



Experimental Evaluation of Passive Cooling PV Module using Different Heat Sink Configurations

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Abstract

This study aimed to evaluate passive cooling performance of a PV module using two different designs of novel passive fin heat sinks. An experimental rig under real environmental conditions was tested. At an average solar radiation of 1000W/m² and an ambient temperature of 33°C, the results revealed that the passive cooling with lapping fins design demonstrates the best performance with mean PV module temperature 24.6 °C lower than the PV module without cooling. Hence, the achieved electrical efficiency and power output are as high as 10.68% and 37.1 W respectively. Whereas, the Life Cycle Cost Analysis (LCCA) was conducted and the analysis showed that the payback period for PV module with longitudinal and lapping fins are 4.2 and 5 years respectively. While, for the reference PV module, the payback period is 8.4 years due to the performance degradation caused by increase in PV temperature. Therefore, PV module cooling using passive technique particularly with lapping fins design is concluded as the preferred option.

Keywords: Passive cooling; heat sink ; concentrated; efficiency, LCCA.

Introduction

Solar energy gained via PV technology is assumed to be the key of sustainable power generation for various applications. In 2018, solar energy accounted for 42.5% of total investment among all new renewable energy systems and the increase in the installation capacity of solar PV power worldwide was recorded at 7% which gives over 107 GW of installation capacity [1]. PV harnesses electrical energy when it absorbs the incident solar radiation. However, in the market today, the most efficient solar panels can convert the absorbed solar radiation to electricity at 22.8% efficiency, whereas most of the panels available in the market are 15% -17% in efficiency. Such efficiency values imply that only a small fraction of the solar radiation is captured and converted to electricity. In addition due to the absorption of solar radiation, panel temperature undesirably increases, which results in drop in efficiency also degradation of the performance of panel components such as the electrical conduits, sealants, solders [2]. Reported in [2], due to the negative effect of 'high temperature' on the PV performance, many research on PV cooling method have been conducted up to date. Figure 1(a) and (b) simplify the tables and presenting an overall image of the temperature reduction variations achieved by passive and active

cooling of PV module, respectively. Figure 1(a) and (b) shows that without cooling, the PV module temperature ranging from 32.8–90.0°C, depending on the working and environmental conditions. Meanwhile, different passive and active cooling approaches have led to lower PV module temperature ranging from 25.0–65.7°C and 32–70°C for passive and active cooling approaches, respectively.

Table 1: PV temperature difference using passive cooling from selected research works

Ref's	Pv module temp without cooling (°C)	Pv module temp with cooling (°C)	PV Temp difference (°C)
[3]	84.0	46.0	38.0
[4]	N/A	N/A	10.0
[5]	N/A	N/A	30.0
[6]	76.7	55.5	21.2
[7]	80.0	60.0	20.0
[8]	83.3	65.7	17.6
[9]	N/A	N/A	18.0
[10]	90.0	65.0	25.0
[11]	62.3	50.1	12.2
[12]	68.3	51.9	16.4
[13]	58.6	34.3	24.3
[14]	65.0	45.0	20.0
[15]	50.0	25.0	25.0
[16]	88.0	45.0	43.0
[17]	54.0	35.0	19.0
[18]	60.0	55.7	4.30
[19]	59.4	30.8	28.6
[20]	63.5	48.7	14.8
[21]	53.0	42.0	11.0
[22]	N/A	N/A	5.20
[23]	80.0	61.0	19.0
[24]	49.2	43.3	5.90
[25]	32.8	31.0	1.80

Table 2: PV/T temperature reduction using active cooling from selected research works

Ref's	Pv module temp without cooling (°C)	Pv module temp with cooling (°C)	PV Temp difference (°C)
[26]	N/A	N/A	22.0
[27]	60.0	37.0	23.0
[28]	58.0	32.0	26.0
[29]	90.0	70.0	20.0
[30]	N/A	N/A	32.0
[31]	62.0	47.0	15.0
[32]	45.0	35.0	10.0
[33]	67.0	60.0	07.0
[34]	59.0	39.0	20.0
[35]	60.0	40.0	20.0

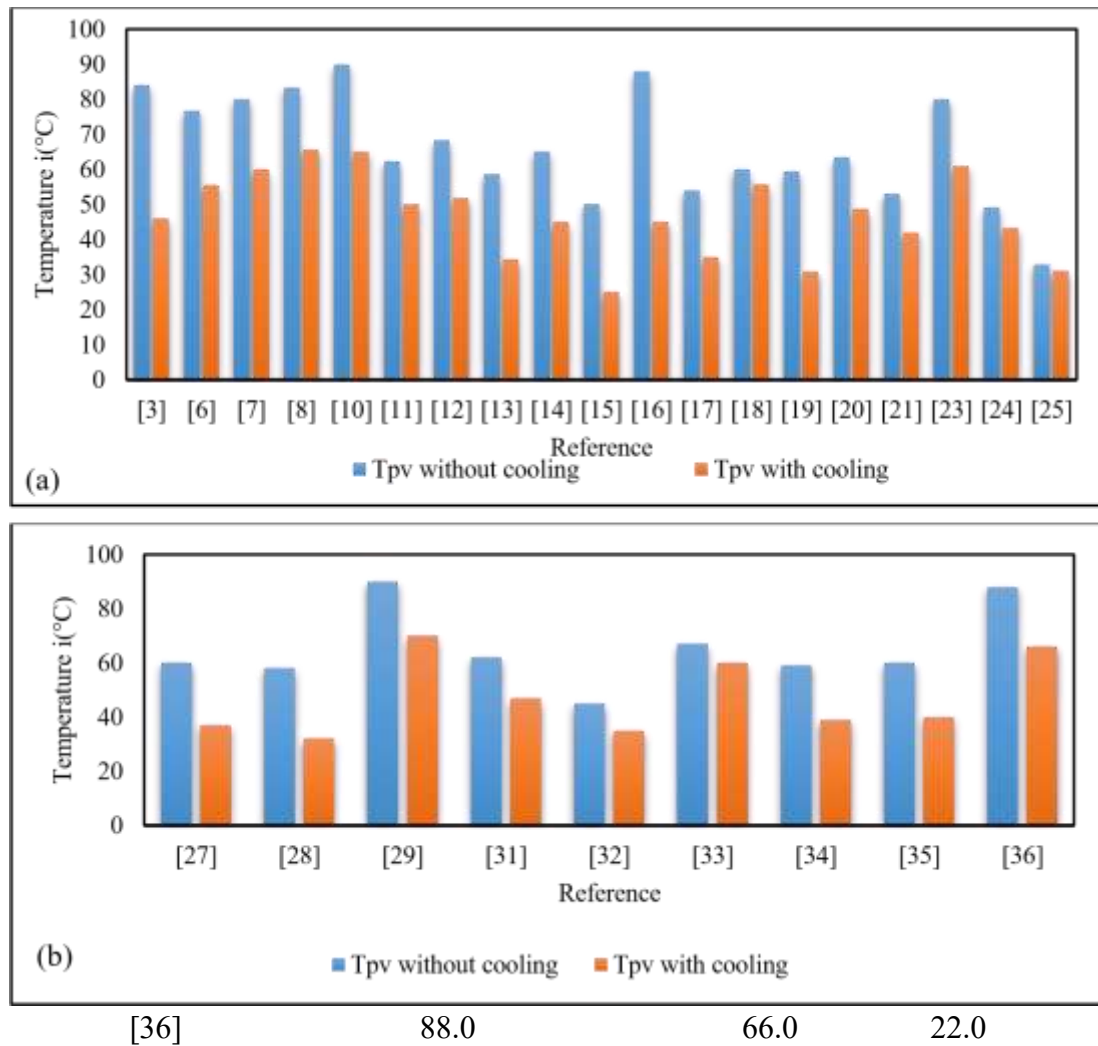


Figure 1: PV temperature with/without cooling (a) passive cooling and (b) active cooling.

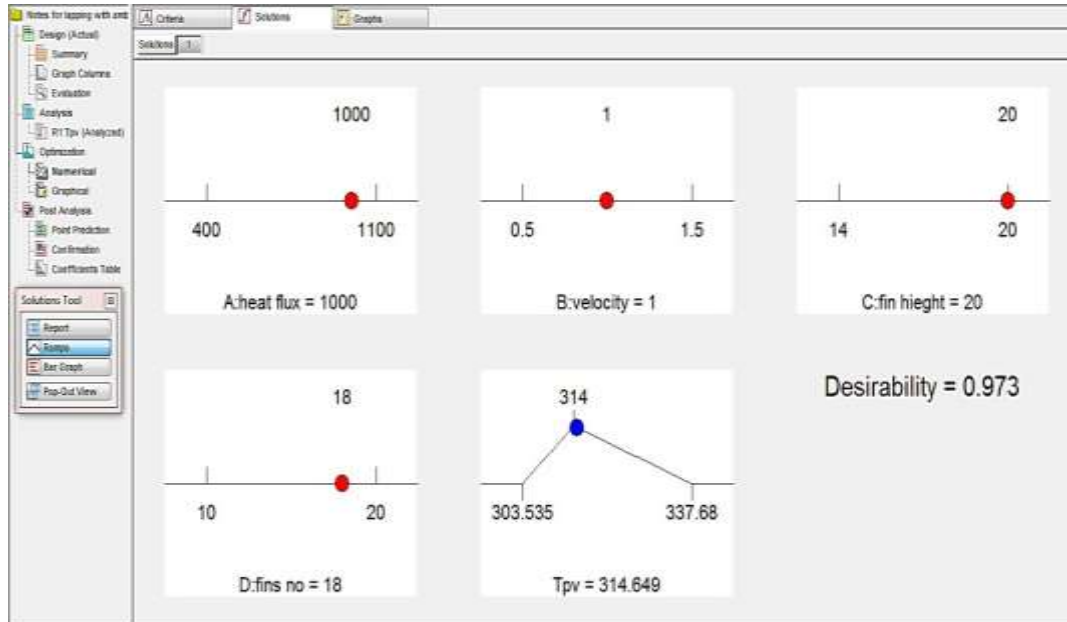
Design of experimental software utilized for optimizing the climate and design parameters

(DOE) approach using response surface method (RSM) / Face Central Composite Design (FCCD) technique to optimize the factors that affect the passive cooling of the PV module with planar reflector and two proposed fin configurations (lapping and Longitudinal fins). Meanwhile, the tilt angle has been well studied in literature review and the optimum tilt angle for Bangi, Selangor location was considered between 10-14° [37]. The design parameters and the four aforementioned factors; fin height, number of fins, wind speed, and solar irradiance factors are called A, B, C, and D, respectively, are presented in Table 3.

Table 3: Input factors and respective variation ranges

	Named	Units	Min	Max	Mean
A	Height of fin	mm	14	20	17
B	Number of fins	-	10	20	15
C	Wind speed	m/s	0.5	1.5	1
D	Solar irradiance	W/m ²	400	1100	750

Figure 2, illustrates an example that presents the optimum lapping fin height and number of fins in DOE software at wind speed and solar irradiance kept constant at 1 m/s, 1000 W/m², respectively, and the mean PV module temperature was set to be minimum. The results showed that at optimum fin height 200 mm, number of fins is 18, wind speed 1 m/s, and solar irradiance 1000



W/m², the mean PV module temperature could reach 41.6 °C with a desirability of 97.3% Meanwhile, for longitudinal fins (not shown in the figure), the optimum fin height is also 200 mm, and the number of fins is 15

Figure 2: Lapping fin height and number of fins optimizing at $w_s = 1\text{m/s}$ and $I_r = 1000\text{W/m}^2$ for reducing the PV module temperature to NCOT

3. Experimental work:

lapping and longitudinal fins were designed and installed from 1st of March until 30 Sep 2017 on the 7th floor at Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia(UKM). Meanwhile, infrared imaging has been performed on a clear sunny day using thermal imaging camera TROTEC IC085LV as shown in Figure3(a). IR help to detect the module defects and temperature gradients within a PV module or array occurring due to convective heat transfer [38]. In addition, two different fin designs (lapping and the longitudinal fins) have been carried out experimentally. Figure 3(b) shows the stages of lapping fins design with a planar reflector.



Figure 3: (a) IFcamera, (b) designing lapping fins with planar reflector

An experimental setup was designed and fabricated. The setup consists of three parts side-by-side Figure 4 (a),(b) and (c) shows the setup of the bare PV module without cooling fins (as a reference), PV module with planar reflector with lapping fins and PV module with planar reflector and longitudinal fins. The experimental data were collected simultaneously from the three designed systems through the data logger and the I-V tracer.

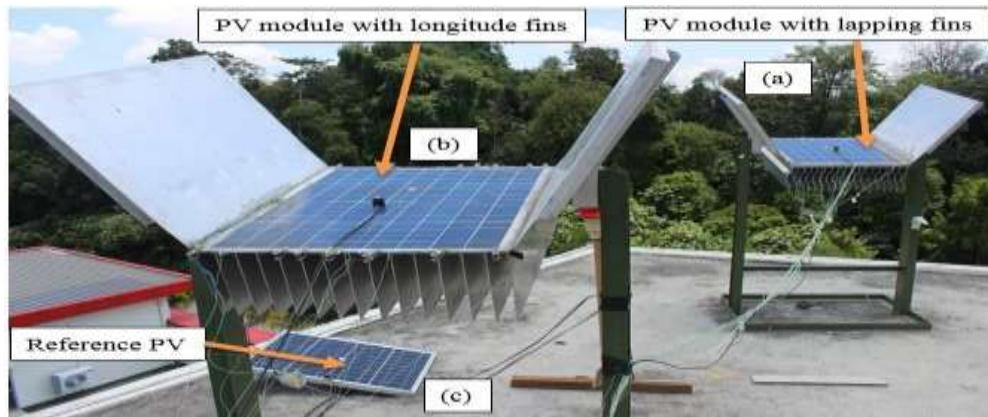


Figure 4: (a) PV with lapping fins and planar reflector (b) PV with longitudinal fins and planar reflector, and (c) Bare PV

Results And Discussion

Figure 5, presents the hourly variation of solar irradiance and ambient temperature distribution with and without reflector.

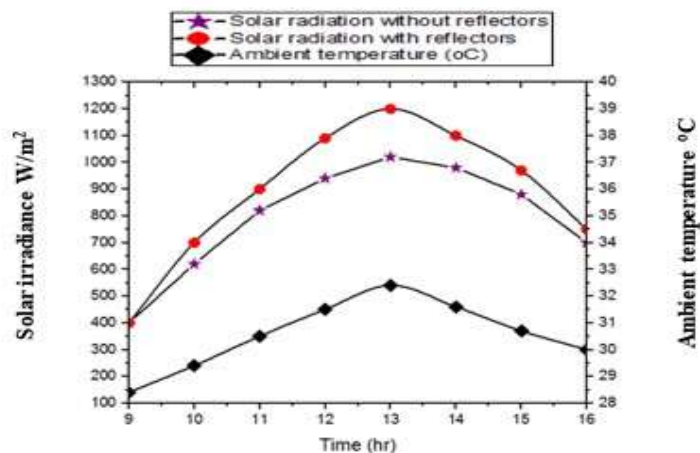


Figure 5: hourly variation of solar irradiance and ambient temperature distribution with and without reflector

1. Bare PV module performance

Table 4 and Figure 6 show the results of the electrical performance of the PV module without cooling at solar irradiance varied from 400-1000 W/m². The results showed that short circuit current increased from 0.94 A to 2.3 A with the increase in solar irradiance. Meanwhile, the open circuit voltage decreased from 19.6 V to 18.5v under the same conditions, the change in the output power was calculated and was found to increase from 11.45w to 18.5 W.

Table 4: Characteristic of bare PV module at different solar irradiance

Solar irradiance W/m ²	Isc (A)	Voc (V)	Pmax (Watt)	Electrical eff (η _{ele})
400	0.94	19.6	11.45	11.09
600	1.35	19.25	14.82	10.66
800	1.93	18.8	17.1	10.25
1000	2.3	18.5	18.5	9.81

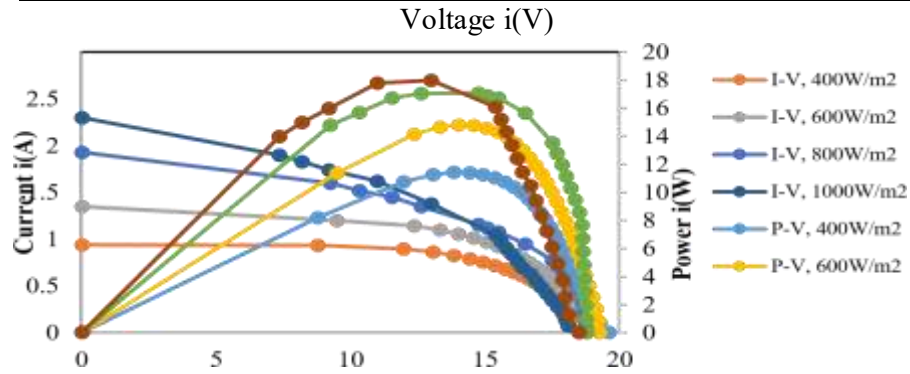


Figure 6: I-V and P-V curves for bare PV module at different solar irradiance
 2. PV module performance with planar reflector and lapping fins The results obtained from PV module with planar reflector and 18 lapping fins “as an optimal number of fins given by DOE software” is shown in Figure 7 and further simplified in Table 5. It can be concluded that for solar irradiance ranging from 400-1000 W/m² the short circuit current, open circuit voltage, and the output power increased from (1.1-2.65 A), (19.0-20.1 V), and (11.26-31.9 W) respectively.

Table 5: PV module results with reflector and 18 lapping fins for solar irradiance varied from 400-1200 W/m²

Solar irradiance W/m ²	Isc (A)	Voc (V)	Pmax (Watt)
400	1.10	19.00	11.26
600	1.50	19.59	16.94
800	2.07	19.85	24.3
1000	2.65	20.10	31.9
1200	3.02	20.15	37.1

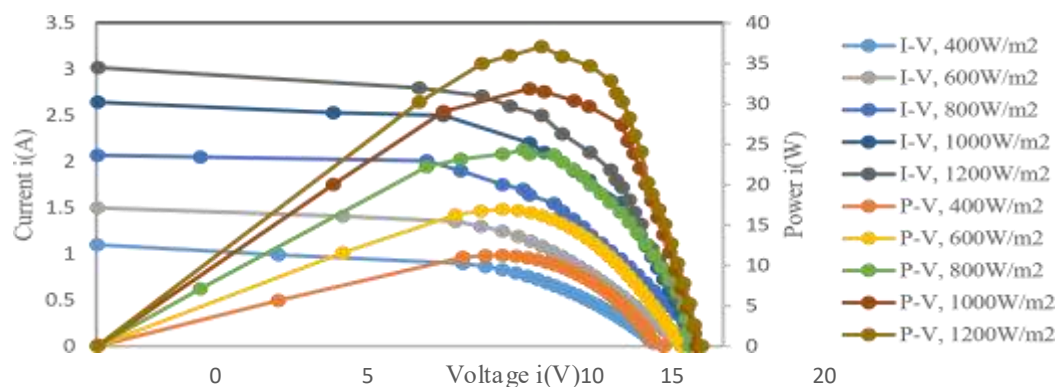


Figure 7: I-V and P-V curves for PV module at 18 lapping fins

3. PV module with planar reflector and longitudinal fins For PV module with planar reflector and longitudinal fins, the optimal number of fins given by DOE software is 15. The experimental results are summarized and shown in Table 6 and Figure 8. It can be concluded that for solar irradiance varied from 400-1000 W/m² the short circuit current, open circuit voltage, and the output power, were increased from (1.1-2.01A), (18.87-19.98V), and (11.11-23.08W), respectively.

 Table 6 : Characteristic of PV module with reflector and 15 longitudinal fins for solar irradiance varied from 400-1200 W/m²

Solar irradiance W/m ²	Isc (A)	Voc (V)	Pmax (Watt)
400	1.10	18.87	11.11
600	1.57	19.25	15.91
800	1.65	19.48	18.19
1000	2.01	19.98	23.08
1200	2.58	20.13	30.65

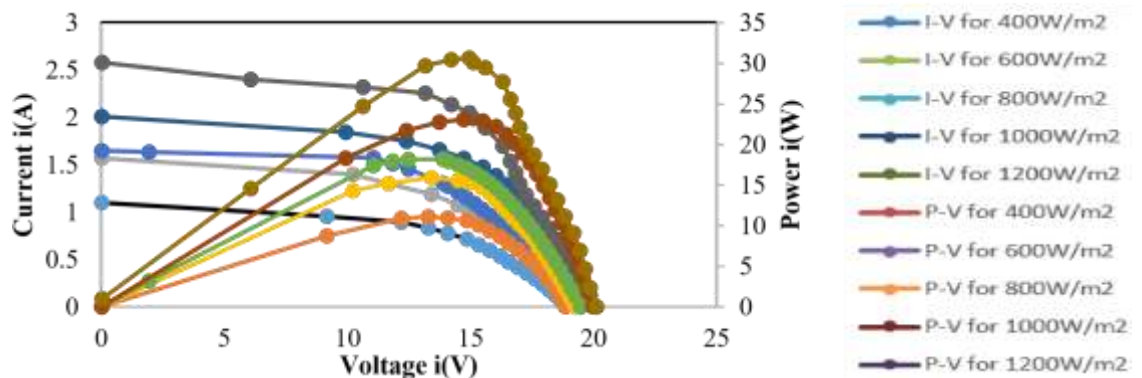


Figure 8: I-V and P-V curves for PV module at 15 longitudinal fins

Overall performance of PV module with and without planar reflector and fins configurations:

Figure 9, shows the overall experimental results for the bare PV module, PV module with planar reflector and 18 lapping fins, and PV module with planar reflector and 15 longitudinal fins. When compared with the PV performance of bare PV module, the results indicated that the PV module with planar reflector and 15 longitudinal fins enhance the electrical efficiency from 9.81% to 10.7%. Meanwhile, in the case of using PV module with planar reflector and 18 lapping fins, the electrical efficiency improved from 9.81% without cooling to 11.2%. Moreover, the experimental results showed that, the PV module temperature with fin cooling at solar irradiance 1000 W/m² was as low as 49.03 °C and 41.6 °C when passive cooled using longitudinal fins and lapping fins, respectively. Under the same experimental conditions, the temperature achieved by the PV module with longitudinal and lapping fins heat sink are 23.8% and 35.3% respectively lower compared to the bare PV module temperature without cooling. In addition, at 1200 W/m² the

power output of the PV module are 30.6 W and 37.1 W for the longitudinal and lapping fins respectively. It can be concluded that the lapping fins has a superior performance compared to longitudinal fins.

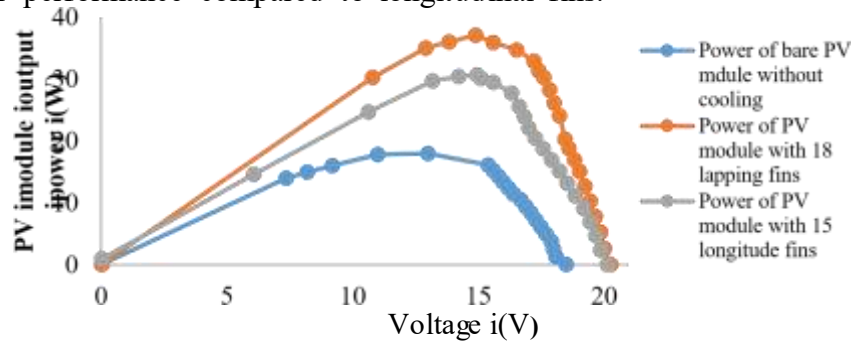


Figure 9: Comparison of output power for the designed fins

Life Cycle Cost Analysis (LCCA) for lapping and longitudinal fins
 The overall LCC for the bare PV module, PV module with lapping fins, PV module with longitudinal fins, net present value, and the annual energy productivity are illustrated in Table 7 and Figure 10.

Table 7: LCC analysis of PV module with lapping and longitudinal fins with optimum parameters

Description	PV+ lapping fins	PV+ longitudinal fins	Bare PV module
Life Cycle Cost LCC (USD)	151.4	140.6	42
Total Initial Cost (USD)	123	113.00	34
Maintenance Cost (USD)	4.37	3.61	2.86
Replacement Cost (USD)	24	24	4.46
Net present value (USD)	262	198	29.79
Annual Energy Productivity (kWh)	54	46.	40.
Simple Payback (Years)	4.20	5.0	8.4

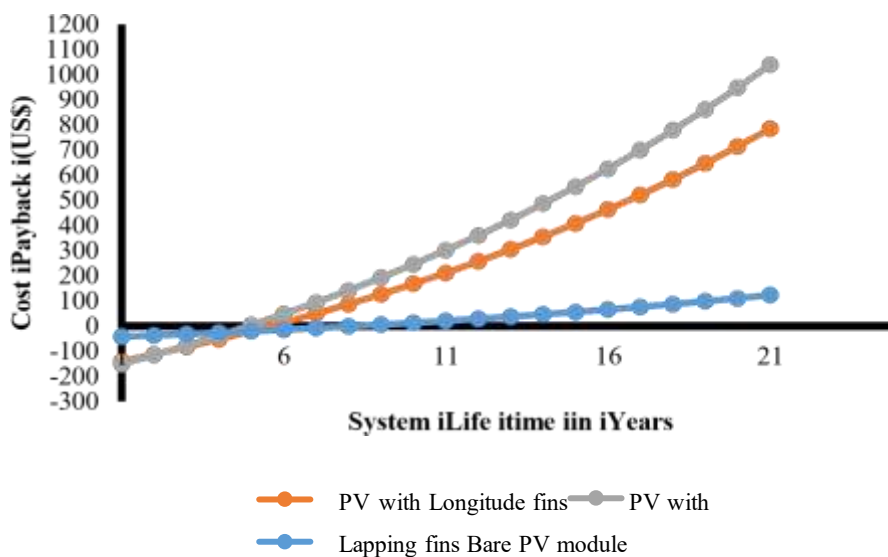


Figure 10: Life cycle cost analysis for lapping and longitudinal fins

Conclusion

From the DOE analysis, the optimum fin height is 200 mm for both lapping and longitudinal fins heat sinks respectively. Meanwhile, the optimum number of fins for lapping and longitudinal fins heat sink are 18 and 15 respectively. Passive cooling with lapping fins demonstrates the best performance with mean PV module temperature 24.6 °C lower than the reference PV module, with the achieved electrical efficiency and power output as high as 10.68% and 37.1 W respectively. The LCCA showed that the payback period for PV module with longitudinal and lapping fins are 4.2 and 5 years respectively. Meanwhile, for the reference PV module, the payback period is 8.4 years due to the performance degradation caused by the increase in average

PV temperature. Therefore, cooling PV module using passive technique particularly with lapping fins design is concluded as the preferred option over longitudinal fins design due to its simplicity and low-cost.

References

- [1] Jäger-Waldau, A. 2019. PV Status Report 2019. Publications Office of the European Union, Luxembourg.
- [2] Sato, D., and Yamada, N. 2019. Review of photovoltaic module cooling methods and performance evaluation of the radiative cooling method. *Renewable and Sustainable Energy Reviews*. 104(1): 151-166.
- [3] Akbarzadeh, A. and Wadowski, T. 1996. Heat pipe-based cooling systems for photovoltaic cells under concentrated solar irradiation. *Applied Thermal Engineering*. 16(1): 81-87.
- [4] Araki, H., Uozumi, and Yamaguchi, "A simple passive cooling structure and its heat analysis for 500 X concentrator PV module." pp. 1568-1571.
- [5] M. Huang, P. Eames, and B. Norton, "Phase change materials for limiting temperature rise in building integrated photovoltaics," *Solar Energy*, vol. 80, no. 9, pp. 1121-1130, 2006.
- [6] J. A. Duffie, and W. A. Beckman, *Solar engineering of thermal processes: John Wiley & Sons*, 2013.
- [7] C. Sangani, and C. Solanki, "Experimental evaluation of V-trough (2 isuns) PV concentrator system using commercial PV modules," *Solar energy materials and solar cells*, vol. 91, no. 6, pp. 453-459, 2007.
- [8] G. Mittelman, A. Alshare, and J. H. Davidson, "A model and heat transfer correlation for rooftop integrated photovoltaics with a passive air cooling channel," *Solar Energy*, vol. 83, no. 8, pp. 1150-1160, 2009.
- [9] A. Hasan, S. McCormack, M. Huang, and B. Norton, "Evaluation of phase change materials for thermal regulation enhancement of building integrated photovoltaics," *Solar Energy*, vol. 84, no. 9, pp. 1601-1612, 2010.
- [10] S. Maiti, S. Banerjee, K. Vyas, P. Patel, and P. K. Ghosh, "Self regulation of photovoltaic module temperature in V-trough using a metal-wax composite phase change matrix," *Solar Energy*, vol. 85, no. 9, pp. 1805-1816, 2011.
- [11] E. Cuce, T. Bali, and S. A. Sekucoglu, "Effects of passive cooling on performance of silicon photovoltaic cells,"

- International Journal of Low-Carbon Technologies*, vol. 6, no. 4, pp. 299-308, 2011.
- [12] S. K. Natarajan, T. K. Mallick, M. Katz, and S. Weingaertner, "Numerical investigations of solar cell temperature for photovoltaic concentrator system with and without passive cooling arrangements," *International Journal of Thermal Sciences*, vol. 50, no. 12, pp. 2514-2521, 2011.
- [13] E. L. Meyer, and M. Busiso, "Comparative study of a directly cooled PV water heating system to a naturally cooled module in South Africa." pp. 001296-001299.
- [14] M. Chandrasekar, S. Suresh, and T. Senthilkumar, "Passive cooling of standalone flat PV module with cotton wick structures," *Energy Conversion and Management*, vol. 71, pp. 43-50, 2013.
- [15] A.-M. CROITORU, and A. Ibađea, "Water cooling of photovoltaic panels from passive house located inside the university politehnica of Bucharest," 2013.
- [16] A. H. Alami, "Effects of evaporative cooling on efficiency of photovoltaic modules," *Energy Conversion and Management*, vol. 77, pp. 668-679, 2014.
- [17] S. Wu, and 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.
- [18] Y. S. Indartono, A. Suwono, and F. Y. Pratama, "Improving photovoltaics performance by using yellow petroleum jelly as phase change material," *International Journal of Low-Carbon Technologies*, pp. 033, 2014.
- [19] S. Mehrotra, P. Rawat, M. Debbarma, and K. Sudhakar, "Performance of a solar panel with water immersion cooling technique," *International Journal of Science, Environment and Technology*, vol. 3, pp. 1161-1172, 2014.
- [20] P. Valeh-e-Sheyda, M. Rahimi, A. Parsamoghadam, and M. M. Masahi, "Using a wind-driven ventilator to enhance a photovoltaic cell power generation," *Energy and Buildings*, vol. 73, pp. 115-119, 2014.
- [21] H. Mahamudul, M. Silakhori, I. H. Metselaar, S. Ahmad, and S. Mekhilef, "Development of a temperature regulated photovoltaic module using phase change material for Malaysian weather condition," *Optoelectronics and Advanced Materials-Rapid Communications*, vol. 8, no. 11-12, pp. 1243-1245, 2014.
- [22] L. Maturi, R. Lollini, D. Moser, and W. Sparber, "Experimental investigation of a low cost passive strategy to improve the performance of building integrated photovoltaic systems," *Solar Energy*, vol. 111, pp. 288-296, 2015.
- [23] P. Atkin, and M. M. Farid, "Improving the efficiency of photovoltaic cells using PCM infused graphite and aluminium fins," *Solar Energy*, vol. 114, pp. 217-228, 2015.
- [24] M. Chandrasekar, and T. Senthilkumar, "Passive thermal regulation of flat PV modules by coupling the mechanisms of evaporative and fin cooling," *Heat and Mass Transfer*, pp. 11-11, 2015.

- [25] C. Ho, W.-L. Chou, and C.-M. Lai, "Thermal and electrical performance of a water-surface floating PV integrated with a water-saturated MEPCM layer," *Energy Conversion and Management*, vol. 89, pp. 862-872, 2015.
- [26] S. Krauter, "Increased electrical yield via water flow over the front of photovoltaic panels," *Solar Energy Materials and Solar Cells*, vol. 82, no. 1, pp. 131-137, 2004.
- [27] M. Abdolzadeh, and 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.
- [28] S. Odeh, and M. Behnia, "Improving photovoltaic module efficiency using water cooling," *Heat Transfer Engineering*, vol. 30, no. 6, pp. 499-505, 2009.
- [29] D. Yang, and H. Yin, "Energy conversion efficiency of a novel hybrid solar system for photovoltaic, thermoelectric, and heat utilization," *IEEE Transactions on Energy Conversion*, vol. 26, no. 2, pp. 662-670, 2011.
- [30] X. Han, Y. Wang, and L. Zhu, "Electrical and thermal performance of silicon concentrator solar cells immersed in dielectric liquids," *Applied Energy*, vol. 88, no. 12, pp. 4481-4489, 2011.
- [31] H. Xiang, Y. Wang, L. Zhu, X. Han, Y. Sun, and Z. Zhao, "3D numerical simulation on heat transfer performance of a cylindrical liquid immersion solar receiver," *Energy Conversion and Management*, vol. 64, pp. 97-105, 2012.
- [32] K. Moharram, M. Abd-Elhady, H. Kandil, and H. El-Sherif, "Enhancing the performance of photovoltaic panels by water cooling," *Ain Shams Engineering Journal*, vol. 4, no. 4, pp. 869-877, 2013.
- [33] A. Al Tarabsheh, S. Voutetakis, A. I. Papadopoulos, P. Seferlis, I. Etiera, and O. Saraereha, "Investigation of Temperature Effects in Efficiency Improvement of Non-Uniformly Cooled Photovoltaic Cells," *CHEMICAL ENGINEERING*, vol. 35, 2013.
- [34] W. Phayom, "Improvement of Photovoltaic Module for Increasing Energy Conversion Efficiency." pp. 1428-1432.
- [35] H. D. Raval, S. Maiti, and A. Mittal, "Computational fluid dynamics analysis and experimental validation of improvement in overall energy efficiency of a solar photovoltaic panel by thermal energy recovery," *Journal of Renewable and Sustainable Energy*, vol. 6, no. 3, pp. 1033138, 2014.
- [36] M. Rahman, M. Hasanuzzaman, and N. Rahim, "Effects of various parameters on PV-module power and efficiency," *Energy Conversion and Management*, vol. 103, pp. 348-358, 2015.
- [37] O. Saadatian, K. Sopian, B. Elhab, M. Ruslan, and N. Asim, "Optimal solar panels' tilt angles and orientations in Kuala Lumpur, Malaysia," *Tomas Bata University Zlin, Czech Republic*, 2012, pp. 100-106.
- [38] A. Pavgi, *Temperature Coefficients and Thermal Uniformity Mapping of PV Modules and Plants: Arizona State University*, 2016.