Design of Augmented Cooling System for Urban Solar PV System

Chong Jia Joon[1] and *Kelvin* Chew Wai Jin[1,*]

[1]School of Computer Science and Engineering, Taylor's University Lakeside Campus, 47500 Subang Jaya, Selangor, Malaysia.

Abstract. Solar photovoltaic (PV) panels have been widely used to convert the renewable energy from the sun to electrical energy to power electrical loads but suffers from relatively low efficiency between 15% to 22%. Typically, the panels have an average lifespan of 25 to 30 years but could degrade quicker due to the panel overheating. Beyond the optimum working temperature of 25°C, a drop of efficiency by 0.4 to 0.5% for every 1°C had been reported. For solar PV applications in urban regions, passive cooling is beneficial due to limited amount of space and lower energy consumption compared to active cooling. A solar PV system with augmented cooling was conducted at a balcony of a condominium from 10am until 2pm. The solar PV system consisted of an Arduino controller, solar panel module, temperature sensor and LCD monitor. Reusable cold and hot gel packs were attached to the bottom of the solar PV. Both setups of solar PV panel with and without the cooling system were placed at the balcony simultaneously for measurement of temperature, output voltage and current. From this research, the outcome of implementing a cooling system to the solar PV increases the efficiency of the energy conversion.

1 Introduction

Pollution on earth have been rising rapidly due to the usage of the non-renewable energy over the renewable energy. Some of the non-renewable energy such as fossil fuels are used as fuel for transportation, heating oil and natural gases that is mainly used to generate electricity. However, the usage of this non-renewable energy will lead to damaging the air quality and environment itself because it emits harmful gases. Therefore, the application and usage of renewable energy such as solar, wind and wave have been prioritized to use as the primary source of power for everyday life leading to a more advance technology. However, the downside to using this renewable source are much more expensive compared to the usage of non-renewable source which still remains comparatively cheaper although the combustion of fossil fuel has led to environmental impact such as the significant rise in carbon dioxide and climate change due to global warming. Although the cost of solar panels has been reduced over decades, the implementation of solar energy for power generation by urban dwellers remains a challenge to them as there is a limited space to mount a solar photovoltaic (PV) panel. However, there is still a downside to the current

* Corresponding author: KelvinWaiJin.Chew@taylors.edu.my

solar PV panel as the panel is mainly placed under the sun to convert sunlight through solar radiation into direct current electricity with the used of semiconductors. This will affect the efficiency to produce electricity because placing under the sun for a long period of time will increase the temperature of the solar PV panel up above the ambient temperature which is 40 °C. This increase will detrimental the energy conversion of the panel leading to energy efficiency lost [1]. The aim of this research is to implement a cooling system to the solar PV system to maintain the desired lower system temperatures for better yields during operation while avoid scavenging the output of the PV system while meeting the space constraint.

The current solar PV panel still have flaws which scientist in this generation is still finding ways to improve the solar PV panel. The solar power panel has, and average lifespan of 25 to 30 years guarantees because as decades pass the modules in the solar panel would not be working as well as first time. Based on the 2012 NREL study, they found out that most solar panel tends to degrade about 0.5% to 3% for each year apart from any equipment issues [2]. This is due to the unavoidable element that leads to the solar PV panel to degrade. Some of the unavoidable are the thermal cycling where it can cause the solder bond to fail which leads to a crack in solar cells, damp heat which is related to the delamination of encapsulants and the corrosion of cells [3]. Moreover, humidity freezing can also cause failure in the junction of box adhesion and long exposure to UV will lead to discoloration and the degradation of the back sheet [3].

Furthermore, the main thing to look out for all electrical appliances is the efficiency of the product. The current solar panel has an efficiency of 15% to 22% to convert solar energy to usable energy. Each solar panel can produce up to 250 to 300 W of power per hour depending on the solar panel rate used and the efficiency [4]. To determine the efficiency, the solar panels are tested under the Standard Test Conditions (STC) at a temperature of 25°C and an irradiance of 1000 W/m2 with the sunlight hitting the panel at a 37° tilted surface [5]. Under these conditions, a solar panel of 1m2 surface area and an efficiency of 15% it will produce 150 W. The two main factors that affect the solar panel efficiency is the PV cell efficiency and the total panel efficiency. The PV cell efficiency is mostly based on the cell design and the silicon material type used which is the P or N type. This can be calculated using the fill factor (FF) equation (1) by Zhang et al. [6].

$$FF = P_{MP} / (V_{OC} \times I_{SC}) \quad (1)$$

where
FF = Fill Factor
P_{MP} = Maximum Power from a solar cell (W)
V_{OC} = Open-circuit Voltage (V)
I_{SC} = Short-circuit Current (A)

Some key characteristics of the cell design are type of silicon, size of wafer, the number of busbars used and the finger layout which all plays an important role in the panel efficiency. The total panel efficiency is measured under standard test conditions (STC) by dividing the output power rating with the total panel area. Some other elements that will affect the efficiency are the cell efficiency, the distance and interconnection of the cell and lastly the back sheet of the panel. As we all know black surface is a good heat absorber therefore the black back sheet will absorb more heat from the sun which increase the cell temperature which will lead to reducing the total conversion efficiency. Basically, the solar panel only absorb the solar energy from the sunlight with the conversion rate of 15% to 22% to convert this solar energy to electrical energy with the remaining percentage converted into heat which will be stored mostly at the bottom of the solar panel. This heat will gradually increase the temperature of the solar panel up to the ambient temperature of 40°C and this rise of temperature will lead to the energy efficiency lost [7]. The relationship between the temperature to the energy efficiency loss can be said as the temperature of the solar panel increases by each degree when it is above 25°C, the energy efficiency loss of the solar panel will drop by 0.4 - 0.5% [8]. As discussed before this high temperature will degrade the lifespan of the solar PV panel. Therefore, to avoid this phenomenon to happen, it is important to come out with a cooling system that will cool down the temperature of the solar panel to 25°C.

Previous studies have concluded that the implementation of cooling system to the solar panel have shown there is an improvement in efficiency of the solar panel. In these studies, there is a total of two cooling method which is the active and passive method. Based on the studies, the active method produces a higher efficiency compared to the passive method because the active method has a higher cooling power however it has a disadvantage as the active method is better for a larger scale of solar panel for big empty land due to the energy return is scientifically higher compare to those solar panel in the urban region which has a space constraint which is mostly on the roof of a certain house. This electrical energy gain is big enough to compensate the electrical energy used by the active method to power the generator or pump depending on medium used to cool the solar panel. Table 1 shows the comparison of all the research studies from literature review.

Table 1. Comparison of solar PV systems with active cooling and passive cooling systems.

Cooling Method	Medium	Efficiency	Energy Consumption	Cost	Location / Scale	Refer-ence
Active	Air / Water	2.4% / 4.7%	High	High	Room / Small	[9]
Active	Air	3 – 5%	High	High	Roof / Small	[10]
Active	Water	12 – 13%	High	High	Land / Big	[11]
Passive	Hydrogel	13 – 19%	~ nil	Mediu m	Land / Small	[1]
Passive	Gel	15 – 19%	~ nil	Mediu m	Land / Small	[12]
Passive	PCM	7 – 8%	~ nil	Mediu m	Roof / Small	[13]

Currently the usage of passive cooling is less compared to the active method because of the cooling power is low compared to the active cooling based on the past literature review. Therefore, this research aimed to study the effect of passive cooling as a cooling system for urban solar PV system. The average solar panel dimension has a 165 cm length and 99 cm wide which has a total area of 16335 cm^2. In this research, the solar panel used will be a scaled down version of the average solar panel which has a 34.5 cm length and 31.5 cm wide which has a total area of 1086.75 cm^2 which has a scaled down factor of 0.067.

2 Methodology

2.1 Material

The material used in this research consist of two solar panel which has a dimension of a 34.5cm length and 31.5cm wide which has a total area of 1086.75 cm^2, two reusable cold and hot gel pack that has a dimensions of 28 cm in length and 14 cm width, a temperature sensor, a LCD display, current and voltage sensor module, a Arduino and material to build a container which will contain water that is place under the solar panel where the reusable cold and hot gel pack is in between them. The solar panel has specifications of maximum power of 15 W, open-circuit voltage of 22.63 V and short-circuit current of 0.91 A.

2.2 Experimental setup

The reusable cold and hot gel pack is placed under the solar panel and it is fastened with a small rectangle Perspex to the frame of the solar panel to ensure that there is maximum contact point between the solar panel and the gel pack. A small container is the build out of Perspex also that is placed under the solar panel where the gel pack is in between the solar panel and container which consist of water. This method is to ensure that the heat from the solar panel transfer to the gel pack and to the water. The setup of the solar panel is the placed at a tilt angle equal to the latitude which is 29.53° because it received the greatest average annual rate of solar radiation according to the Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors [14]. Figure 1 and 2 show the setup of the solar PV panel with the gel pack and container chamber.

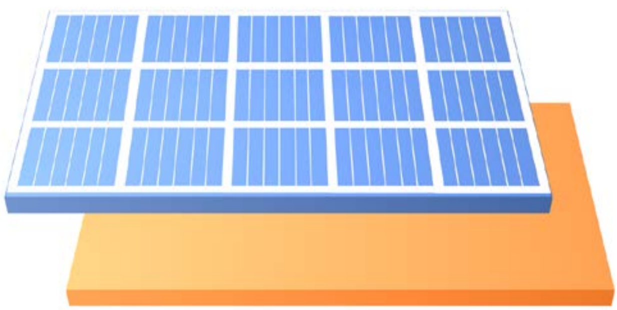

Fig. 1. Setup for attachment of gel pack (orange layer) on solar PV panel.

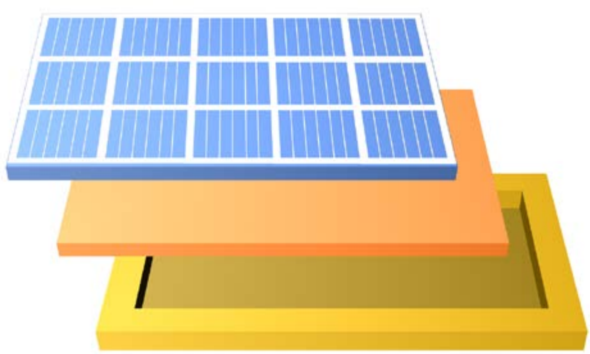

Fig. 2. Setup for container chamber (yellow) on solar PV panel and gel pack (orange).

The electronic parts were built around the Arduino where they were connected to the solar PV panels to obtain parameters for V_{OC}, I_{SC}, and temperature of the surroundings. Figure 3 shows the electrical circuit all the electrical components used for this study.

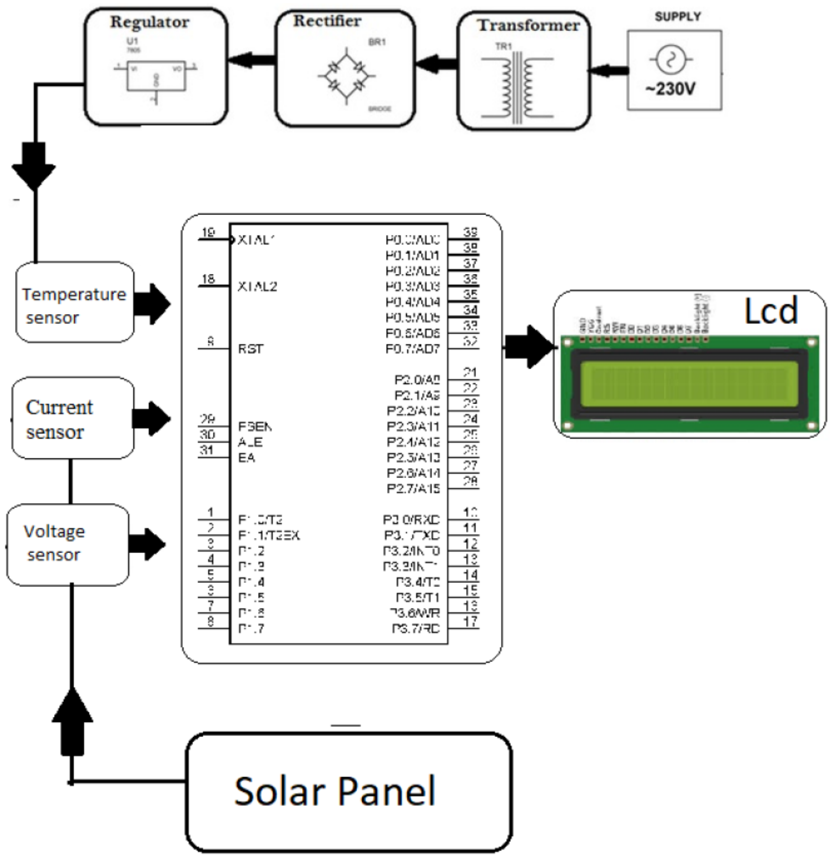

Fig. 3. Electrical connection for all electronic parts of the solar PV system.

2.3 Measurement and analysis

The solar PV systems with and without cooling system was placed at an open area of a condominium where it received sunlight from 10 am to 2 pm daily. The experiment was conducted for 4 hours per day for several days. Reading of output current and voltage were acquired every 15 minutes for 4 hours per day and at the end of the day the average reading per hour was calculated using equation (2). In addition, both ambient and panel temperatures were monitored.

$$Average\ reading = \sum All\ readings\ per\ hour\ /\ 4 \qquad (2)$$

2.4 Calculation of System Efficiency

The calculation needed for this research is fill factor which can be calculated using equation (1), efficiency of the solar panel by using equation (3) by Borkar et al. [15], efficiency enhancement by using equation (4) by Li etal. [1] and efficiency gain by using equation (5).

$$\eta = (V_{OC} \times I_{SC} \times FF) / P_{IN} \quad (3)$$

$$E = [(\eta \textit{ with cooling system} / \eta \textit{ without cooling system}) - 1] \times 100\% \quad (4)$$

$$\textit{Efficiency Gain} = [(\eta \textit{ with cooling system}) - (\eta \textit{ without cooling system}) \quad (5)$$

where
η = Efficiency of solar panel
FF = Fill Factor
V_{OC} = Open-circuit Voltage (V)
I_{SC} = Short-circuit Current (A)
P_{IN} = Maximum Power from a solar cell (W), determined from panel surface area with typical solar insolation of 100 mW/cm^2
E = Efficiency enhancement (%)

3 Results and Discussion

During operation outdoors, the temperature of solar panels tends to vary due to their exposure to dynamic ambient conditions with different weather elements. As the performance of a solar photovoltaic module is dependent on its operating temperature, control of the temperature of solar panel is one key aspect to ensure its optimum performance. As the operating temperature of solar panel was increased from 0 to 75°C, the power-voltage curves, as illustrated in Figure 4, decreased substantially with correspondingly lower maximum power generated [11]. Without any cooling systems in place, the temperature of solar panels had been reported to reach between 60°C and 80°C when under operation [16].

Heat dissipation to keep solar panel cool during operation can be achieved via either active or passive cooling methods. Active cooling by a method combining metal plate as heat sink and electrical fans had been shown to reduce the solar panel temperature by up to 12°C [16]. Room for improvement for both active and passive cooling methods still exists as active cooling methods tend to be more effective in heat removal but require electrical energy and conversely, passive cooling methods do not require electrical energy for operation but the amount of heat dissipation is generally lower than that of active methods [17, 18].

Preliminary results of the present in terms of the power output in comparison with those from other researchers are as shown in Figure 5. In general, the power output of the solar panel declined with rising temperature from 25°C to 60°C without any cooling mechanism being employed. This finding is in agreement with the drop of maximum power output reported by Zaini et al. [19] and Ahmad et al. [20] for monocrystalline silicon (Si) and polycrystalline silicon (Si) solar panels, respectively. However, both groups of researchers tested their solar panels under constant solar irradiation supplied by electrical lamps while the present study was conducted under ambient conditions, in which the solar irradiation might be varying. It should also be noted that the power ratings of the solar panels were different among the studies.

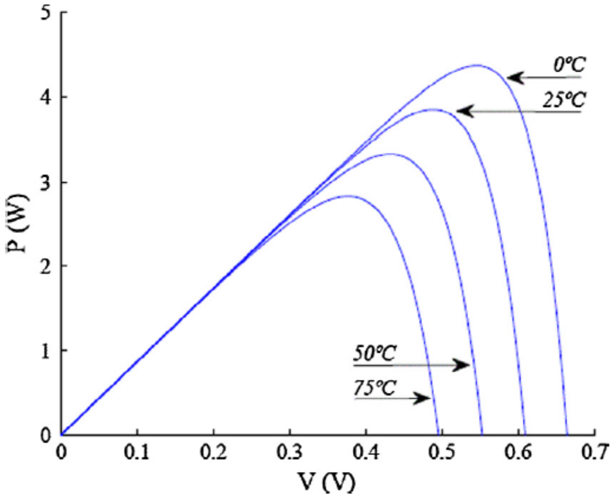

Fig. 4. Output power-voltage (PV) curves of solar panel under different operating temperatures. [11]

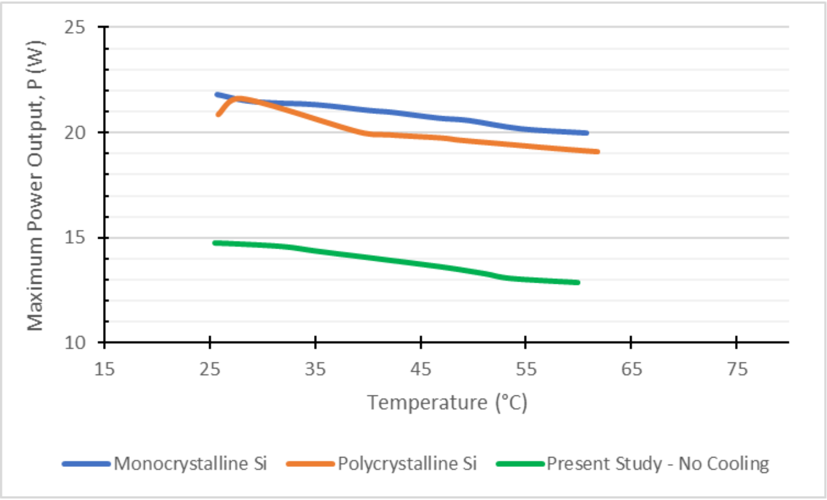

Fig. 5. Maximum power output of different solar panels with increasing temperatures. [19, 20]

Subsequent test run of the solar panel with the designed cooling system showed positive signs with the maximum power output ranging between 13.7 to 14.5 W with the temperature not exceeding the 40°C mark. However, repeated runs are needed to confirm this data trend. Upon confirmation, the data trend would indicate that the augmented passive cooling mechanism could possibly improve the solar photovoltaic operation and hence, a rise in the overall efficiency of the solar panel operation. As the efficiency of modern solar panels are between 20% to 40%, an improvement in the overall power output would be significant, especially when the number of panels are abundant such as in solar farms for renewable energy generation.

4 Conclusions

The present study has verified the degradation of the performance of solar panel when operating without cooling system due to increasing temperature. Preliminary results also indicated that the augmented cooling system designed was able to increase the maximum power output while keeping the temperature below 40°C, and hence, could possibly improve the efficiency of the solar photovoltaic operation. Nevertheless, the finding need repeated runs for confirmation as well as future work such as extended duration of exposure and the measurement of solar irradiation during test runs. Findings from the present research can help to make solar energy more economical to encourage the adoption by both domestic and industrial users as the government prioritizes renewable energy sources for future energy mix.

The authors would like to express their gratitude to the management staff of engineering laboratory of Taylor's University for providing the tools and to the School of Computer Science and Engineering for the budget for this project.

References

1. R. Li, Y. Shi, M. Wu, S. Hong, P. Wang, Nat. Sustain. **3**, 636 (2020)
2. D. Jordan, S. Kurtz, Prog. Photovoltaics: Res. Appl. **21**, 16 (2011)
3. C. A. Escoffery, W. Luft, Sol. Energy **4**, 1 (1960)
4. W. G. J. van Helden, R. J. Ch. van Zolingen, H. A. Zondag, Prog. Photovoltaics: Res. Appl. **12**, 415 (2004)
5. S. M. Menke, N. A. Ran, G. C. Bazan, R. H. Friend, Joule **2**, 25 (2018)
6. X. Zhang, N. Yao, R. Wang, Y. Li, D. Zhang, G. Wu, J. Zhou, X. Li, H. Zhang, J. Zhang, Z. Wei, C. Zhang, H. Zhou, F. Zhang, Y. Zhang, Nano Energy **75**, 105032 (2020)
7. S. K. Natarajan, T. K. Mallick, M. Katz, S. Weingaertner, Int. J. Therm. Sci. **50**, 2514 (2011)
8. H. Lee, J. Mun, N. N. Nguyen, J. Rho, K. Cho, Nano Energy **78**, 105336 (2020)
9. R. Ali, S. Celik, Int. P. Chem. Biol. Environ. Eng. **100**, 118 (2017)
10. H. G. Teo, P. S. Lee, M. N. A. Hawlader, Appl. Energy **90**, 309 (2012)
11. K. A. Manoharram, M. S. Abd-Elhady, H. A. Kandil, H. El-Sherif, Ain Shams Eng. J. **4**, 869 (2013)
12. R. F. Service, Sci. Magazine, May, 11 (2020)
13. R. Stropnik, U. Stritih, Renew. Energ. **97**, 671 (2016)
14. M. A. Dunlap, W. Marion, S. Wilcox, Technical Report NREL/TP-463-5607 (1994)
15. D. S. Borkar, S. V. Prayagi, J. Gotmare, Int. J. Eng. Res. **3**, 536 (2014)
16. Z. Farhana, Y. M. Irwan, R. M. N. Azimmi, A. R. N. Razaliana, N. Gomesh, 2012 IEEE Symposium on Computers & Infomatics (ICSI), 165 (2012)
17. S. A. Zubeer, H. A. Mohammed, M. Ilkan, International Conference on Advances in Energy Systems and Environmental Engineering (ASEE17), E3S Web Conf. **22**, 00205 (2017)
18. S. A. Rakino, S. Suherman, S. Hasan, A. H. Rambe, Gunawan, J. Phys. Conf. Ser. **1373**, 012017 (2019)
19. N. H. Zaini, M. Z. Ab Kadir, M. Izadi, N. I. Ahmad, M. A. M. Radzi, N. Azis, 2015 IEEE Conference on Energy Conversion (CENCON), 249 (2015)
20. N. I. Ahmad, M. Z. Ab Kadir, M. Izadi, N. H. Zaidi, M. A. M. Radzi, N. Azis, 2015 IEEE Conference on Energy Conversion (CENCON), 244 (2015)