the effect of using phase change materials on the performance of an air-cooled photovoltaic system.** Renewable and Sustainable Energy Reviews, 101, pp. 103-111, 2019.

[29] S. A. Nada, D. H. El-Nagar, & H. M. S. Hussein. **Improving the thermal regulation and efficiency enhancement of PCM-Integrated PV modules using nano particles.** Energy conversion and management, 166, pp. 735-743, 2018.

[30] S. Khanna, K. S. Reddy, & T. K. Mallick. **Optimization of finned solar photovoltaic phase change material (finned pv pcm) system.** International Journal of Thermal SCiences, 130, pp. 313-322, 2018.

[31] S. M. Baygi, & S. M. Sadrameli. **Thermal management of photovoltaic SCs using polyethylene glycol 1000 (PEG1000) as a phase change material.** Thermal Science and Engineering Progress, 5, pp. 405-411, 2018.

[32] F. Hachem. **Improving the performance of photovoltaic cells using pure and combined phase change materials–Experiments and transient energy balance.** Renewable Energy, 107, pp. 567-575, 2017.

[33] J. Xie, K. F. Choo, J. Xiang, & H. M. Lee. **Characterization of natural convection in a PCM-based heat sink with novel conductive structures.** International Communications in Heat and Mass Transfer, 108, p. 104306, 2019.

[34] T. Ma, J. Zhao, & J. Han. **A parametric study about the potential to integrate phase change material into photovoltaic panel.** Energy Procedia, 142, pp. 648-654, 2017.

[35] L. Idoko, O. Anaya-Lara, & A. McDonald. **Enhancing PV modules efficiency and power output using multi-concept cooling technique.** Energy Reports, 4, pp. 357-369, 2018.

[36] A. A. R. Amr, A. A. M. Hassan, M. Abdel-Salam, & A. M. El-Sayed. **Enhancement of photovoltaic system performance via passive cooling: Theory versus experiment.** Renewable energy, 140, pp. 88-103, 2019.

[37] Gan, CK. Tan, PH. & Khalid, S. **System performance comparison between crystalline and thin-film technologies under different installation conditions.** In IEEE Conference on Clean Energy and Technology, 2013, 362-367.

[38] I. K. Karathanassis, E. Papanicolaou, V. Belessiotis, & G. C. Bergeles. **Experimental and numerical evaluation of an elongated plate-fin heat sink with three sections of stepwise varying channel width.** International Journal of Heat and Mass Transfer, 84, pp. 16-34, 2015.

[39] F. Selimefendigil, F. Bayrak, & H. F. Oztop. **Experimental analysis and dynamic modeling of a photovoltaic module with porous fins.** Renewable

Energy, 125, pp. 193-205, 2018.

[40] J. G. Hernandez-Perez, JG. Carrillo, A. Bassam, A. M. Flota-Banuelos, & L. D. Patino-Lopez. **A new passive PV heatsink design to reduce efficiency losses: A computational and experimental evaluation.** Renewable Energy, 147, pp. 1209-1220, 2020.

[41] B. Zhao, M. Hu, X. Ao, & G. Pei. **Performance analysis of enhanced radiative cooling of SCs based on a commercial silicon photovoltaic module.** Solar Energy, 176, pp. 248-255, 2018.

[42] H. Li, et al. **Performance analysis of passive cooling for photovoltaic modules and estimation of energy-saving potential.** Solar Energy, 181, pp. 70-82, 2019.

[43] M. Hu, et al. **Field investigation of a hybrid photovoltaic-photothermic-radiative cooling system.** Applied Energy, 231, pp. 288-300, 2018.

[44] A. Shukla, K. Kant,A. Sharma, & P. H. Biwole. **Cooling methodologies of photovoltaic module for enhancing EE: A review.** Solar Energy Materials and SCs, 160, pp. 275-286, 2017.

[45] J. Siecker, K. Kusakana, & B. P. Numbi. **A review of solar photovoltaic systems cooling technologies.** Renewable and Sustainable Energy Reviews, 79, pp. 192-203, 2017.

[46] A. Saleem, et al. **The effect of environmental changes on the efficiency of the PV system.** Indones. J. Electr. Eng. Comput. SCi., Vol. 18, no. 1, pp. 558-564, 2020.

[47] J. Assadeg, K. Sopian, & A. Fudholi. **Performance of grid-connected solar photovoltaic power plants in the Middle East and North Africa.** International Journal of Electrical and Computer Engineering, Vol. 9, no. 5, p. 3375, 2019.

[48] Y. Hishikawa, et al. **Voltage-dependent temperature coefficient of the I–V curves of crystalline silicon photovoltaic modules.** IEEE Journal of photovoltaics, Vol. 8, no. 1, pp. 48-53, 2017.

[49] S. Wu, & C. Xiong. **Passive cooling technology for photovoltaic panels for domestic houses.** International Journal of Low-Carbon Technologies, Vol. 9, no. 2, pp. 118-126, 2014.

[50] S. Jamali, M. Yari, & S. M. S. Mahmoudi. **Enhanced power generation through cooling a semi-transparent PV power plant with a solar chimney.** Energy Conversion and Management, 175, pp. 227-235, 2018.

[51] Zilli, et al. **Performance and effect of water-cooling on a microgeneration system of photovoltaic solar energy in Paraná, Brazil.** Journal of Cleaner Production, 192, pp. 477-485, 2018.

[52] S. Nižetić, et al. **Water spray cooling technique applied on a photovoltaic panel: The performance response.** Energy conversion and management, 108, pp. 287-296, 2016.

[53] M. Abdolzadeh, & M. Ameri. **Improving the effectiveness of a photovoltaic water pumping system by spraying water over the front of photovoltaic cells.** Renewable energy, Vol. 34, no. 1, pp. 91-96, 2009.

[54] D. P. Winston, et al. **Experimental investigation on hybrid PV/T active solar still with effective heating and cover cooling method.** Desalination, 435, pp. 140-151, 2018.

[55] I. Ceylan, A. E. Gürel, H. Demircan, & B. Aksu. **Cooling of a photovoltaic module with temperature controlled solar collector.** Energy and Buildings, 72, pp. 96-101, 2014.

[56] K .A. Moharram, M. S. Abd-Elhady, H. A. Kandil, & H. El-Sherif. **Enhancing the performance of photovoltaic panels by water cooling.** Ain Shams Engineering Journal, Vol. 4, no. 4, pp. 869-877, 2013.

[57] H. Bahaidarah, A. Subhan, P. Gandhidasan, & S. Rehman. **Performance evaluation of a PV (photovoltaic) module by back surface water cooling for hot climatic conditions.** Energy, 59, pp. 445-453, 2013.

[58] B. Du, E. Hu, & M. Kolhe**. Performance analysis of water cooled concentrated photovoltaic (CPV) system.** Renewable and Sustainable Energy Reviews, Vol. 16, no. 9, pp. 6732-6736, 2012.

[59] R. Hosseini, N. Hosseini, & H. Khorasanizadeh. **An experimental study of combining a photovoltaic system with a heating system.** In World Renewable Energy Congress-Sweden; Linköping; Sweden, Linköping University Electronic Press, 057, pp. 2993-3000, 2011.

[60] S. Verma, S. Mohapatra, S. Chowdhury, & G. Dwivedi. C**ooling techniques of the PV module: A review.** Materials Today: Proceedings, 2020.

[61] A. K. Behura, B. N. Prasad, & L. Prasad. **Heat transfer, friction factor and thermal performance of three sides artificially roughened solar air heaters.** Solar Energy, 130, pp. 46-59, 2016.

[62] B. N. Prasad, A. K. Behura, & L. Prasad. **Fluid flow and heat transfer analysis for heat transfer enhancement in three sided artificially roughened solar air heater.** Solar Energy, 105, pp. 27-35, 2014.

[63] F. Grubišić-Čabo, S. Nižetić, D. Čoko, I. M. Kragić, & A. Papadopoulos. **Experimental investigation of the passive cooled free-standing photovoltaic panel with fixed aluminum fins on the backside surface.** Journal of Cleaner Production, 176, pp. 119-129, 2018.

[64] M. Firoozzadeh, A. Shiravi, & M. Shafiee. **An experimental study on cooling the photovoltaic modules by fins to improve power generation: economic assessment.** Iranian (Iranica) Journal of Energy & Environment, Vol. 10, no. 2, pp. 80-84, 2019.

[65] Zubeer, SA. Mohammed, HA. & Ilkan, M. **A review of photovoltaic cells cooling techniques.** In E3S web of conferences EDP Sciences, 2017, 22, 00205.

[66] Odeh, S. & Behnia, M. **Improving photovoltaic module efficiency using water cooling.** Heat Transfer Engineering, 2009, 30(6), 499-505.

[67] M. Fujii, et al. **Improvement of conversion efficiency through water-cooled equipment in photovoltaic system.** Journal of International Council on Electrical Engineering, Vol. 3, no. 1, pp. 97-101, 2013.

[68] P. Dwivedi, K. Sudhakar, A. Soni, E. Solomin, & I. Kirpichnikova. **Advanced cooling techniques of PV modules: A state of art, Case Studies** in Thermal Engineering, 21, p. 100674, 2020.

[69] R. Wang, J. Wang, & W. Yuan. **Analysis and optimization of a microchannel heat sink with V-Ribs using nanofluids for micro SCs.** Micromachines, 620, Vol. 10, no. 9, 2019.

[70] S. Saadi, S. Benissaad, S. Poncet, & Y. Kabar. **Effective cooling of photovoltaic SCs by inserting triangular ribs: a numerical study.** International Journal of Energy and Environmental Engineering, Vol. 12, no. 7, pp. 488-494, 2018.

[71] M. Ali, et al. **Performance enhancement of PV cells through micro-channel cooling.** WEENTECH Proceedings in Energy GCESD, Technology Park, 24, p. 211, 2015.

[72] A. A. Hachicha, C. Ghenai, & A. K. Hamid. **Enhancing the performance of a photovoltaic module using different cooling methods.** Int. J. Energy Power Eng, Vol. 9, no. 9, pp. 1106-1109, 2015.

[73] M. Sardarabadi, M. Passandideh-Fard, & S. Z. Heris. **Experimental investigation of the effects of silica/water nanofluid on PV/T (photovoltaic thermal units).** Energy, 66, pp. 264-272, 2014.

[74] A. Hasan, H. Alnoman, & A. H. Shah. **Energy efficiency enhancement of photovoltaics by phase change materials through thermal energy recovery.** Energies, Vol. 9, no. 10, p. 782, 2016.

[75] R. Mazón-Hernández, et al. **Improving the electrical parameters of a photovoltaic panel by means of an induced or forced air stream.** International Journal of Photoenergy, 2013.

[76] W. He, Y. Zhang, & J. Ji. **Comparative experiment study on photovoltaic and thermal solar system under natural circulation of water.** Applied Thermal Engineering, Vol. 31, no. 16, pp. 3369-3376, 2011.

[77] E. Z. Ahmad, et al. **Recent advances in passive cooling methods for photovoltaic performance enhancement.** International Journal of Electrical & Computer Engineering, Vol. 11, no. 1, 2021.

[78] F. G. Cabo, S. Nizetic, & T. G. Marco. **Photovoltaic panels: a review of the cooling techniques.** Trans FAMENA, Vol. 40, no. S1-1, pp. 63-74, 2016.

[79] A. Hassan. **Phase change materials for thermal regulation of building integrated photovoltaics.** Doctoral Thesis, 2010.

[80] A. K. Pandey, et al. **Energy, exergy, exergoeconomic and enviroeconomic (4-E) assessment of solar water heater with/without phase change material for building and other applications: A comprehensive review.** Sustainable Energy Technologies and Assessments, 45, p. 101139, 2021.

[81] I. A. Laghari, M. Samykano, A. K. Pandey, K. Kadirgama, and V. V. Tyagi. **Advancements in PV-thermal systems with and without phase change materials as a sustainable energy solution: energy, exergy and exergoeconomic (3E) analytic approach.** Sustainable Energy & Fuels, Vol. 4, no. 10, pp. 4956-4987, 2020.

[82] X. Tang, Z. Quan, Y. Zhao. **Experimental Investigation of Solar Panel Cooling by a Novel Micro Heat Pipe Array.** Energy and Power Engineering, 2, pp. 171-174, 2010.

[83] M. A. Farahat. **Improvement the Thermal Electric Performance of a Photovoltaic Cells by Cooling and Concentration Techniques.** In 39th UPEC International, Bristol, 2, pp. 623-628, 2004.

[84] A. Akbarzadeh, T. Wadowski. **Heat Pipe-Based Cooling Systems for Photovoltaic Cells under Concentrated solar Radiation.** Applied Thermal Engineering, Vol. 116, no. 1, pp. 81-87, 1996.

[85] Anderson, W. G. et al. **Heat Pipe Cooling of Concentrating Photovoltaic Cells.** In 33rd IEEE Photovoltaic Specialists Conference, San Diego, pp. 1-6, 2008.

[86] Zhao, Y. H. et al. **A Sort of Micro Heat Pipe Array and Processing Technics.** Chinese Patent: 200810225649.

[87] Zhao, Y. H. et al. **Photovoltaic Cells Radiating Equipment.** Chinese Patent: 200810239002.0.

[88] E. Z. Ahmad, et al. **Recent advances in passive cooling methods for photovoltaic performance enhancement.** International Journal of Electrical & Computer Engineering, Vol. 11, no. 1, pp. 146-154, 2021.

[89] D. Zhao, et al. **Development of a single-phase thermosiphon for cold collection and storage of radiative cooling.** Applied Energy, 205, pp. 1260-1269, 2017.

[90] B. Zhao, et al. **Performance analysis of a hybrid system combining photovoltaic and nighttime radiative cooling.** Applied energy, 252, p. 113432, 2019.

[91] B. Zhao, M. Hu, X. Ao, Q. Xuan, & G. Pei. **Comprehensive photonic approach for diurnal photovoltaic and nocturnal radiative cooling.** Solar Energy Materials and SCs, 178, pp. 266-272, 2018.