VOL. 17, NO. 3, FEBRUARY 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EFFECTS OF SIMPLE COOLING METHODS ON POWER OUTPUT AND EFFICIENCY OF SOLAR PANELS IN OUTDOOR CONDITIONS

M. M. Hasan[1], A. A. Rifat[1], O. F. Safwan[1], K. M. E. Hasan[2] and A. B. M. A. Malek[1]
[1]School of Applied Sciences and Technology, Shahjalal University of Science and Technology, Sylhet, Bangladesh
[2]Department of Physics, Shahjalal University of Science and Technology, Sylhet, Bangladesh
E-Mail: muhammad.hasan-ipe@sust.edu

ABSTRACT

Solar energy applications are always attracting the scientific community all over the world for offsetting fossil-fuel based energy. One of the popular way is to utilize photovoltaic (PV) modules for harnessing solar energy. The power yields from solar panels are badly affected by temperature increase during outdoor operations. Therefore, the methods to maintain temperatures as low as possible are widely being investigated. In this research work, a number of techniques has been investigated for two traditional PV modules; one is polycrystalline silicon (Poly-Si) and the other monocrystalline silicon (Mono-Si). An experimental setup has been developed and installed on the roof-top of an academic building in our university. For measuring different parameters to evaluate power output and temperatures, a data logging device was designed and fabricated using a ESP 32 microprocessor and different sensors (current, voltage and temperature). A number of experimental runs in outdoor conditions was carried out on mostly sunny days. The power output of the Mono-Si module (50W) for the water cooling method reaches its maximum with a value of 48W at lower module temperatures (~30 °C) and an efficiency of 17.8 percent. Efficiency of the Mono-Si and Poly-Si modules are found to degrade at a rate of 0.04-0.11 and 0.05-0.13%/°C, respectively.

Keywords: solar energy, photovoltaics (pv) modules, polycrystalline-si, monocrystalline-si, cooling methods.

1. INTRODUCTION

Energy obtained from sunlight striking the earth in one hour is more that the energy consumed by humans in one year [1]. In fact, the solar energy resource dominates over all other renewable and fossil-based energy resources. With increasing attention toward carbon-neutral energy production, solar electricity or photovoltaic (PV) technology is receiving heightened attention as a promising approach towards sustainable energy production. Solar or PV cells are electronic devices that essentially convert the solar energy from sunlight into electric energy or electricity. Moreover, the costs of Si-based solar panels have declined so rapidly that panel costs now make up <30% of the costs of a fully installed solar-electricity system [2].

According to the International Energy Agency (IEA), Photovoltaics (PV) is expected to produce around 11% of global electricity by the year 2050, thereby avoiding 2.3 Gt of carbon dioxide (CO_2) emissions per year [3]. PV module is one of the most sustainable and environment-friendly products that can directly convert solar irradiation into electrical energy. In practice, only 15-20% of incident solar irradiation is converted into electricity, and the rest is transformed into heat [4].

PV module efficiency is reported to decreases as module temperature increases [5-8]. A decrease in output power of the PV module for every 1 °C increase in module temperature are reported to be about 0.65% [8]. The decrease in module efficiency ranges from 0.25% to 0.5% per degree Celsius depending on the type of PV material [6, 9].

A number of research work [5, 6, 10-15] was found to investigate different cooling techniques where PV modules were attempted to cool by active and passive cooling methods. In these research work, various materials such as aluminium, water with ice blocks, phase change materials etc. were employed to enhance cooling effects.

So far, there is few research found in the literature investigating the effect of a particular cooling technique on different types PV materials (Amorphous Si, polycrystalline Si, monocrystalline Si). To find an optimum cooling technique to enhance output power for actual outdoor conditions is still worth investigating. Therefore, this research aims at investigating the effects of temperature on output power of different types of PV materials using passive cooling techniques.

2. EXPERIMENTAL METHODS

The local solar irradiation level is crucial for the sustainable and high efficiency of solar modules. The solar irradiance was monitored almost continuously by collecting experimental data using a solar irradiation measuring device (PYRANOMETER) interfaced with Mooshimeter. The value of irradiance (E) in W/m^2 is determined using the equation below:

$$E = \frac{U_{emf}}{S}$$

where, U_{emf} (µV) is the output voltage and S is the sensitivity of the Pyranometer (73.4 µV/W/m²).

A typical Pyranometer (SP Lite2, Kipp & Zonen, Netherlands) was used to measure the total solar irradiation. The Mooshimeter (Mooshim Engineering, USA) was employed with a resolution of 10 µV. The solar irradiance data was logged in every 10 seconds using the Mooshimeter wirelessly connected (Bluetooth) with a cell phone. An experimental setup had been developed for testing solar photovoltaic panels as shown in Figure-1. A customized table was constructed that is capable of

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

mounting two solar panels at a time and tilting the solar PV at any angle below 90^0. In the present work, it supports solar panels for experimental runs. A water flowing channel has been fabricated for water cooling methods. A data-logging device is built to measure a number of voltages, currents and temperatures, simultaneously using a ESP-32 microprocessor (32 bit). For programing, ARDUINO based coding as an open source platform has been employed to build the data logging device.

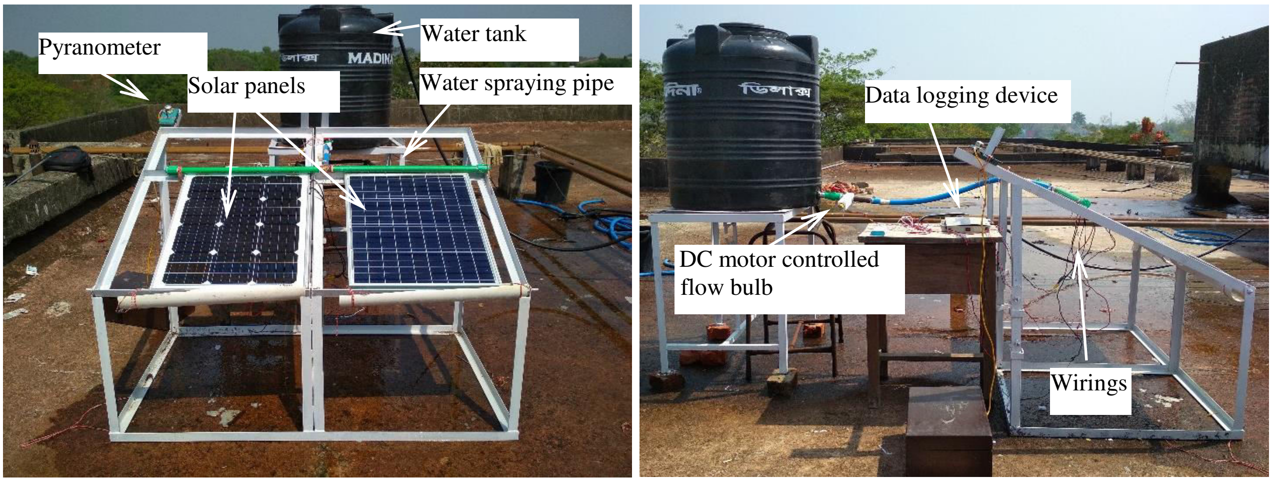

Figure-1. Photographic views of the typical experimental setup for testing different cooling methods of PV modules.

Figure-2 shows the block diagram of the data logging device. The device uses current/voltage sensors and four temperature sensors. Prior to our final experimental runs, all measurement data from different sensors are calibrated. For this purpose, the voltage and current are manually determined using a precision Multimeter (GW Instek Digital Multimeter GDM-394, Taiwan), the temperature by an infrared thermometer (Fluke 62 Max Infrared Thermometer and General DT4947SD Digital K Type Thermometer with 4 Channels, and SD Card capability) and compared with the data collected using the Arduino programming based data logging device. To investigate the effects of cooling on PV module output, two commercially available solar panels having peak power of 50W were selected. One of them is made of polycrystalline Si and the other is monocrystalline Si. The detail specifications of the studied modules are given in Table-1. The simple cooling techniques investigated in this present work are natural air cooling, forced air cooling and water spray cooling.

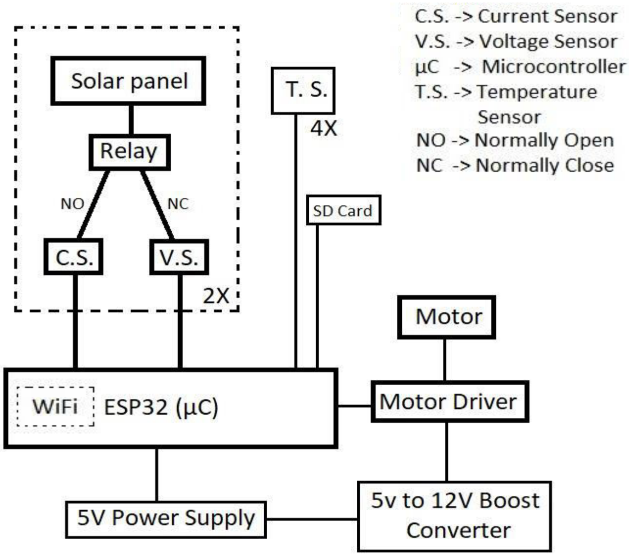

Figure-2. Block diagram of the automatic data logging device.

Table-1. Specifications of the PV modules.

	Solar Panel-1	**Solar Panel-2**
Place of origin	**China**	**China**
Brand name	AK Solar	Xihe Solar
Materials	Monocrystalline silicon	Polycrystalline silicon
Size	700×540×30 mm	680×560×30 mm
Peak power (W)	50	50
V_{oc} (V)	21.24	21.60
I_{sc} (A)	3.00	3.22
V_{mp} (V)	18.00	17.5
I_{mp} (A)	2.78	2.86
Total area of cells	640×470 mm (3.008×10^{-1} m^2)	630×485 mm (3.056×10^{-1} m^2)
Weight (kg)	3.5	4.0
Typical filling factor	0.7853	0.7196

3. RESULTS AND DISCUSSIONS

A number of experimental runs using three simple cooling methods, namely, natural air cooling, forced air cooling and water spray cooling have been carried out in Sylhet, Bangladesh under actual weather conditions during the months of March 2021. During the days of experiments, relative humidity was recorded in the range of 40-70% and ambient temperature ranges from 28 to 35 °C. For natural cooling method, no external cooling was performed while wind speed was found to be intermittent up to a maximum of 10 km/hr. On the other hand, forced air cooling was carried out using two similar electric fans. Using a standard anemometer, the wind speed was determined and found to vary in the range of 15-20 km/hr. A novel water spraying technique maintaining intermittent water flow over the solar modules was developed and fabricated as shown earlier (Figure-1).

As the experiments has been performed in outdoor conditions, a number of different conditions were considered or recorded during the experimental runs. One polycrystalline and the other monocrystalline-Si PV panels have been tested with an area of 3.008×10^{-1} m^2 and 3.056×10^{-1} m^2, respectively. The filling factors of the solar panels are calculated from the standard data provided by the manufacturers using the formula given below.

$$\text{Filling Factor (FF)} = \frac{\text{Peak Power } (V_p \times I_p)}{V_{OC} \times I_{SC}}$$

where V_P and I_P are the voltage and current at optimum or peak power in standard testing conditions, V_{OC} and I_{SC} are the open circuit voltage and short circuit current, respectively. Using the above equation, the filling factors of the studied panels (Mono-Si and Poly-Si) are found to be 0.7853 and 0.7196, respectively (Table-1). Hence, observed peak power was determined by multiplying the filling factor of the module and the observed product of V_{OC} and I_{SC}.

To observe the worst case scenario of temperature effects on power output of two widely used solar modules, they were left without any passive cooling which is specified as the natural air cooling method. An occasional wind flow below 5 km/hr was observed during the experimental durations. Figure-3 presents the different profiles of the selected PV modules for natural air cooling method: solar irradiance, panel temperatures and peak power. Peak power of the Mono-Si panel is observed to be higher compared with the Poly-Si panel for the whole duration. It is also noted that the panel temperature is higher for the Mono-Si module that that for the Poly-Si. However, the power degradation is not significantly affected due to higher temperatures for the Mono-Si module. It is thought to be correlated with their efficiency.

ARPN Journal of Engineering and Applied Sciences

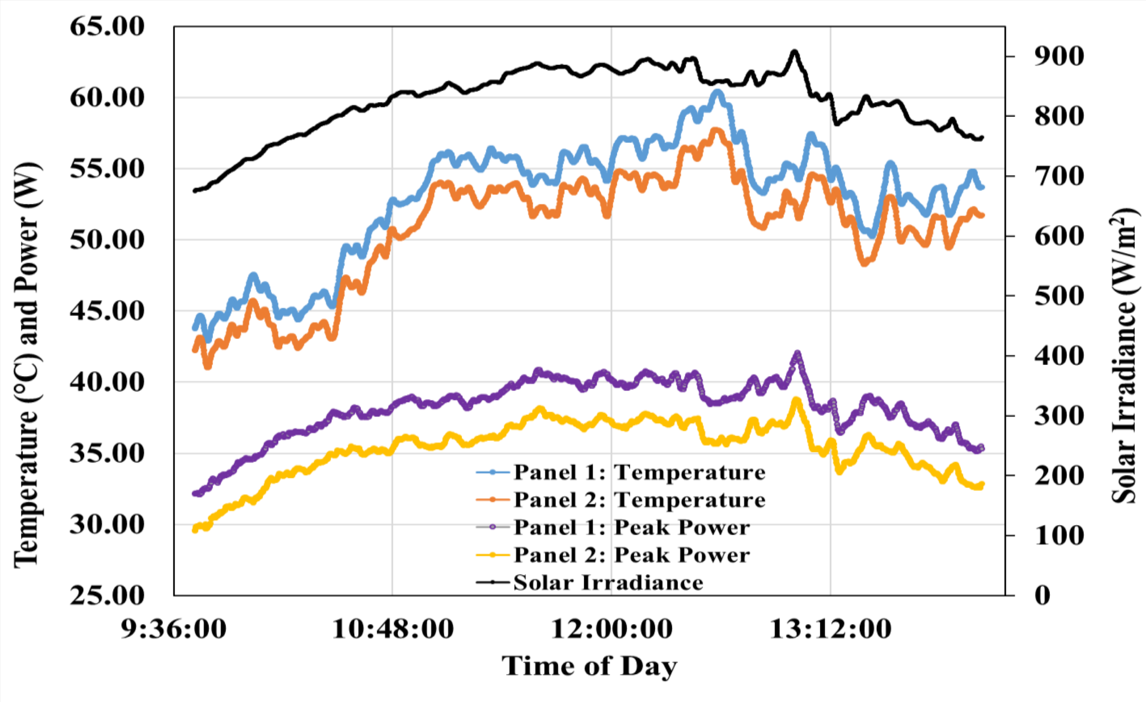

Figure-3. Solar irradiance, temperatures and peak power of the solar modules during natural air cooling. (Panel 1: Mono-Si and Panel 2: Poly-Si).

For the forced air cooling method, air is blown over the solar panels recorded as an average of 18 km/hr. We are not able to assess the effect of natural wind speed along various directions; therefore, it has been neglected. Figure-4 shows the variation of solar irradiance, peak power and temperatures for the studied modules. For this method, temperatures of both panels were found to fluctuate in the range of 39-46 °C as seen in the figure. However, the maximum power output of the monocrystalline panel is found higher than that for the polycrystalline one for similar solar radiation.

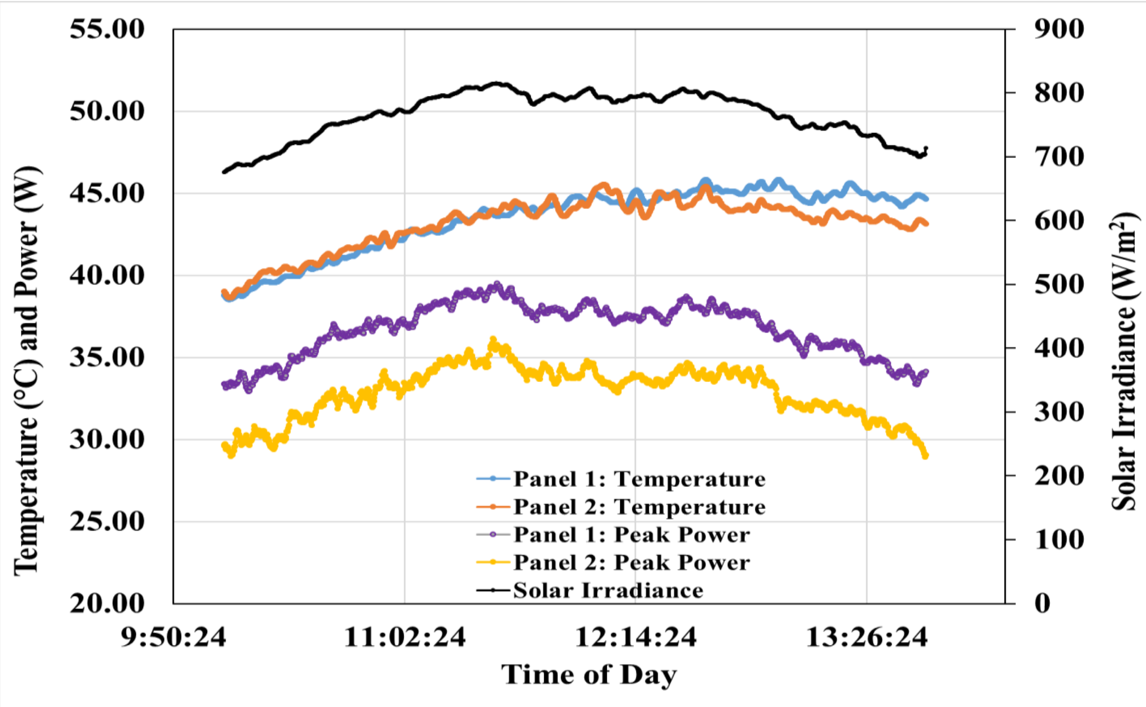

Figure-4. Solar irradiance, temperatures and peak power of the solar modules during forced air cooling. (Panel 1: Mono-Si and Panel 2: Poly-Si).

ARPN Journal of Engineering and Applied Sciences

During the novel water spray technique, a constant and uniform flow rate of water over the solar modules was maintained intermittently. The DC motor controlled pump gets actuated to initiate water spray whenever the temperature of panel raises to 38 °C and it turns off automatically while the panel temperature is just less than 33 °C. The average flow rate of water for a single panel was calculated taking a number of observations and is found to be about 9 liters/minute. This high flow rate is found to be necessary for flowing water over the whole surface of the panel at the same time. Moreover, it is possible to maintain the maximum cooling efficiency so that the temperature of the panels remains below 35 °C most of the experimental duration. The variation of solar irradiance, peak power and temperatures of the studied modules during the water spray method is shown in Figure-5. It is observed that the heating of the modules is quite fast as seen in the figure, therefore, the initiation of water spray repeats in about every 2 minutes. Similar faster cooling was observed to reduce the module temperature below 33 °C so that water spray ceased in about every 2 minutes. The maximum power output of the Mono-Si panel is found to be 48W, while the Poly-Si module exhibits a peak power of 46W.

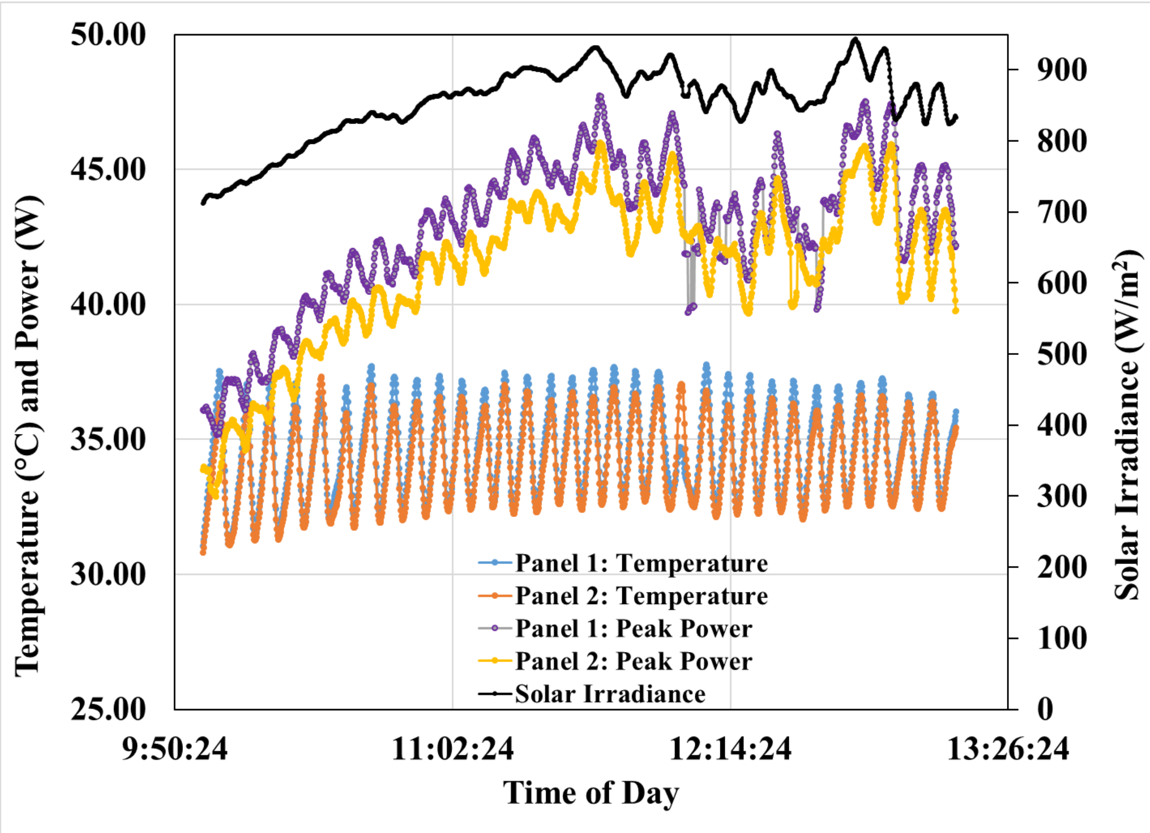

Figure-5. Solar irradiance, temperatures and peak power of the solar modules during forced air cooling. (Panel 1: Mono-Si and Panel 2: Poly-Si).

The overall efficiency of the solar modules is the key issue affected by their temperature rise. It is determined using the following equation from our observed data during the experimental runs of different cooling methods.

$$\text{Efficiency of a module} = \frac{\text{Peak Power}}{\text{Total cell area} \times \text{Observed solar irradiance}}$$

Efficiency versus temperature plots are produced using the data for different cooling methods as shown in Figure-6. Linear regression models are developed for the plotted data as shown inside the figures. R^2 values are found to be mostly greater than 80%, indicating that the linear regression models have a sufficient goodness-of-fit. Using the developed linear equations, the efficiency of the solar panels calculated at different temperatures is taken into account for further discussion. The summary of research highlights including the efficiency values are presented in Table-2. For natural air cooling, the efficiency of the solar panels was calculated and found to be higher for the Mono-Si module with a maximum of 17.8%, while a maximum of 17.1% efficiency is evaluated for the Poly-Si panel. Whereas, for forced air cooling, the efficiency for both type of solar modules shows a very slight variation consistent with a small temperature fluctuations of the panels; 15.8-16.2 for Mono-Si and 14.5-14.8 for Poly-Si. On the other hand, the efficiency of the Mono-Si and the Poly-Si modules during water spray cooling, reaches up to 17.8% and 17.1%, respectively. Among all these cooling methods, water spray cooling

ARPN Journal of Engineering and Applied Sciences

maintains the least temperature, hence produce the highest peak power with highest efficiency. However, for all simple cooling methods, the monocrystalline Si module is found to have higher peak power and higher efficiency than the polycrystalline Si module. The rate of decrease in efficiency for every 1 °C is found to be quite low ranging 0.04-0.13. In a couple of earlier research work, the rate of deterioration is reported as low as 0.25 %/°C [6, 9]. The possible reason behind the low values in our research work may be due to the outdoor variations of solar irradiance below 1000 W/m^2 and the newly purchased modules used.

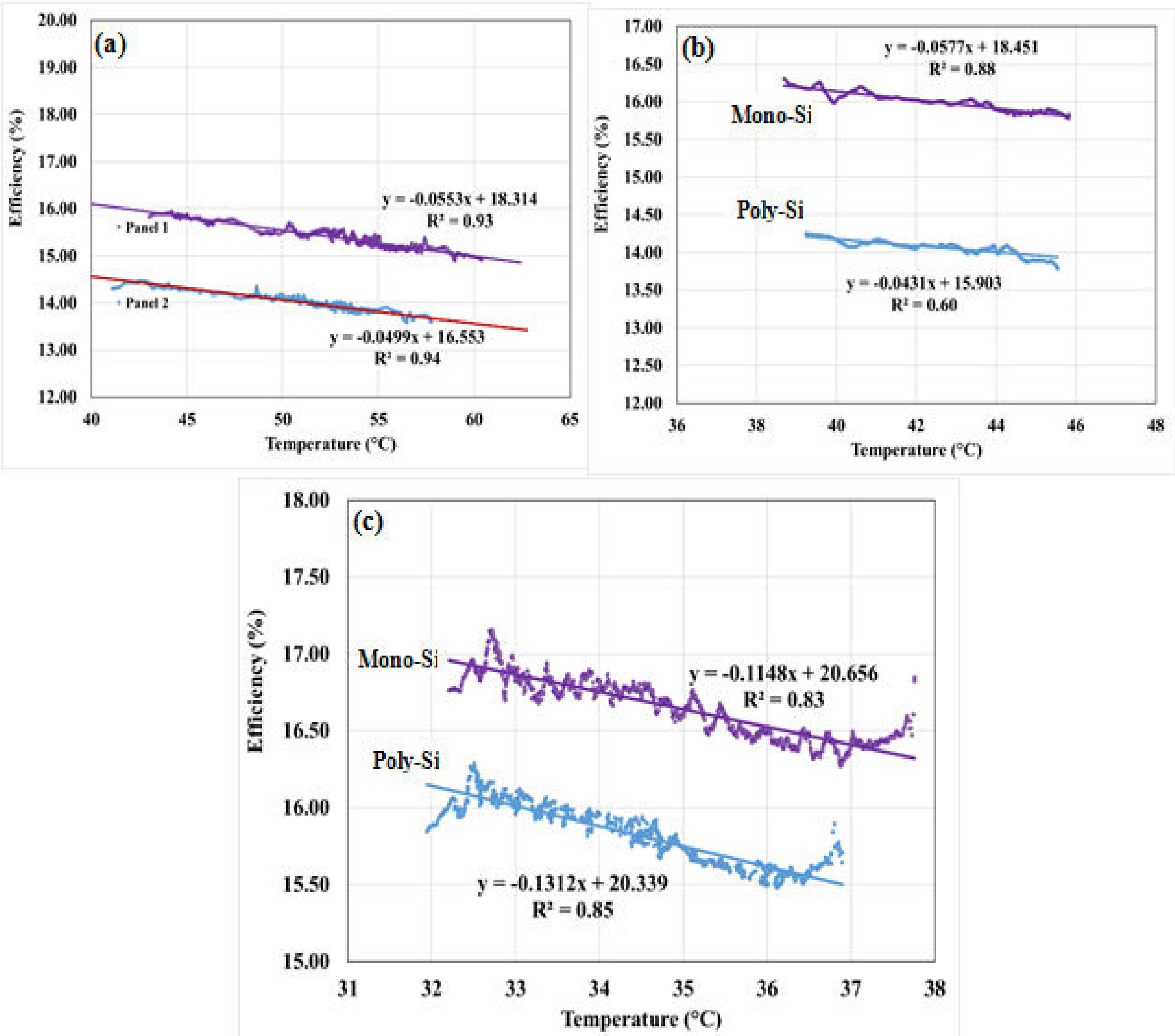

Figure-6. Efficiency of the studied solar modules during (a) natural air cooling, (b) forced air cooling and (c) water spray cooling (Panel 1: Mono-Si and Panel 2: Poly-Si).

Table-2. Summary of the effects of different cooling techniques on module performance.

	Natural air cooling		Forced air cooling		Water spray cooling	
	Mono-Si	**Poly-Si**	**Mono-Si**	**Poly-Si**	**Mono-Si**	**Poly-Si**
Operating temperature (°C)	43-60	41-58	39-46	39-46	32-38	32-38
Maximum peak power (W)	41.6	38.6	39.5	36.2	48	46
Efficiency range (%)	15-15.9	13.7-14.5	15.8-16.2	14.5-14.8	16.3-17.0	15.4-16.1
Maximum efficiency at 25 °C (%)	16.9	15.3	17.0	14.8	17.8	17.1
Efficiency deterioration rate (%/°C)	0.06	0.05	0.06	0.04	0.11	0.13

4. CONCLUSIONS

In this study, a variety of simple cooling methods for increasing solar power output have been investigated. The efficiency of the panels is found to be the least for the natural cooling, while moderately higher for the forced air cooling and finally the highest for the water spray cooling. For all cooling methods, the monocrystalline Si module is found to have higher peak power and higher efficiency than the polycrystalline Si module. The power output of the Mono-Si module for the water cooling method reaches its maximum of 48 W at a low module temperature of 30 °C. During natural air cooling of the solar panels, most of the time, the studied panels operates at temperatures above 50 °C. Efficiency of the Mono-Si and Poly-Si modules are found to degrade at a rate of 0.04-0.11 and 0.05-0.13%/°C, respectively. It is well-known that the operation of solar panels at a high temperature not only deteriorate their performance, the lifetime of the panels is negatively affected. Developing a novel cooling method to enhance the efficiency of solar panels requires further investigations.

ACKNOWLEDGMENT

The authors would like to acknowledge the financial support provided by the SUST Research Centre, Shahjalal University of Science and Technology, Sylhet under the Project Code: AS/2020/1/53.

REFERENCES

[1] Lewis N. S. 2007. Toward cost-effective solar energy use. Science. 315(5813): 798-801.

[2] Lewis N. S. 2016. Research opportunities to advance solar energy utilization. Science, 351(6271): 353-aad1920-9.

[3] Touati F., Al-Hitmi M. A., Chowdhury N. A., Hamad J. A. and San Pedro Gonzales A. J. R. 2016. Investigation of solar PV performance under Doha weather using a customized measurement and monitoring system. Renewable Energy. 89: 564-577.

[4] Teo H. G., Lee P. S. and Hawlader M. N. A. 2012. An active cooling system for photovoltaic modules. Applied Energy. 90(1): 309-315.

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

[6] Rahman M. M., Hasanuzzaman and M., Rahim N. A. 2015. Effects of various parameters on PV-module power and efficiency. Energy Conversion and Management. 103: 348-358.

[7] Rajvikram M., Leoponraj S., Ramkumar S., Akshaya H. and Dheeraj A. 2019. Experimental investigation on the abasement of operating temperature in solar photovoltaic panel using PCM and aluminium. Solar Energy. 188: 327-338.

[8] Radziemska E. 2003. The effect of temperature on the power drop in crystalline silicon solar cells. Renewable Energy. 28(1): 1-12.

[9] Sainthiya H. and Narendra Beniwal S. 2017. Different types of cooling systems used in photovoltaic module solar system: A review. In: IEEE WiSPNET 2017 conference. 17: 1500-1506.

[10] Bayrak F., Oztop H. F. and Selimefendigil F. 2020. Experimental study for the application of different cooling techniques in photovoltaic (PV) panels. Energy Conversion and Management. 212(112789): (1-9).

[11] Irwan Y. M., Leow W. Z., Irwanto M., Fareq M., Amelia A. R., Gomesh N. and Safwati I. 2015. Indoor test performance of PV panel through water cooling method. Energy Procedia. 79: 604-611.

[12] Kabeel A. E., Abdelgaied M. and Sathyamurthy R. 2019. A comprehensive investigation of the optimization cooling technique for improving the performance of PV module with reflectors under Egyptian conditions. Solar Energy. 186: 257-263.

[13] Lim J. H., Lee Y. S. and Seong Y. B. 2017. Diurnal thermal behavior of photovoltaic panel with phase change materials under different weather conditions. Energies. 10(1983): 1-14.

[14] Koteswararao B., Radha K., Vijay P. and Raja N. 2016. Experimental analysis of solar panel efficiency with different modes of cooling. International Journal of Engineering and Technology. 8(3): 1451-1456.

[15] Hasan M. M., Malek A. B. M. A., Talukder M. I. A. and Imon A. N. 2021. Solar irradiance measurement in Sylhet and performance evaluation of photovoltaic (PV) modules in outdoor conditions. Journal of Engineering Research, Innovation and Education. 3(1): 5-12.