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Investigation of Solar Energy Production by Photovoltaic (PV) System Using Rooftop Coating as Passive Cooling Technique at Bukit Tinggi, Malaysia

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ABSTRACT

Solar power energy is known as one of the popular renewable energies that has been studied by many researchers all over the world. Photovoltaic (PV) panels are used to produce electricity directly from the sunlight. Cooling is a very important technique used in the PV system industry. This is because the heat generated by the PV system can reduce its performance, resulting in higher costs. The cooling technique consists of two types: active cooling technique and passive cooling technique. In this investigation, the passive cooling technique is selected. This is due to its advantages such as less maintenance, did not require large space and affordable. The nanocoating method is a widely used as passive cooling method for glass and PV panels. However, this investigation is carried out to investigate the rooftop coating integrated with PV panels system at Bukit Tinggi due to the limited previous research found worldwide. M168 coating is applied to the rooftop and the effects on the PV systems have been investigated. Two sets of On-Grid Connected PV systems were set up; where each system consists of two inverters were set up to analyze the output. The results then were recorded. According to the investigation results, the PV system with a coated rooftop generates a higher voltage of 249.80V and total power production difference of 16% compared to the PV system with an uncoated rooftop. Although the temperature for coated rooftop PV system quite higher than the uncoated rooftop PV system at the beginning, then the temperature constantly lower than the uncoated rooftop PV system. This study can be used as a guideline for PV system passive cooling methods at Bukit Tinggi.

1. Introduction

Renewable energy has grown in popularity as an alternative to conventional energy. This is to protect the earth from pollution and the greenhouse effect, which can shorten the earth's lifespan and the environment. Solar energy is one of the renewable energies that is widely used throughout the world, particularly in hot and tropical climates. This is due to the easy accessibility for the solar

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energy. Therefore, the irradiances emitted from the sun can be very advantage and beneficial as they can help to generate electricity. The most important instruments to convert the irradiance into electricity is Photovoltaic (PV) panels. These PV panels can produce electricity directly from sunlight when the sunbeams touch them. These PV panels must be connected in a complete system to generate the electricity. The electricity produced then be fed back into the utility grid or used directly for consumer utility supply depends on the system used. However, this PV system also create some heat during the process. As a result, cooling is a critical technique for the PV system to maintain the system efficiency, prevent the PV system from overheating and to maintain their performances. The cooling technique can be carried out in a variety of ways depends on their necessary. However, the main cooling technique is divided into two categories which are passive cooling techniques and active cooling techniques [1–5]. Based on previous research, active cooling techniques need large space, external power source and regular maintenance while the passive cooling techniques required none of the above.

The advantages of passive cooling technique include the fact that it does not require an external energy source. Besides that, its energy consumption can be zero or negligible, and that it is inexpensive as stated by Emy Zairah Ahmad *et al.*, [6]. As illustrated in Figure 1, this technique can be divided into several methods. The methods are water, air, Phase Change Material (PCM), coating, radiative and others as mentioned by previous studies [6–8].

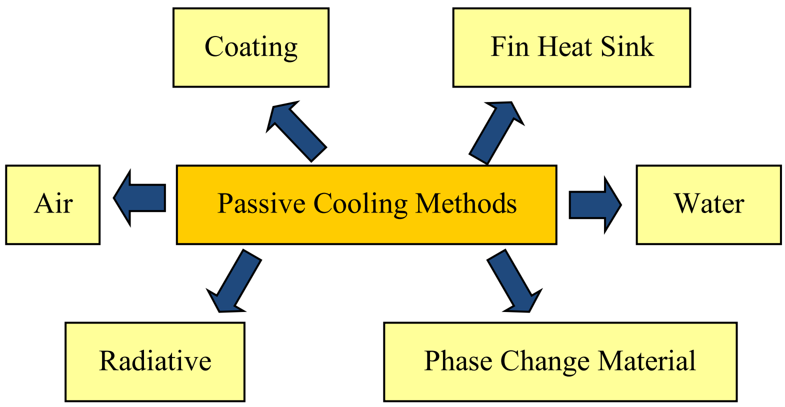

Fig. 1. Passive cooling methods

The coating method was chosen in this investigation for the passive cooling technique. This is due to their advantages and excellent qualities. Nanotechnology coatings are also widely used in the glass coating and PV panel industries. It has been proven by many studies that the hydrophobic and hydrophilic characteristics can improve the lifetime of substances. This is due to the self-cleaning and self-maintenance ability to prevent dust deposition and allow the system to perform as intended. According to Anjian Pao *et al.*, dust deposition density is considerably reduced by the coating when compared to the bare surface [9]. While Peyman Zanganeh *et al.,* claimed that the wettability can be decreased when nano-coating was applied to the surface, a study by Pedrazzi *et al.,* demonstrates that nano-coating is effective for high solar radiation circumstances [10,11]. According to a study by Jin Hu *et al.,* and Jamal-e-Din Mahdi Nejad *et al.*, nanotechnology can be applied properly to make the best use of solar energy [12,13]. Based on the research of K. Mallikarjuna *et al.*, the heat transmission for nanocoating is also excellent [14]. From previous researches, the self-cleaning capacity of the hydrophobic effect of nanocoating provides a cooler effect and increase system efficiency [15–16].

From the studies by Anang *et al.,* and Daut *et al.*, Northern of Peninsular Malaysia received higher solar irradiance and has the potential to generate more electricity by using PV Solar system which is suitable for feed-in tariffs (FiT) [17,18]. Most of the researched showed that On-Grid PV System have many benefits and advantages as the system can help the user to generate their own electricity and incomes [19,20]. This system is very different from the Off-Grid PV System which is used only for the consumer power requirements only and the user cannot sell the excess power electricity into the utility grid. The design of On-Grid PV system that is very simple as it can be connected to the utility grid and also used by backup power system if the PV system down has made the system is very reliable and suitable to install for household and building areas [21–25]. The illustration is shown by Figure 2.

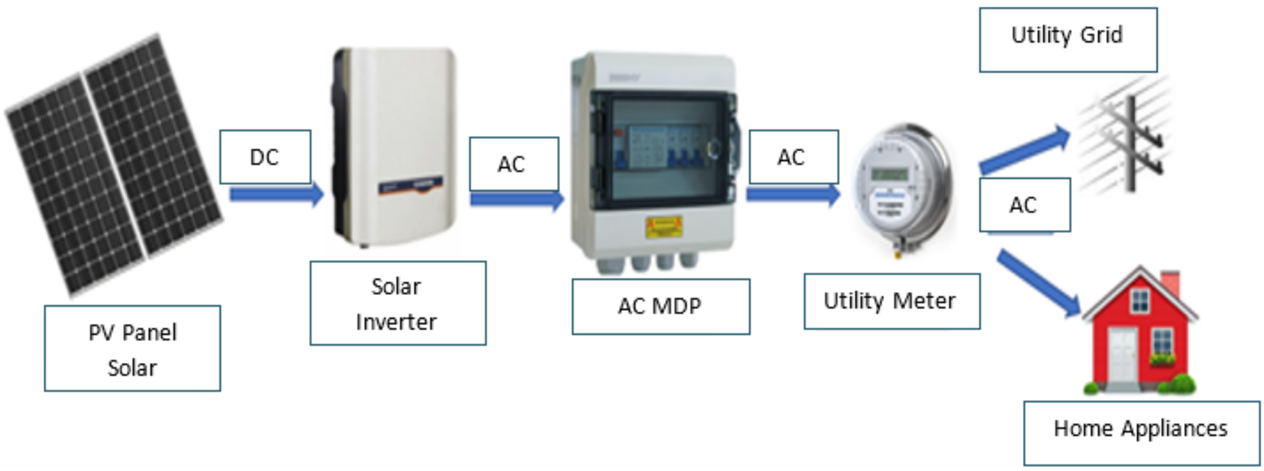

Fig. 2. On-grid connected PV system illustration

The irradiation data can get easily from the Solargis and Meteonorm. These two platforms provide most reliable worldwide global climatological database on the meteorological history of the climate, temperature, humidity, wind, and energy assessment [26]. Meteonorm is a one-of-a-kind combination of trustworthy data sources and powerful computation methods that calculates the lowered global radiation caused by a high horizon and can be access worldwide. The data can be access based on the locations by using the location longitude and latitude coordinates.

This investigation purpose is to investigate whether rooftop coating is ideal as the passive cooling techniques for solar PV panels system at Bukit Tinggi, Malaysia. This is because previous studies mostly are doing the investigation by applying the coating directly into the PV panels. In addition, the previous research for the rooftop coating integrated with PV panels system were very limited and only been research outside from Malaysia.

2. Methodology

2.1 Formulation

In this investigation, the desired power for each set of PV system is 8.1kWp daily for 405W PV panel solar. Therefore, the number of PV solar needed must be calculated first. By using Eq. (1), the number of 405W panels required for this investigation is 20 PV panels.

$$\text{Number of solar panels needed} = \frac{Desired\ energy\ production\ (kW)}{Solar\ panel\ wattage(kW)} \tag{1}$$

The percentage of solar panel efficiency can be calculated by Eq. (2). However, the efficiency will be varies based on the manufacturer's panel and types.

$$\text{Efficiency}\ (\%) = \frac{Pmax}{\left(Area\ x \frac{1000W}{m^2}\right)}\ x\ 100 \tag{2}$$

where irradiance 1000W/m^2 at STC, pmax is max panel power (W) and area is panel area (m^2).

2.2 Rooftop Coating

This investigation is taking place at Kampung Bukit Tinggi site in Malaysia, with coordinates of 6.21 °N latitude and 100.43 °E longitude. According to Solargis and Meteonorm, this location is one of several that receives higher and more significant solar irradiance. Therefore, it is suitable for the PV system installation. However, for this investigation, the nanocoating is applied to the roof rather than directly to the PV panels. The nanocoating colour that is used in this investigation is white colour. This is because white colour can give better performances for the cooling effect compared to other colours based on previous studies [27]. Before the installation of the PV system begin, the rooftop was divided into two sections, coated and uncoated, as shown in Figure 3. This is to provide the data collection for comparison.

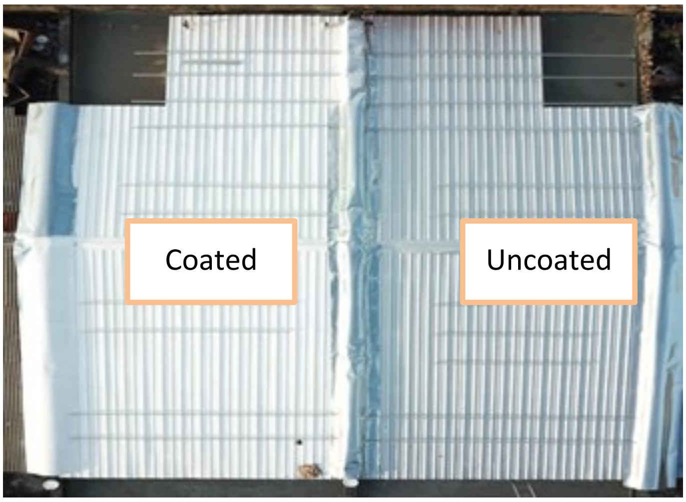

Fig. 3. View of coated and uncoated rooftop

M168 nanocoating was chosen for this investigation. This nanocoating is a heat-insulated coating that can reflect 90% of the heat radiation and cool the temperature inside. This nanocoating is made of nano-mid silica, which creates a thermal barrier that prevents rust and corrosion. It also can do self-cleaning. As a result, the lifetime of rooftop can be extended by ten years or more. This is due to the advantages of the selected nanocoating technology.

The nanocoating is applied by using sprayer and brush. However, the rooftop surfaces must be cleaned first before applying the nanocoating. The cleaning process is by using pressurize waterjets. This step is important to maximize the surfaces protection for the rooftop when the nanocoating takes effect on them. In addition, this nanocoating also can repair the holes on the rooftop before the installation of PV panels.

2.3 PV System Installation

After the rooftop nanocoating process was completed, two on-grid connected PV systems were installed, as shown in Figure 4 and Figure 5. On-grid connected PV systems have been chosen because they offer more benefits to the consumer. The system exports the excess energy produces to the utility, allowing consumers to save money on their utility bills through feed-in tariffs (FiT) schemes. They also can provide back up to the PV systems when the PV system malfunction or failed to generate electricity. Each PV system set consists of 20 modules of Q.Cell Q.Peak Duo L-G7.3 405W silica-monocrystalline PV panels connected in series. Other than that, each system includes two inverters and two main distribution panels (MDPs).

PV system 1 is a PV system with coated rooftop and consist of inverter A and inverter B. PV system 2 is a PV system with uncoated rooftop and consist of inverter C and inverter D. The readings have four data samples from four inverters. This is to meet the consumer demands and provides support to the PV system. Before feeding the energy to the household and utility grids, the inverters convert the direct current (DC) to alternating current (AC). This is because many appliances used AC to operate. As a result, data for each system can be collected separately via the inverters. For this investigation, the data was collected on 8/1/2023 from 08:05 until 16:35 for data analysis, with 30-minute intervals. After that, the data samples from the inverters A and B were labelled as a and b, while c and d were labelled for the inverters C and D. The results have been discussed in results section.

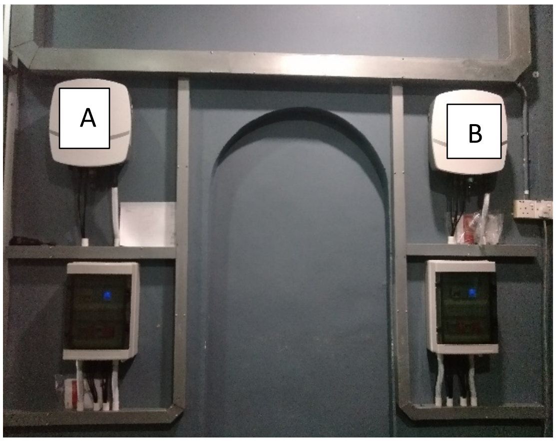

Fig. 4. PV system with coated rooftop

Fig. 5. PV system with uncoated rooftop

3. Results and Discussions

The findings of this investigation are presented here in this section. The data comparison between voltage, current and total power generated will be analysed here. The data was recorded in Table forms and illustrated in graph forms. Table 1 shows the irradiance data from Meteonorm for this site. From the Table 1, the highest Horizontal Global for this site is in March which is 181.2 kWh/m^2. The highest quantity of energy received per unit area by a surface that has been scattered by molecules and particles in the atmosphere rather than arriving on a direct path from the sun at this site is in August with reading of 92.7 kWh/m^2.

Table 1
Irradiance data from Meteonorm

Month	Horizontal global (kWh/m^2)	Horizontal giffuse (kWh/m^2)	Temperature (℃)	Wind velocity (m/s)
January	160.2	62.8	27.0	1.3
February	163.9	66.1	27.7	1.3
March	181.2	76.9	28.1	1.0
April	167.7	77.1	28.0	0.7
May	158.6	78.2	28.3	0.7
June	145.3	82.7	27.6	0.8
July	149.1	87.6	27.8	0.9
August	146.0	92.7	27.7	0.9
September	142.0	83.7	26.9	0.8
October	137.3	75.3	27.0	0.8
November	130..6	73.1	26.6	0.7
December	137.9	70.5	26.8	1.1
Year	1819.8	926.5	27.5	0.9

According to Table 2, the reading of voltage generated form the PV system 1 is higher than PV system 2. It is proven when one of the inverters in PV system 1 generated more AC voltage compared to the inverters in PV system 2. The highest AC voltage generated by inverter a is 249.80V at 13:35. The lowest AC voltage generated by inverter c is 225.60V at 11:05. The results can be seen clearly in Figure 6. Therefore, voltage generated by PV system 1 is higher than the PV system 2.

Table 2
Voltage generated by PV systems inverters

Time	Voltage a (V)	Voltage b (V)	Voltage c (V)	Voltage d (V)
08:05:00	236.90	235.40	232.20	229.90
08:35:00	235.80	234.10	226.20	230.10
09:05:00	232.60	231.60	229.40	229.20
09:35:00	233.30	232.20	233.30	233.90
10:05:00	235.60	234.10	233.90	233.70
10:35:00	237.10	235.40	234.70	235.40
11:05:00	235.20	233.30	225.60	231.10
11:35:00	241.50	239.80	233.30	233.70
12:05:00	238.40	236.70	238.60	239.40
12:35:00	240.10	237.90	241.10	239.40
13:05:00	240.10	239.00	242.00	237.10
13:35:00	249.80	247.30	240.30	242.60
14:05:00	236.90	236.00	237.90	237.50
14:35:00	237.90	236.40	236.40	236.20
15:05:00	239.80	237.90	231.10	231.30
15:35:00	240.90	239.20	237.50	239.00
16:05:00	243.50	242.80	237.70	238.40
16:35:00	243.00	242.00	238.80	239.40

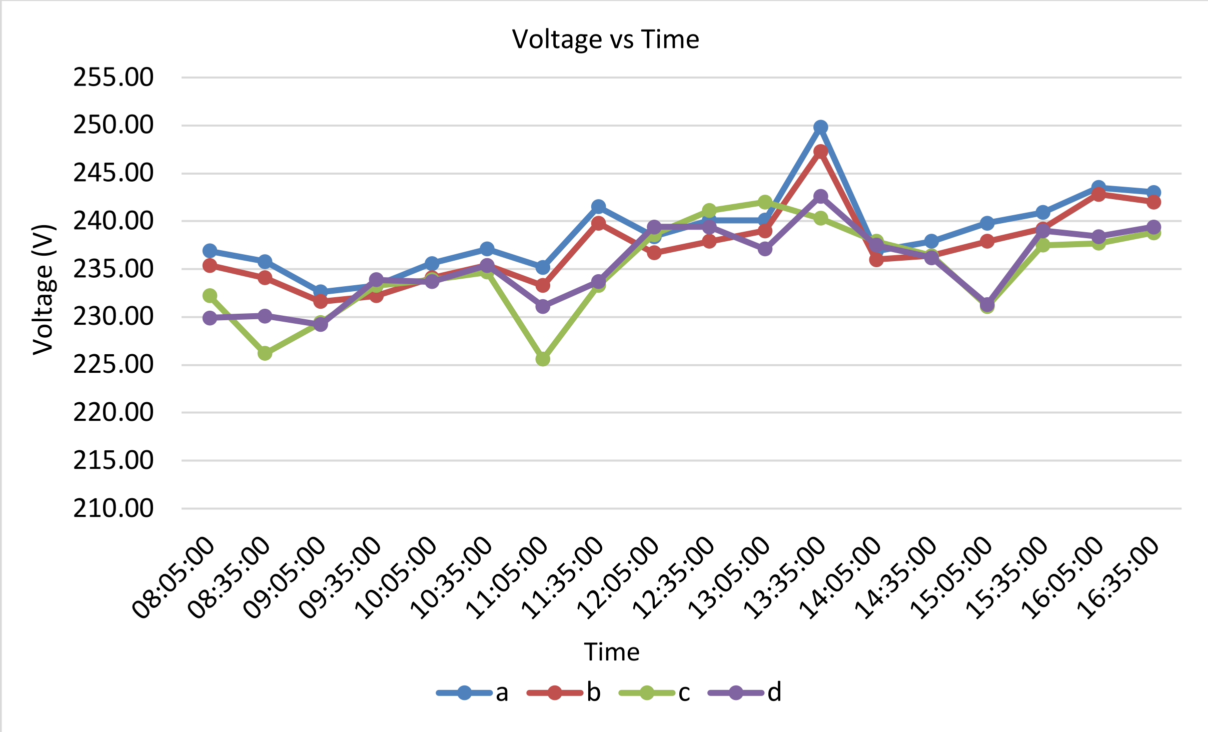

Fig. 6. Voltage versus time graph

However, the current generated by both PV systems only differs slightly from one another, as shown in Table 3. Inverter d has the largest current value, which is 13.39A at 13:35, while inverter c has the lowest current value, which is 0.40A at 08:05. Inverter c has some different patterns, as the current generated at 13:05 is slightly higher at 12.04A. The illustration for the current variations can be seen in Figure 7. From the Table 3 and Figure 7, the highest current produces by both PV systems are at 13:35 except for inverter c which is highest at 12:35 and 13:05. However, the pattern of reading for the current and voltage for the uncoated rooftop PV system are not in irregular pattern and inconsistent compared to the coated rooftop PV system. This situation needs further investigation to know the cause of the irregular pattern.

Table 3
PV systems current generated

Time	Current a (A)	Current b (A)	Current c (A)	Current d (A)
08:05:00	0.41	0.41	0.40	0.45
08:35:00	0.54	0.59	0.54	0.59
09:05:00	0.89	1.08	0.81	1.04
09:35:00	1.74	2.20	1.70	2.05
10:05:00	2.12	2.76	2.14	2.65
10:35:00	2.05	2.58	2.04	2.51
11:05:00	4.24	5.24	4.28	5.23
11:35:00	4.55	5.76	5.13	5.99
12:05:00	7.83	9.75	6.66	9.62
12:35:00	9.00	9.29	12.04	9.55
13:05:00	6.43	7.44	12.04	8.09
13:35:00	10.98	12.86	11.12	13.39
14:05:00	4.86	5.97	5.61	5.89
14:35:00	5.85	7.86	5.30	6.97
15:05:00	2.25	2.72	2.51	2.85
15:35:00	3.83	4.68	3.74	4.63
16:05:00	7.42	8.14	6.97	8.50
16:35:00	5.27	5.62	6.63	6.13

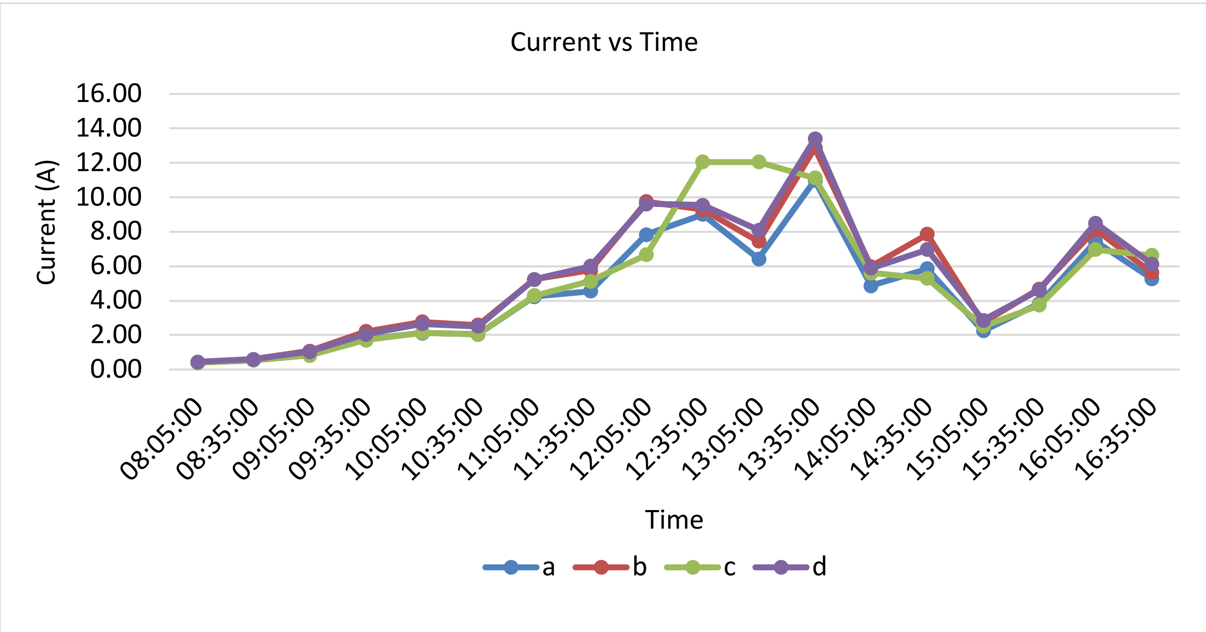

Fig. 7. Current versus time graph

When these data were collected, the PV system 1 with coated rooftops produced greater power, as shown by PV inverters a and b, in terms of total power generated by the PV system, which is quite clear. Table 4 and Figure 8 demonstrate that the power generated followed constant patterns and did not experience any significant fluctuations. The amount of power produced is measured in kWh. PV system 2 with uncoated rooftop generates less power from the PV system 1 with coated rooftop. The difference of power generated from both PV systems is about 16%.

Table 4
PV system total power production

Time	Total Power Production a (kWh)	Total Power Production b (kWh)	Total Power Production c (kWh)	Total Power Production d (kWh)
08:05:00	1027.11	1213.09	896.62	719.65
08:35:00	1027.15	1213.15	896.66	719.70
09:05:00	1027.24	1213.25	896.74	719.80
09:35:00	1027.41	1213.47	896.91	720.01
10:05:00	1027.68	1213.79	897.17	720.32
10:35:00	1027.94	1214.12	897.44	720.65
11:05:00	1028.32	1214.59	897.81	721.10
11:35:00	1028.92	1215.32	898.40	721.82
12:05:00	1029.68	1216.25	899.16	722.75
12:35:00	1030.68	1217.45	900.13	723.95
13:05:00	1031.52	1218.45	900.97	724.96
13:35:00	1032.10	1219.15	901.54	725.65
14:05:00	1032.87	1220.03	902.30	726.57
14:35:00	1033.82	1221.15	903.24	727.69
15:05:00	1034.42	1221.85	903.83	728.41
15:35:00	1034.81	1222.33	904.22	728.88
16:05:00	1035.60	1223.20	904.96	729.79
16:35:00	1036.39	1224.04	905.50	730.68

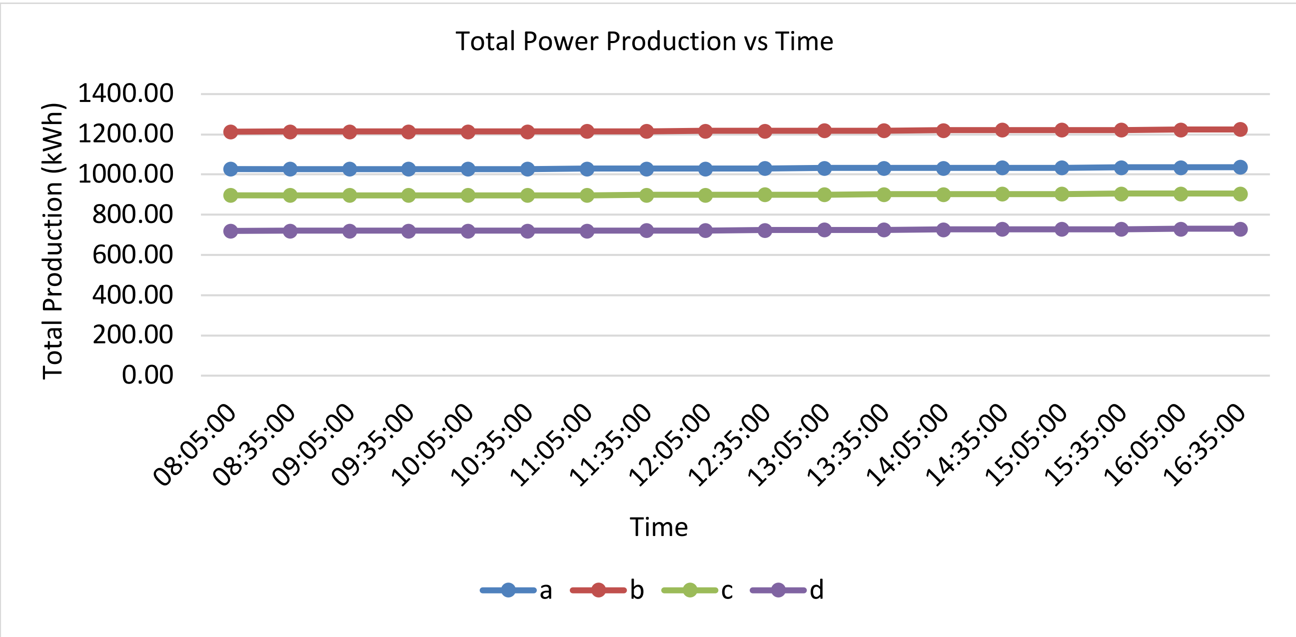

Fig. 8. Total power production versus time

The temperature between the coated and uncoated rooftop is shown in Table 5 and Figure 9. From the Table 5, the temperature for coated system is higher at the beginning compared to the uncoated system. However, over the period, the temperature for coated system is constantly lower than the uncoated system. The temperature is slightly difference between both systems.

Table 5
Temperature differences

Time	Coated (° C)	Uncoated (° C)
08:05:00	29.00	28.90
08:35:00	30.80	30.65
09:05:00	32.45	32.40
09:35:00	34.15	34.15
10:05:00	35.70	35.75
10:35:00	36.45	36.55
11:05:00	37.85	38.00
11:35:00	40.20	40.45
12:05:00	42.60	43.10
12:35:00	46.15	46.85
13:05:00	47.90	48.65
13:35:00	44.95	44.95
14:05:00	44.40	45.15
14:35:00	46.45	47.20
15:05:00	44.30	44.95
15:35:00	42.35	43.00
16:05:00	44.70	45.40
16:35:00	45.10	45.40

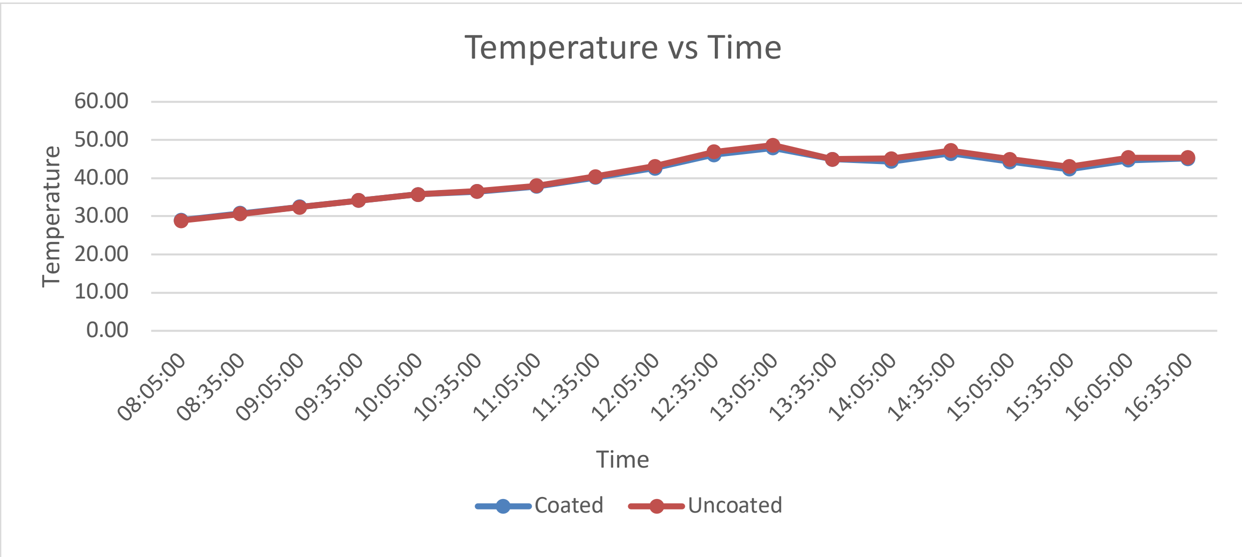

Fig. 9. Temperature differences

4. Conclusions

In conclusion, the PV system 1 with coated rooftop produces more energy and maintain its efficiency due to the passive cooling approaches achieved by applying the M168 coating technology. The performances of the PV systems also achieve the expectation for this investigation. This has been proven by the total energy production of the PV system 1. Total power production from PV system 1 is higher compared to PV system 2. The difference of power generated from both PV systems is about 16%. According to the findings of the investigation, the four PV inverters' current values are only marginally different from one another. However, the current readings for the uncoated rooftop PV system showed irregular and inconsistent pattern compared to the coated rooftop PV system. Therefore, this investigation will required further investigate to find the cause of the patterns. The voltage generated also shows that PV system with coated rooftop can produced more voltage compared to the PV system with uncoated rooftop. Although the coated rooftop PV system showed a little higher temperature reading at the beginning, the temperature constantly lower than the uncoated rooftop PV system after 09:30. From the result, countries with hot, tropical climates can also use this nanocoating passive cooling technique. However, depending on their requirements, the user may select a particular type of nanotechnology coating that will be used as a passing cooling technique approach. This is due to the various coating technologies available on the market, which can be chosen based on their price, benefits, and other variables. Many experiments need to be done for more reliable and accurate data. This is because the external factor such as weather, interruption of power connection, glitch on the PV system, overvoltage and others can affect the PV system performance. This study can serve as a reference for PV system nanocoated passive cooling methods selection.

Declaration

There is no competing intellectual, academic, personal, political, religious, or ideological interests. The author claims to have no conflicts of interest.

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