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Studying the Effect of Cooling Methods on the Performance of Solar Cells

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ABSTRACT

The effect of photovoltaic cells is due to the photons of light that stimulate electrons to move from a lower energy level to a higher energy level and thus we get an electric current. The current work deals with an experimental study showing the effect of water cooling on the front face of the plate using multiple nozzles (2, 4, 6, and 8) at different angles (0°, 30°, and 60°) and air cooling on the back face. From the PV panel with different flow rates (0.1, 0.2, 0.3, 0.4, 0.5, and 0.6) on the PV panel, you can also find the optimal air flow rate. The results obtained indicated that cooling reduces the average temperature of the panels from 58℃ without cooling to 35℃, and thus the productive capacity of the panels increased from (155 to 205.5 W), with an improvement rate of 24%, thus improving the electrical efficiency from (9.78 to 16.76%) between the cooling and non-cooling processes. The optimum flow rate is (0.25 kg / s), and the optimal number of nozzles is 6 at a spray angle of 30°. The results also showed that the cooling process in water and air is the best in other cases.

1. INTRODUCTION

Panels utilize air energy as energy input and then supply electrical energy to the accompanying demand. Radiation and convection cause a considerable portion of solar energy to be converted to heat and lost to the environment. Terrible electrical efficiency, a material deterioration in PV panels, and a poor economic climate result as result. Therefore, cooling PV panels with the proper cooling method is one way to partially alleviate this issue. This will boost the financial aspects and raise the power output of solar PV systems per square meter of space. There were numerous suggestions made for cooling PV panels. Evaporative cooling, forced air, water, phase change materials (PCM), and ambient air are a few of them. The most basic and affordable method of cooling that doesn't include electricity is to use the natural flow of air, although this method isn't particularly effective due to air's low density, volumetric heat capacity, and thermal conductivity. It is possible to put this strategy into effect by mounting PV panels on the building walls in a way that allows air to flow between the panels and the building walls [1-4] or by using extended metallic surfaces like fins [5-10]. Between 50 and 70℃ are possible for PV panels [11]. Teo et al. [8, 12, 13] conducted an experimental study on forced air ventilation cooling. PV panel efficiency was found to have increased from 8 to 9% to 12 to 14%. The experiment was conducted in Singapore, where the average maximum ambient temperature is only 31℃. For V cooling, many researchers have studied water flow over or below the PV panel. By using water flow over the solar panels, Krauter [14] was able to lower the temperature from 60 to 22℃ while maintaining an electrical output of 8-9%. Additionally, Krauter [15] examined how the PV panels functioned when submerged in water. The temperature of the panels could be kept low ls throughout most of the day. The weight of the solar system, which was 200 kg per module, was a drawback of this method. The current work aims to show how the evaporative cooler's water and air cooling process affects the performance of solar panels, as well as how the number of nozzles and angle of inclination of the water spraying affect those results.

2. EXPERIMENTAL SETUP AND DETAILS

The experimental device consists of a wooden frame in the form of a cuboid box containing two entrance holes in a circular shape, where air passes through air passages that have just been installed under the solar photovoltaic tiles for the experimental setup. The photovoltaic cells are placed on top of the wooden frame, and the specifications of the photovoltaic panels are shown in Table 1 (see Figures 1 and 2).

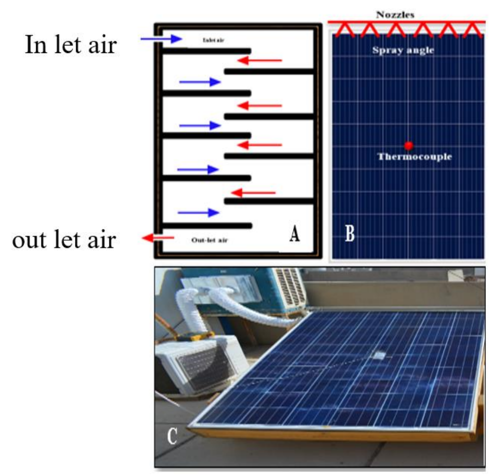

Figure 1. (A) Wooden frame, (B) PV panel, (C) The experimental device with all details

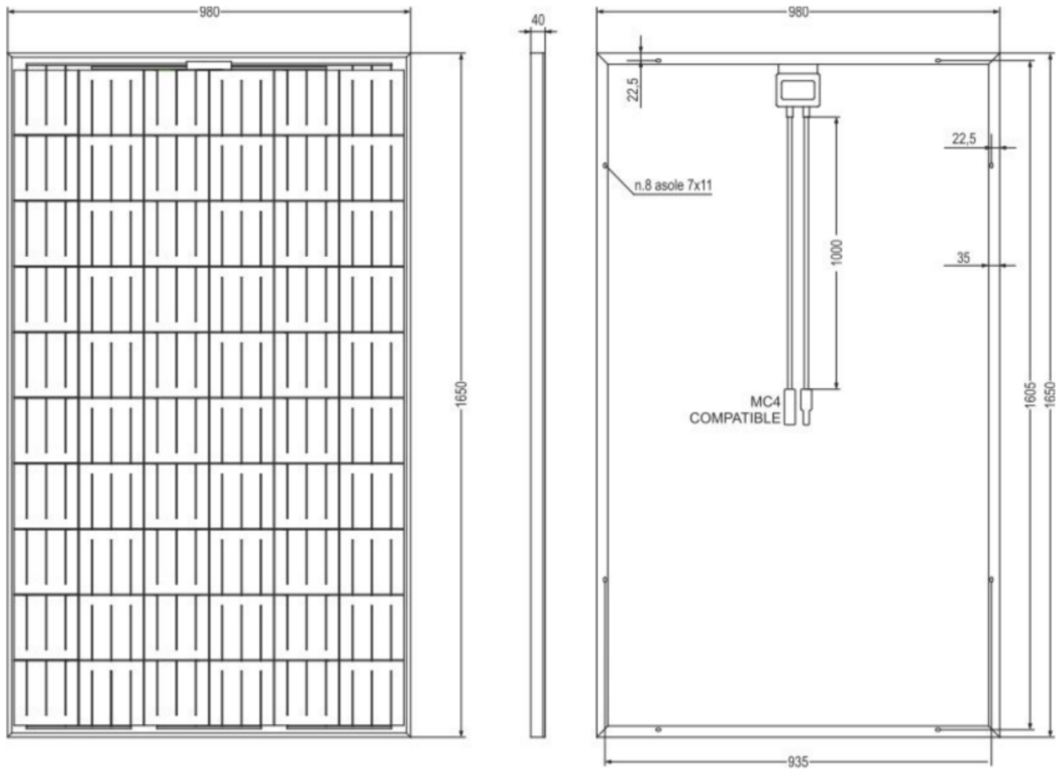

Figure 2. Schematic view of the tested PV module

The front upper surface is cooled by water with multiple nozzles (2, 4, 6, and 8) and at different angles (0, 30, and 60), while the back surface of the panels is cooled by air. An evaporative cooler is used to supply air and cold water to cool the panels that supply the electric power to the cooler. All details of the experimental device are shown in Figures 3 and 4.

Table 1. Properties of PV panel [16]

Parameter	Specification		
Power	250W	Co-eff. Power	-0.4% / ^{0}K
Open circuit	37.74V	Co-eff. Voltage	-0.34% / ^{0}K
Short circuit	8.74A	Co-eff. Current	+0.005% / ^{0}K
voltage maximum	30.5V	Weight	18.0 Kg
Current Maximum	8.2A	Dimension	16.45 x 9.92 x 4.2 cm

Two K-type thermocouples were installed and allocated for air temperature measurements to evaluate the effect of air temperature at the inlet and outlet of the wooden box. It also uses two K-type thermocouples, the first is placed in the upper front of the unit, and another temperature sensor is placed on the back surface of the unit to measure the temperature of the surface below and above the panels. The nozzles illustrated in Figure 2 and created for irrigation purposes are selected and tested among hundreds of sprinklers on the market with the scope of building an effective, lightweight, simple-to-mount, and inexpensive spraying cooling system. The parameter that must be chosen during the trial campaign to differentiate them is the spraying angle. The nozzles are attached to a flexible tube (20 mm in diameter) made specifically for gardening. This type of pipe ensures quick nozzle fixation and orientation, as well as quick installation on the top edge of the module, through the use of clips (see Figures 2 and 3). Clips and flexible tubes also make it possible to significantly lessen the modification of the PV module required for the cooling system installation.

Figure 3. Nozzles angle: (A) Strip, (B) 30°, (C) 90°

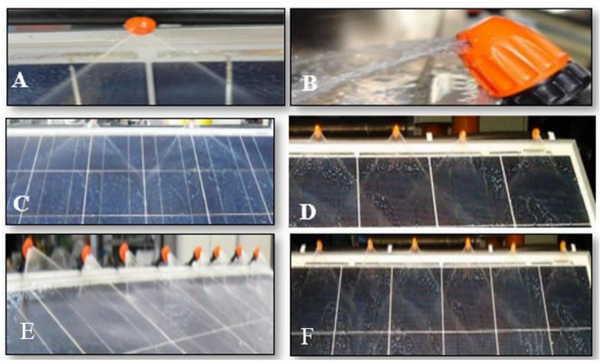

Figure 4. Spring test with: (A) front view, (B) Side view, (C) 2 nozzles, (D) 4 nozzels, (E) 6 nozzels, (F) 8 nozzels

3. MEASURING DEVICES

In the current work, measuring devices such as solar radiation, air velocity, water flow rate, and K-type temperature measuring devices were used. Two of them are placed at the air inlet and outlet, and two others are in the middle of the front and back surfaces of the photovoltaic panels. Table 2 and Figure 5 show the details of each device. The devices used.

Figure 5. Measurement devices

Table 2. Measurement inaccuracy of each piece of equipment (1)

Measuring Name	Measure	Error
Solar power meter	solar irradiation (W/m^2)	±10 (W/m^2)
Flow-meter	Volume flowrate (CPM)	±0.1%
Digital Thermometer	Temperature (°C)	±0.5°C
Anemometer	Air Velocity (m/s)	±0.1%

Table 3 shows the four conditions (No cooling, Air cooling, Water cooling and Air-Water cooling), that use in the present work with the measure quantity such as surface temperature and power. Also, Table 4 shows the four conditions with different values of mass-flow rate that use in the present work for all cases.

Table 3. Conditions with measure quantity

CONDITION	MEASURE QUANTITY
1-No cooling	Front and back surface Temp.(°C). Power(W)
2-Air cooling	Front and back surface Temp.(°C). Power(W)
3-Water cooling	Front and back surface Temp.(°C). Power(W)
4-Air-Water cooling	Front and back surface Temp.(°C). Power(W)

Table 4. Conditions with mass flow rate

CONDITION	Mass flow rate (kg/sec)
1-No cooling	No flow rate.
2-Air cooling	0, 0.1 ,0.2,0.3,0.4,0.5,0.6
3-Water cooling	Spray water 2,4,6,8 nozzle with 3 angle
4-Air-Water cooling	Case 2 and 3 together

4. RESULTS AND DISCUSSION

4.1 Effect cooling on cell temperature

Figure 6 shows how cooling by both water and air affects the cell's surface temperatures throughout the day (front and back). Cell variance the temp. for cooling and non-cooling conditions is displayed and the average temperatures of the cell non-cooling condition for the front and back surface were (58 and 51°C) respectively. Cooling the back side of the board with air reduced the average front and back cell temperature (53 and 42°C) by 9.3% and 21.4%, respectively. In the case 3, it reduced the average temperature of the front and back cells (43 and 46.5°C) by 34.3% and 11%, respectively. Finally, cooling the front surface with water and the back surface with air reduced the average temperature of the front and back cell (39 and 35°C) by 48% and 45.7%, respectively. The max. temperatures (front and back) were found to be 58°C and 51°C at mid time.

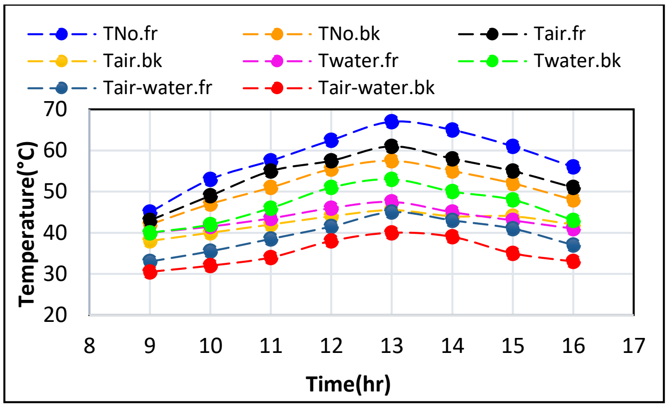

Figure 6. PV temperate at daily time

4.2 Effect cooling on the power

Figure 7 compares the panel's electrical power output for the four situations on the test day. The maximum value of power output of the module was 1555 W at 1 pm whereas the maximum power output with cooling for other cases was (180, 195 and 205.5W), respectively. An improvement of the power output was observed in the cases of cooling shown in Figure 8.

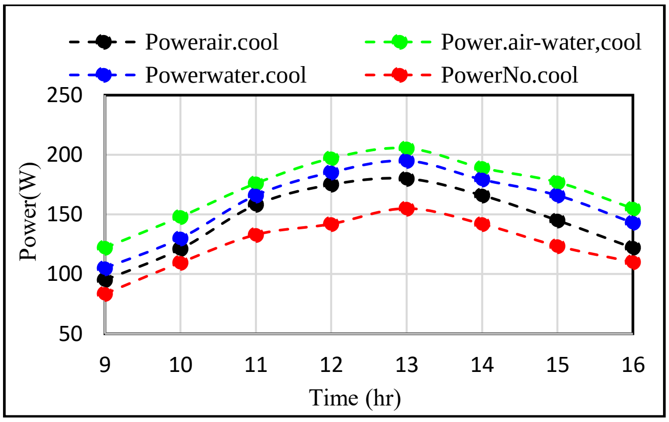

Figure 7. PV temperature at the daily time

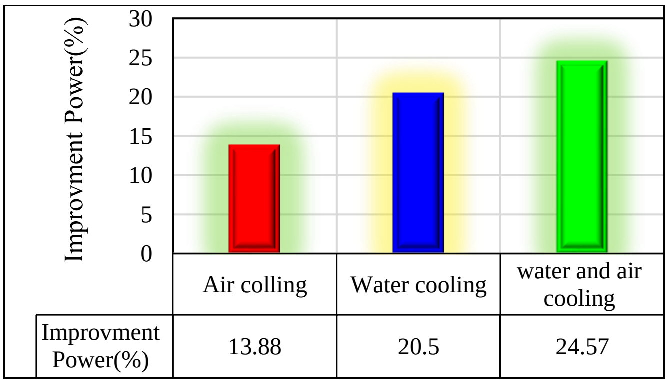

Figure 8. Improvement power at the daily time

4.3 Effect cooling on the efficiency

As seen in Figure 9, the electrical efficiency significantly increases as the temperature drops. Both water cooling and air cooling show a considerable improvement in efficiency. The maximum efficiency without cooling was 9.78%, whereas the maximum efficiency in each of the three cooling instances was (12.67, 14.56, and 16.67%), respectively.

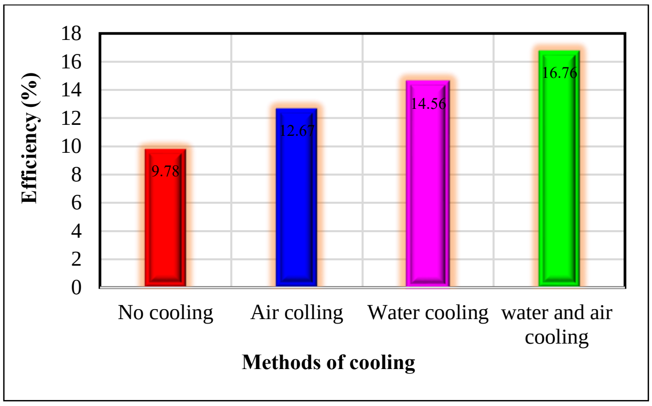

Figure 9. Efficiency with types cooling

4.4 Analysis of mass flow rate

Changes in air mass flow rate values and their effect on photovoltaic surface temperature Figure 10 shows that, in addition to the temperature decreasing as the mass flow rate is increased daily, the temperature uniformity also increases. Since the max. and min. values of the surface temperature of the PV panels were (67°C) at uncooled and (50°C) and cold only from the backside of the panels by air, it follows that a higher flow rate will result in improved performance due to lower temperatures as well as better temperature uniformity. Figure 11 illustrates how the temperature rise diminishes as the mass flow rate rises.

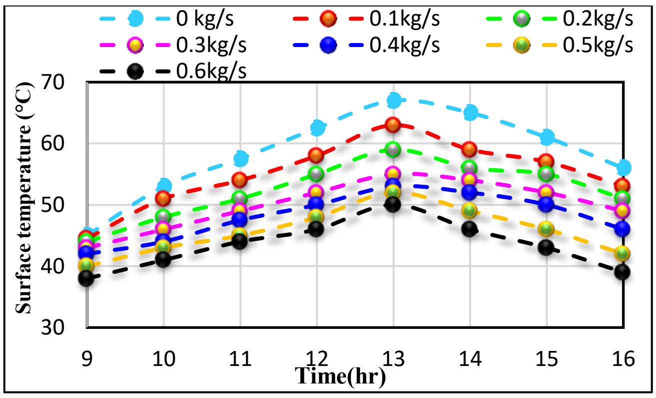

Figure 10. PV temp. daily time at different flow rates

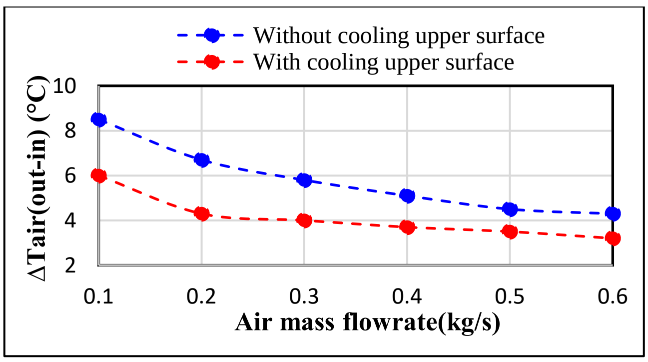

Figure 11. Air temperature difference with mass flow rate

The temperature of photovoltaic cells drops from 67 to 47°C, as shown in Figure 12, as the mass flow rate increases, leading to a large increase in electrical output. Since a photovoltaic cell's electrical performance will decrease as its temperature rises, resulting in reduced power, the variation trend of electrical power is the reverse of that of photovoltaic cell temperature.

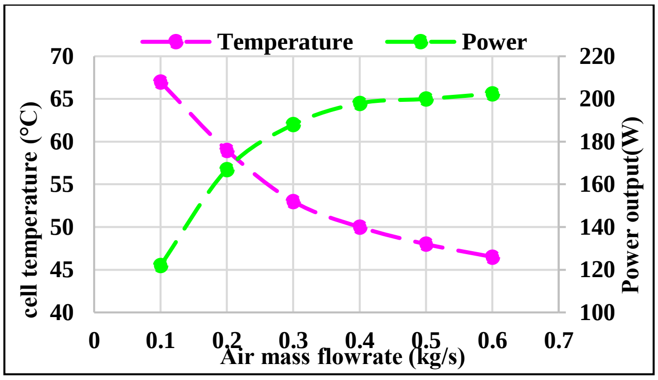

Figure 12. Cell temperature and power with mass flow rate

The selection of nozzle numbers was the main emphasis of the current study. To achieve this, cooling tests with nozzle counts ranging from 2 to 8 are carried out. Nozzles must be positioned as depicted in Figure 13 on the upper edge of the module. In this way, the water spray moves independently of the panel tilt angle and by gravity from the top to the bottom of the module surface. Keep in mind that water can chill the surface both directly and indirectly through evaporation. Additionally, the water flow ensures that the module surface will be free of dust, which will benefit the self-cleaning mechanism. The upper portion of the module cannot be completely cooled by air because it is impossible to create a homogeneous coating on the surface. Contrarily, 4, 6, or 8 nozzles create a fairly uniform water coating, but there is a significant loss of water around the module borders between 30 and 70 percent of the sprayed flow rate is lost along the edges of the module. Based on these experiments, six nozzles can provide the maximum output power at this angle and nozzle number, as a result, the suggested cooling system has six nozzles that are positioned on the top edge of the module and have a spraying angle of 30°.

Figure 14 shows the relationship between power and air flow rate and the difference between cooling the outer surface of the board with water, as it is found that the power with cooling increases as a result of the increase in the voltage difference as a result of cooling.

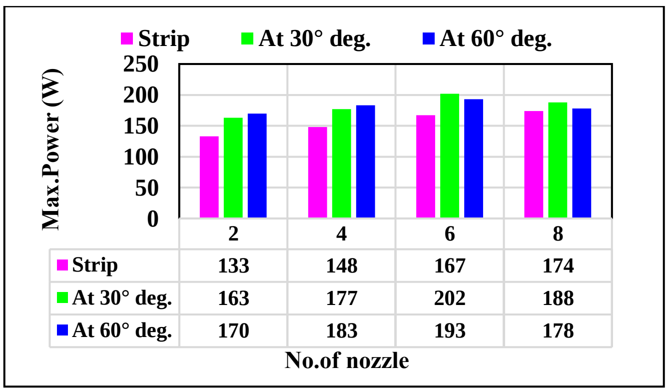

Figure 13. Max power with nozzles at a different angle

Table 5. PV cell performance compared with previous studies

Ref.	Cooling Techniques	$\eta_{ele.}$ increment	Power increment (W)	Tempe. reduction (°C)
[12]	Spraying water	2.09	33.43	24
[13]	Water cooling	1.57	5	12.6
[14]	Spraying water	3.5	38	20
[15]	Evaporating cooling	7.25	16.3	10.2
Current study	Spraying water	6.98	50.5	23

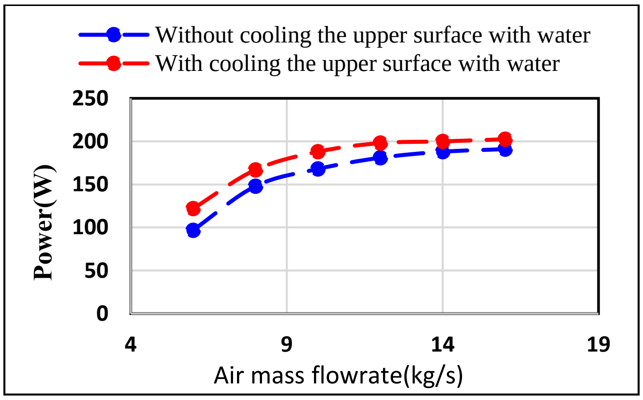

Figure 14. Power with air flow rate

The PV module performance is contrasted in Table 5 with that of earlier studies that enhanced the performance of the PV module using related cooling techniques. Comparing the performance of the PV module to the reference PV module without cooling, it can see how evaporative cooling affects the PV module's performance.

5. CONCLUSIONS

In this study, an economical water spray-based cooling for solar modules is experimentally evaluated. Six water nozzles are positioned at the upper edge of the module to cool the PV panel's front surface, and air is pumped from an evaporative cooler to cool the panel's back. Nozzles are among the products that may be bought commercially in addition to connecting tubes and wooden frames. The temperature of the PV module and the ambient air are both measured using thermocouples. The type, location, angle, and number of nozzles as well as the air mass flow rate are recorded while numerous sprinkler management options are suggested and evaluated. The experiment's findings revealed that:

1) Cooling the photoelectric panels with water and air together at the same time enhances the panels.
2) Cooling the photovoltaic panels with water and air simultaneously, reducing the average surface temperature from 58 to 35°C.
3) Based on the results, six nozzles can provide maximum output power at this angle and nozzle number, as well as a uniform film and acceptable water loss along the boundaries (less than 10%).
4) Based on the results, an optimum air flow rate that can produce the maximum output power is 0.25 kg/s.
5) Improve panel power by 13% when just air is used, 20% when only water is used, and 24% when both water and air are used.
6) Increase electricity efficiency by 41% when utilizing water and air simultaneously, 32% when using only air, and 22% when using only water.
7) Enhancement electrical power and efficiency.
8) More temperature distribution of PV panels.
9) Cooling the air -water is the best method from the others (No cooling, Air cooling, Water cooling).

REFERENCES

[1] Andreev, V.A.C.M., Grilikhes, V.A., Rumiantsev, V.D. (1997). Photovoltaic Conversion of Con- Centrated Sunlight. Wiley.

[2] Kumar, K., Sharma, S., Jain, L., Al Khaimah, R. (2007). Standalone Photovoltaic (PV) module outdoor testing facility for UAE climate. Submitted to CSEM-UAE Innovation Center LLC.

[3] Edenburn, M. (1980). Active and passive cooling for concentrating photovoltaic arrays. Sandia Labs., Albuquerque, NM (USA).

[4] Minano, J., Gonzalez, J., Zanesco, I. (1994). Flat high concentration devices. Proceedings of 1994 IEEE 1st World Conference on Photovoltaic Energy Conversion - WCPEC (A Joint Conference of PVSC, PVSEC and PSEC), pp. 1123-1126. https://doi.org/10.1109/WCPEC.1994.520159

[5] Mei, L., Infield, D., Eicker, U., Fux, V. (2003). Thermal modelling of a building with an integrated ventilated PV façade. Energy Build, 35(6): 605-617. https://doi.org/10.1016/S0378-7788(02)00168-8

[6] Yun, G.Y., McEvoy, M., Steemers, K. (2007). Design and overall energy performance of a ventilated photovoltaic façade. Sol Energy, 81(3): 383-394. https://doi.org/10.1016/j.solener.2006.06.016

[7] Du, D.F., Darkwa, J., Kokogiannakis, G. (2013). Thermal management systems for Photovoltaics (PV) installations: A critical review. Sol Energy, 97: 238-254. https://doi.org/10.1016/j.solener.2013.08.018

[8] Teo, H., Lee, P., Hawlader, M. (2021). An active cooling system for photovoltaic modules. Applied Energy, 90(1): 309-315. https://doi.org/10.1016/j.apenergy.2011.01.017

[9] Moharram, K.A., Abd-Elhady, M., Kandil, H., El-Sherif, H. (2013). Enhancing the performance of photovoltaic panels by water cooling. Ain Shams Engineering Journal, 4(4): 869-877. https://doi.org/10.1016/j.asej.2013.03.005

[10] Benato, A., Stoppato, A., De Vanna, F., Schiro, F. (2021). Spraying cooling system for pv modules: Experimental measurements for temperature trends assessment and system design feasibility. Designs, 5(2): 25. https://doi.org/10.3390/designs5020025

[11] Vat, S., Attakorn, A., Thoranis, D., Tanongkiat, K. (2020). A new method for evaluating nominal operating cell temperature (NOCT) of the unglazed photovoltaic thermal module. Energy Reports, 6: 1029-1042. https://doi.org/10.1016/j.egyr.2020.04.026

[12] Wojciech, L., Grzegorz, P., Mirosław, J., Leszek, P., Michał, S., Jarosław, K., Paweł, R. (2020). Assessing the

impact of water cooling on PV modules efficiency. Energies, 13(10): 2414. https://doi.org/10.3390/en13102414

[13] Haidar, Z.A., Orfi, J., Kaneesamkandi, Z. (2021). Photovoltaic panels temperature regulation using evaporative cooling principle: Detailed theoretical and real operating conditions experimental approaches. Energies, 14(1): 145. https://doi.org/10.3390/en14010145

[14] Krauter, S. (2004). Increased electrical yield via water flow over the front of photovoltaic panels. Sol Energy Mater Sol Cells, 82(1-2): 131-137. https://doi.org/10.1016/j.solmat.2004.01.011

[15] Krauter, S. (1995). Thermal and optical enhanced PV-modules. Proceedings of the 13th European Photovoltaic Solar Energy Conference, pp. 2306-2309.

[16] Jasim, Q.K. (2022). Effect of the different types of dust on the performance of photovoltaic panels in Iraq. Fluid Mechaics and Thermal Sciences, 100(3): 1-10. https://doi.org/10.37934/arfmts.100.3.110