JOURNAL OF TECHNIQUES

Journal homepage: http://journal.mtu.edu.iq

RESEARCH ARTICLE - ENGINEERING

An Experimental Study for Enhancing the Performance of the Photovoltaic Module Using Forced Air

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Article Info.

Article history:

Received
14 February 2022

Accepted
30 May 2022

Publishing
30 June 2022

Abstract

The performance of the photovoltaic (PV) module is greatly affected by ambient conditions such as solar irradiance and air temperature. Increasing the ambient temperature plays a major role in raising the PV temperature and then reducing its performance by reducing its voltage. In this work, an experimental investigation was carried out to enhance the performance of the PV module by using the thermal-photovoltaic (PVT) technique. The PVT was prepared by integrating the PV module with an air duct. The air was forced by an electrical centrifugal fan with variable speeds (1.5, 2.5, and 3.5 m/s). The analysis of the obtained results showed that the PVT technique can lower the PV temperature from 5 to 16 °C when the air volume flow rate changes from 335 to 760 m^3/h. In contrast, the maximum enhancement of PVT power was recorded at 8.2% at a maximum air volume flow rate of 760 m^3/h causing a maximum electrical efficiency of about 17.9%.

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Publisher : Middle Technical University

Keywords: Photovoltaic; Active Cooling; Efficiency; Forced Air; Solar.

1. Introduction

The performance of the photovoltaic (PV) module is greatly affected by ambient conditions such as solar radiation, temperature, and wind speed [1, 2]. Increasing the ambient temperature plays a major role in raising the temperature of the PV cells and thus reducing their performance [3, 4]. Where increasing the cell temperature by 1°C leads to a decrease in its efficiency by 0.5% [5-9]. To overcome this problem, several techniques have been used by researchers in the last few years to reduce the PV cell temperature. These techniques are classified as active and passive cooling techniques [10]. The active technique means using pumps to circulate the water [11] or fans to force the air [12] to remove the heat from the PV module. On the contrary, the passive technique means dispensing any electrical unit and replacing it by using heat sink materials such as fins and channels [13]. Most of the previous studies focused on the use of air or water to cool the PV module. For example, Mazón-Hernández et al. [14] investigated an experimental study to enhance the output characteristics of PV modules using two scenarios of air convection: natural and forced convection. The results showed that the electrical power of the PV module was improved up to 15% in the case of forced convection due to the reduction of PV module temperature by 16 °C. A comparison between active and non-active conditions was used by Mazón-Hernández et al. [15] to improve the electrical characteristics of the PV modules. The results of non-active conditions showed that the module efficiency was not exceeded 8% to 9%, while, the efficiency of active conditions was reached between 12% to 4%. In addition, Ameri et al. [16] used the natural and forced convection techniques to enhance the output characteristics of the PV module. The forced convection was tested with two, four, and eight fans to subtract the hot air. In general, the results showed that the increase in airflow rate lead to improve the electrical efficiency of the PV module. Othman et al. [17] investigated an indoor experimental study to analyze the performance of photovoltaic/thermal (PVT) systems as integral to water and air heating systems. The best results from the experiments under the conditions of (irradiance of 800 W/m^2, airflow rate of 0.05 kg/s, and water flow rate of 0.02 kg/s) showed that the average electrical power, electrical efficiency, and thermal efficiency of the PVT were recorded at 145 W, 17% and 76%, respectively. The main objective of this study was to carry out an experimental investigation to enhance the performance of PV modules by using the thermal-photovoltaic (PVT) technique. The PVT was prepared by integrating the PV module with an air duct. The air was forced by an electrical centrifugal fan with variable speeds (1.5, 2.5, and 3.5 m/s).

Nomenclature				
PV	photovoltaic	A	PV module area	m^2
SC	SolarCert	FF	Fill factor	%
P_m	maximum power	G	Solar irradiance	W/m^2
V_{mp}	maximum power point voltage	Imp	Maximum power point current	A
Symbols		Isc	Short circuit current	A
V_{mp}	Maximum power point voltage V	Pmax	maximum electrical power	W
V_{oc}	Open circuit voltage V	TPV	PV panel temperature	°C

2. Experimental setup

2.1. Preparation of PV and PVT modules

Two polycrystalline PV modules of the same type (FRS-165 W) were selected and installed on a steel frame. The PV modules are fixed with an inclination angle of 33° towards the south which is equal to the latitude of the site as shown in Fig. 1. The technical data of the PV modules are presented in Table 1. One of these modules was selected as a reference case (PV) and the second one was integrated with a forced-air duct as a PVT. The air duct of PVT was fabricated from a steel plate with a thickness of 0.125 cm and designed as a rectangular cross-section with a length of 149 cm, a width of 67 cm, and a depth of 15 cm. In addition, the outlet of the duct was modified as a converge section with a length of 30 cm, a straight section of 10 cm, and diverge section of 20 cm to fix the air fan. The duct is thermally isolated using a thermal insulator consisting of two layers with a total thickness of 2 cm (1cm fiberglass and 1 cm cork). A centrifugal fan type VMA30C4S with a maximum volumetric flow rate of 760 m^3/h was selected to pull the air in the duct. It was modified to operate at three speeds (1.5, 2.5, and 3.5) m/s with corresponding to air volume flow rate (335, 540, and 760) m^3/h.

Table 1 Technical data of the PV module

PV Characteristics	Specifications
Module type	Protonix Fotuner India FRS-165 W
Module dimensions	149x67 cm
Maximum power (P_{max})	165 W
Short circuit (I_{sc})	9.81 A
Open circuit voltage (V_{oc})	22.05 V
Maximum current (I_{mp})	9.17 A
Maximum voltage (V_{mp})	18 V

Fig 1. Photographs of PV and PVT modules

2.2. Measurements and instrumentations

The I-V tracer (SEAWARD PV200) was used to measure the output characteristics of the PV including open circuit voltage (V_{oc}), short circuit current (I_{sc}), maximum power point voltage (V_{mp}), maximum power point current (I_{mp}), maximum power (P_m), and fill factor (FF). The technical data of SEAWARD PV200 were described in Table 2. The PV200 is an accurate and easy-to-use electronic device that tracks the I-V curve, making it an effective and versatile tester for photovoltaic systems. A 999 data set can be stored on the device to analyze and simulate and compare them with the standard test conditions data. In addition, a Solar survey (SS200R) unit was used to measure the solar irradiance, ambient temperature, and PV temperature which is connected and synchronized with the I-V tracer as shown in Fig. 1. All measured data were transferred from the I-V tracer to the computer and displayed by SolarCert (SC) software. Furthermore, eight thermocouples (Type-K) were used and distributed as shown in Fig. 2. Three thermocouples were installed along the reference PV module to measure the below temperature of the module. In addition, five thermocouples were used in the PVT technique and distributed as three couples along the duct and two couples were supported at the inlet and outlet of the duct.

Table 2 Technical specifications of I-V tracer (SEAWARD PV200)

Open circuit voltage	Short circuit current
Display Range 0.0 VDC -1000 VDC	Display Range 0.0 ADC -15 ADC
Measuring Range 5 VDC -1000VDC	Measuring Range 0.5ADC -15 ADC
Resolution 0.1 VDC maximum	Maximum Power 10 kW
Accuracy ± (0.5 % + 2 digits)	Resolution 0.01ADC maximum
Enunciators DC voltage polarity correct or reversed	Accuracy ± (1% + 2 digits)

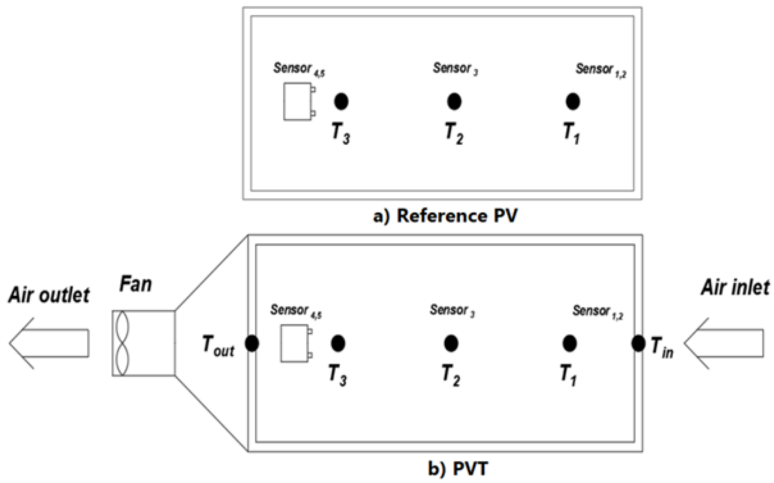

Fig 2. Sketch diagram of distributing the thermocouples

2. Weather Data

In this test, the weather data for seven days (1st, 5th, 10th, 15th, 20th, 25th, and 30th of July 2021) were recorded and represented as an average value in Fig. 3 and 4 between 7:00 AM to 6:00 PM. As shown in Figure 3, the average solar irradiance was recorded at a maximum value of about 980 W/m2 at 12:00 PM. At the same time, the maximum average ambient temperature was recorded 48 °C between 2:00 PM and 3:00 PM as shown in Fig. 4.

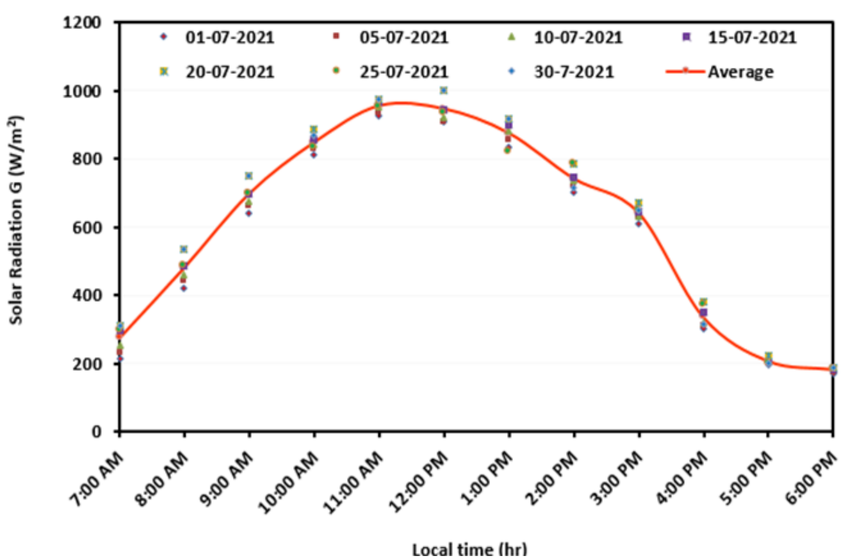

Fig 3. Variation of solar radiation with local time during July

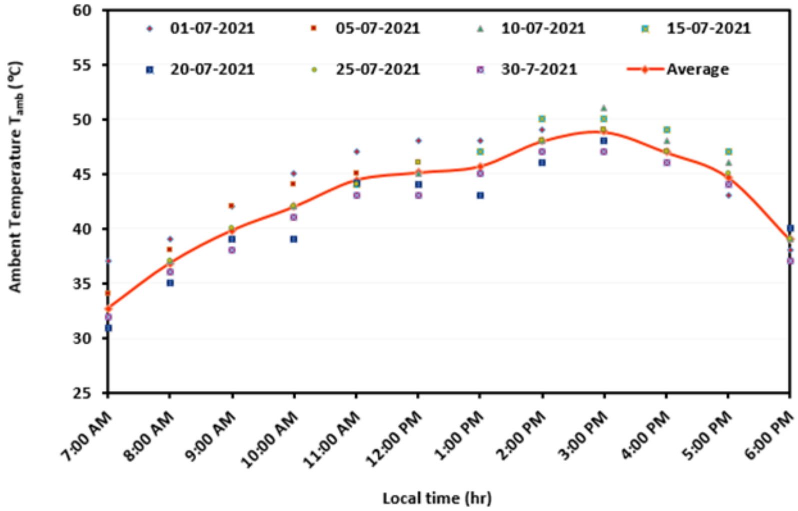

Fig 4. Variation of ambient temperature local time during July

4. Results and Discussion

The active technique includes a forced-air cooling (PVT) at three air speeds (1.5, 2.5, and 3.5 m/s) with corresponding air volume flow rates (335, 540, and 760 m^3/h). Generally, the figures were indicated in four cases: (ref) indicates the PV reference module, force1 indicates PVT at a volume flow rate of 335 m^3/h, force2 indicates PVT at a volume flow rate of 540 m^3/h and force3 indicates PVT at a volume flow rate 760 m^3/h. The evolutions for all the four cases of PV modules were measured directly in terms of module temperature (Tc), open-circuit voltage (*Voc*) which means the voltage of the PV module at the open circuit with no load, short circuit current (I_{SC}) that means the current of the PV module at the short circuit with no load, maximum power point voltage (*Vmp*), maximum power point current (*Imp*). In addition, the maximum power (*Pm*) and electrical efficiency (*ηele*) were calculated according to the:

The maximum output power of the PV module can be expressed as [18]:

$$P_m = V_{mp} \times I_{mp} \tag{1}$$

The efficiency of the PV module can be represented as [19]:

$$\eta_{ele} = \frac{P_m}{G \times A} \tag{2}$$

Where: G is the incident solar irradiance on the module (W/m^2) and A is the area of the module (m^2).

4.1. PV modules temperature

Physically, the temperature of the PV module increased due to the thermal energy falling on its surface. Increasing the temperature of the PV module leads to losses in its efficiency due to the sharp drop in its voltage. The back temperature of the PV modules for the four cases is represented in Fig. 5. As shown in the figure, the maximum back temperature of the reference PV module was reached at about 69 °C at 2:00 PM. Whereas, after turning the fan to force the air in the duct of PVT, the back temperature of the PV module dropped significantly to (64, 60, and 53 °C) at force1, force2, and force3 respectively. In other words, the PVT can decrease the PV module temperature from (5 to 16) °C.

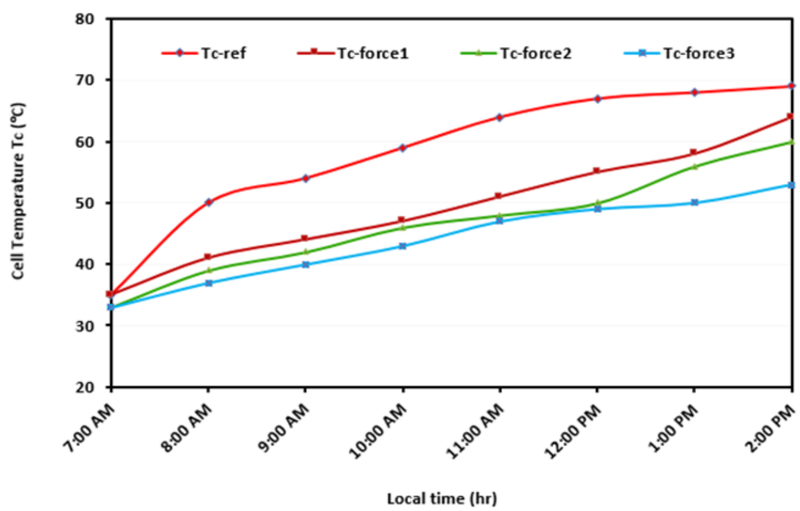

Fig 5. Variation of the back temperature of the PV module during the test period

4.2. Maximum power point characteristics

In this section, the influence of active cooling on the maximum *Imp*, *Vmp*, *Pm*, and η_{ele} of the module is presented in Figures (6-9). As shown in Fig. 6, the *Imp* increases as the PV module temperature increase until 12:00 PM. After the temperature drops, the current gradually decreases. In the case of the reference PV module, the *Imp* has recorded a maximum value of about 8.7 A at 12:00 PM at a high temperature of about 69 °C and a minimum value of about 2.9 A at 7:00 AM at a low temperature of 35 °C. In the case of PVT, the current drops a little whenever increasing the air flow rate. So that the reduction of the PV module temperature to 64 ^{o}C leads to reduce the *Imp* to 8.52 A at airflow rate of 0.093 kg/s. While increasing the air flow rate to 0.155 kg/s leads to a drop in the current up to 8.45 A at the PV module temperature of 60 °C. With more increase in the airflow rate to 0.22 kg/s, the temperature drops to 53 °C causing the drop in current to 8.36A.

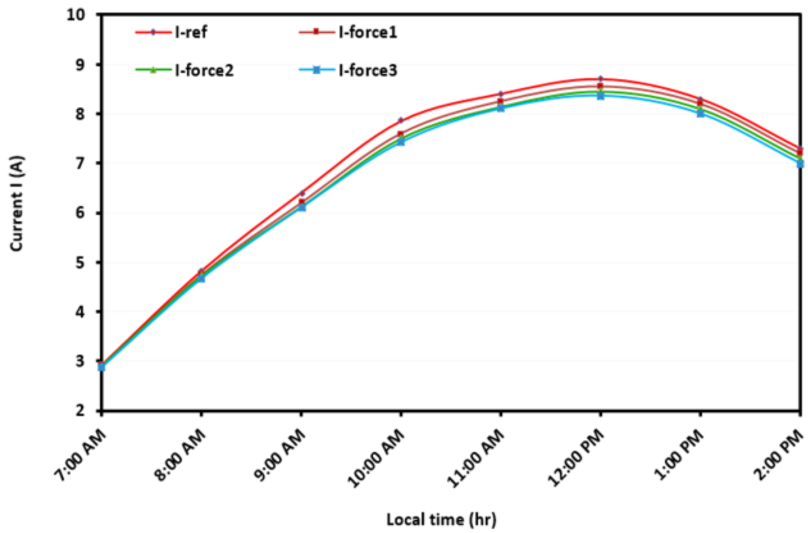

Fig 6. Variation of the current I_{mp} with time

As shown in Fig. 7, the Vmp of the reference PV module reached the maximum value of about 16.7 V at 7:00 AM and then sharply dropped to 14.2 V. As compared with the PVT technique, the PVT was kept slightly dropped in the Vmp until 2:00 PM. Where the reduction begins from 16.8 V to 15.1 V at an airflow rate of 0.093 kg/s. In the same manner, the reduction begins from 16.9 V to 15.3 V and 17.1 V to 15.45 V at an airflow rate of 0.155 and 0.22 kg/s respectively.

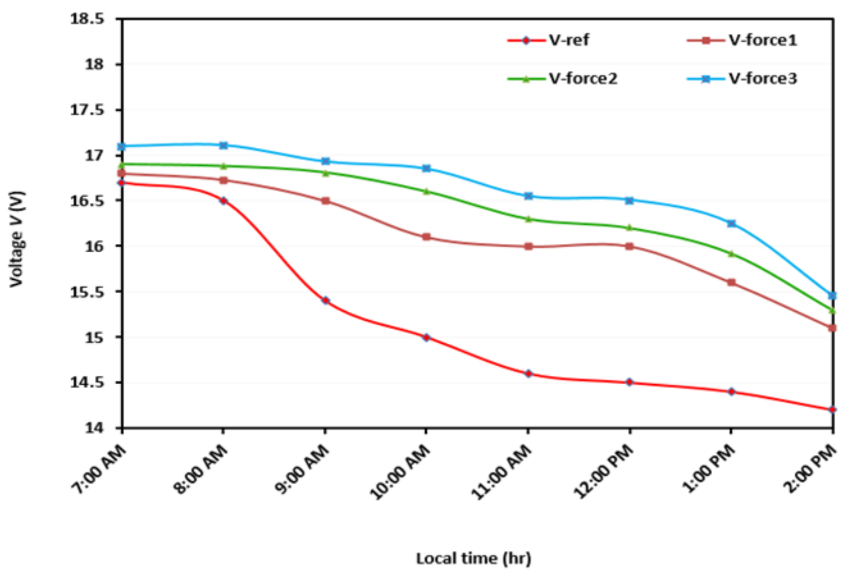

Fig. 7 Variation of the voltage V_{mp} with time

The enhancement of the *Vmp* in PVT was directly reflected in increasing the maximum power of the modules. The enhancement of the power was clarified in Fig. 8. As shown in the figure, the highest enhancement of PVT power was reached at 8.2% at an airflow rate of 0.22 kg/s and the lowest value was recorded at about 5.8% at an airflow rate of 0.093 kg/s. Furthermore, the reference PV module records a maximum electrical efficiency of about 17.3% at 7:00 AM and then dropped to 12.8% at 2:00 PM. While, the range of electrical efficiency of the PVT was achieved between (17.5-13.4) %, (17.7-13.5)%, and (17.9-13.6)% at flow rate 0.093, 0.155, and 0.22 kg/s respectively as shown in Fig. 9.

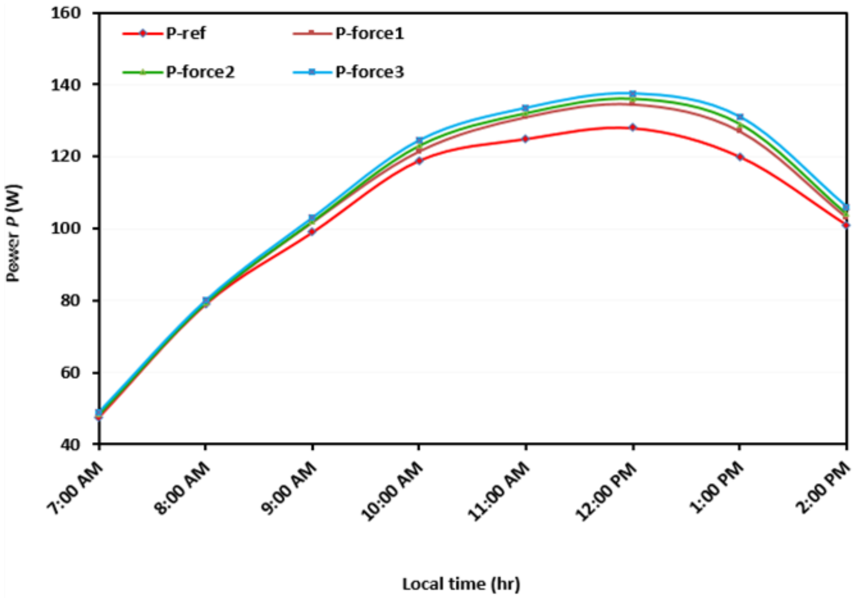

Fig 8. Variation of the maximum power P with time

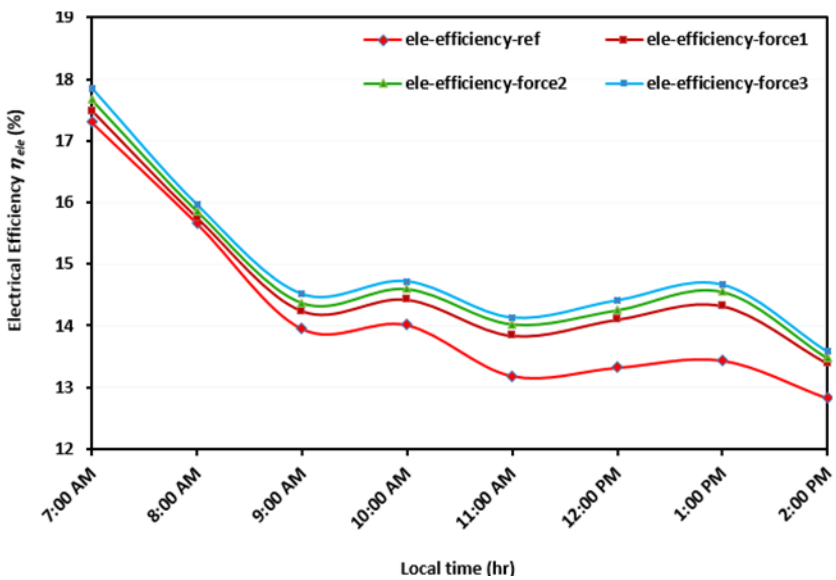

Fig 9. Variation of the maximum electrical efficiency ηele with time

4.3. Generated power

The experimental results obtained by the I-V tracer (SEAWARD PV200) are collected and plotted by Solar Cert software as I-V and P-V curves with variable solar irradiance and ambient temperature as shown in Fig. (10-13). In this section, four graphs were selected to represent the I-V and P-V curves for each case. The graphs were selected according to the convergence between the values of solar irradiance and ambient temperature. Furthermore, each graph contains seven strings to cover the ranges of solar irradiance between (300 to 1000 W/m^2) and ambient temperature between (30 to 45°C). As shown in the Figures, the discrepancy between the values of solar irradiance for all the cases does not exceed 1.3% at a minimum and 1.7% at a maximum. While the discrepancy of ambient temperature did not exceed 15.8% at minimum ambient temperature and 13% at maximum ambient temperature. Generally, the minimum power of all cases was recorded between (44 to 55 W) with lower ambient temperature and solar radiation. But, the maximum power was increased from 120 W in the reference PV module to (126-131 W) in the case of PVT. In the other words, the enhancement percentage of power was recorded as a maximum value of about 9% in the case of PVT.

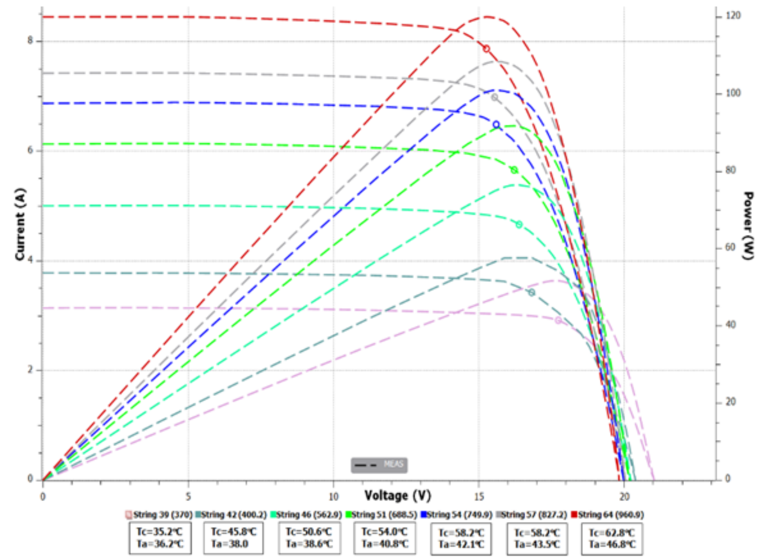

Fig 10. Measured I-V and P-V curves for the reference PV module

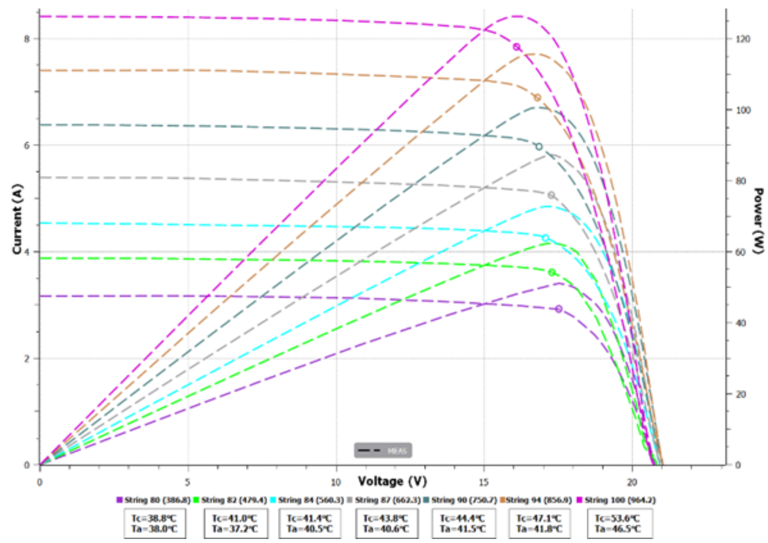

Fig 11. Measured I-V and P-V curves for the PVT module at an airflow rate of 0.093 kg/s

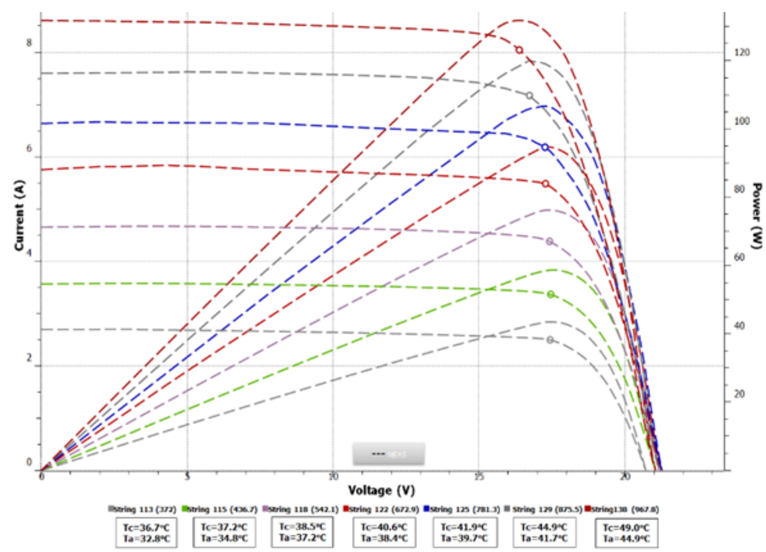

Fig 12. Measured I-V and P-V curves for the PVT module at an airflow rate of 0.155 kg/s

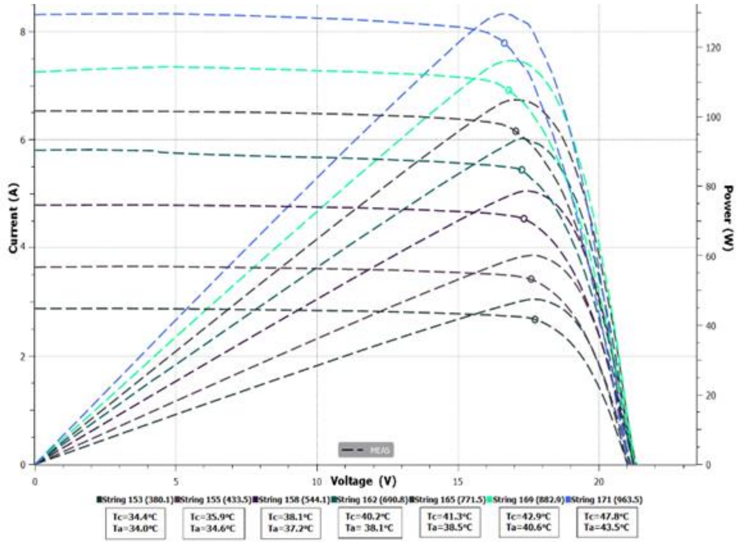

Fig 13. Measured I-V and P-V curves for the PVT module at an airflow rate of 0.22 kg/s

4.4. Comparison with published results in the literature

The performance of the active cooling technique in the present study is compared with the results of Almuwailhi and Zeitoun [20] as presented in Table 1. The comparison is based on some of the similar factors between the experimental work of reference [20] and this current experimental work including the Type of the modules (polycrystalline), the similar environment between the current study (Iraq) and the previous study (Saudi Arabia), and the same type of the PVT technique. As presented in Table 2, the performance of the cooling techniques of the PV module in the present study is better than in the reference [20] for all the air speeds. In the reference [20], it is observed that the maximum drop of PV module temperature was recorded at 11.3 °C in the case of PVT at airs peed 3 m/s leading to an increase in the electrical efficiency of the PV module of about 4%. While in the present study, it was recorded a maximum drop in PV module temperature about 16 °C at an air speed of 3.5 m/s with an increase in the electrical efficiency of the PV module of about 6.2%

Table 2 Comparison of the present results with results of reference [20]

Reference	Airspeed (m/s)	Forced convection	
		Reduction of the PV temperature ΔT (^{o}C)	Increasing electrical efficiency η (%)
[20]	1.0	2.2	0.6
	2.0	7.6	2.4
	3.0	11.3	4.0
Present study	1.5	5.0	4.7
	2.5	9.0	5.4
	3.5	16.0	6.2

5. Conclusion

This work presents an experimental investigation under real outdoor weather conditions to enhance the performance of the PV module using the forced air cooling technique. According to the obtained results, the following conclusions can be summarized:

1. The PVT can lower the module temperature by (ΔT=5 to 16) °C.
2. The maximum power voltage of the reference PV module was dropped to 14.2 V at a maximum PV module temperature of about 69 °C.
3. The PVT recorded a voltage higher than 15.1 V as compared with the reference PV module.
4. The enhancement percentage of the PV electrical efficiency was recorded between (4.7% to 6.2%) in the case of PVT at different volume flow rates (335, 540, and 760) m^3/h.

Acknowledgement

The authors would like to thank the Middle Technical University for the financial support of this project.

Reference

[1] García, M.A. and Balenzategui, J. Estimation of photovoltaic module yearly temperature and performance based on nominal operation cell temperature calculations. Renewable energy 2004; 29: 1997-2010. https://doi.org/10.1016/j.renene.2004.03.010

[2] Grunow, P., Lust, S., Sauter, D., Hoffmann, V., Banking, C., Litzenburger, B., and Podlowski, L. Weak light performance and annual yields of PV modules and systems as a result of the basic parameter set of industrial solar cells. 19th European Photovoltaic Solar Energy Conference, 7-11 June 2004, Paris, France Solar Energy Conference 2004; 2190-93.

[3] M.J. Jeng, Yu.L. Lee, L.B. Chang. Temperature dependences of lnGaN/GaN multiple quantum well solar cells. Journal of Physics D: Applied Physics 2009; 42: 1-11 DOI: 10.1016/j.solmat.2021.111253.

[4] D. T. Cotfas, P. A. Cotfas, and S. Kaplanis. Methods to determine the dc parameters of solar cells: a critical review. Renewable and Sustainable Energy Reviews 2013; 28: 588-96. https://doi.org/10.1016/j.rser.2013.08.017.

[5] Penmetsa V., Holbert K.E. Climate Change Effects on Solar. Wind and Hydro Power Generation. In 2019 North American Power Symposium (NAPS) 2019:1-6. DOI: 10.1109/NAPS46351.2019.9000213.

[6] S. Natarajan, T. 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 2011; 50: 2514-21. https://doi.org/10.1016/j.ijthermalsci.2011.06.014

[7] Dubey, S.; Tiwari, G.N. Thermal modeling of a combined system of photovoltaic thermal (PV/T) solar water heater. Sol. Energy 2008; 82: 602-12. https://doi.org/10.1016/j.solener.2008.02.005.

[8] S. R. Reddy, M. A. Ebadian, and C. Lin. A review of PV-T systems: Thermal management and efficiency with single phase cooling. International Journal of Heat and Mass Transfer 2015; 91: 861-71. doi: 10.1016/j.ijheatmasstransfer.2015.07.134.

[9] M. M. Rahman, M. Hasanuzzaman, and N. A. Rahim. Effects of various parameters on PV module power and efficiency. Energy Convers. Manag. 2015; 103: 348-58. doi: 10.1016/J.ENCONMAN.2015.06.067.

[10] M. Sivashankar, C. Selvam, S. Manikandan, Sivasankaran Harish. Performance improvement in concentrated photovoltaic using nano-enhanced phase change material with graphene nanoplatelets. Energy Volume 2020;208, DOI: 10.1016/j.energy.2020.118408.

[11] Mah C.-Y., Lim B.-H., Wong C.-W., Tan M.-H., Chong K.-K., Lai A.-C. Investigating the Performance Improvement of a Photovoltaic System in a Tropical Climate using Water Cooling Method. Energy Procedia 2019; 159: 78-83. https://doi.org/10.1016/j.egypro.2018.12.022.

[12] Fatoni E.K.A., Taqwa A., Kusumanto R.Solar Panel Performance Improvement using Heatsink Fan as the Cooling Effect, Journal of Physics: Conference Series 2019; 1167.

[13] Raja Harahap, Suherman Suherman. Active versus passive cooling systems in increasing solar panel output. Procedia Environmental Science. Engineering and Management 2021; 8: 157-66. file:///C:/Users/User/Downloads/18_02.18.Suherman_21%20(1).pdf.

[14] [14] R. Mazón-Hernández, J. R. García-Cascales, F. Vera-García, A. S. Káiser, and B. Zamora. Improving the Electrical Parameters of a Photovoltaic Panel by Means of an Induced or Forced Air Stream. International Journal of Photoenergy 2013; 2013:1-10. http://dx.doi.org/10.1155/2013/830968.

[15] H.G. Teo, P.S. Lee, M.N.A. Hawlader. An active cooling system for photovoltaic modules. Applied Energy 2012; 90: 309-15. https://doi.org/10.1016/j.apenergy.2011.01.017.

[16] M. Ameri, M. M. Mahmoudabadi, A. Shahsavar. An Experimental Study on a Photovoltaic/Thermal (PV/T) Air Collector with Direct Coupling of Fans and Panels. Energy Sources, Part A 2012; 34: 929-47. https://doi.org/10.1080/15567031003735238

[17] M.Y. Othman, S.A. Hamid, M.A.S. Tabook, K. Sopian, M.H. Roslan, Z. Ibarahim. Performance analysis of PV/T Combi with water and air heating system: An experimental study. Renewable Energy Volume 2016; 86: 716-22. **https://doi.org/10.1016/j.renene.2015.08.061**

[18] Zekiye ERDEMa , M.Bilgehan ERDEM, A Proposed Model of Photovoltaic Module in Matlab/SimulinkTM for Distance Education, Procedia - Social and Behavioral Sciences 103 (2013) 55 – 62.

[19] Daniel Tudor Cotfas , Petru Adrian Cotfas , Octavian Mihai Machidon, Study of Temperature Coefficients for Parameters of Photovoltaic Cells, International Journal of Photoenergy Volume 2018, Article ID 5945602, 1-12.

[20] A. Almuwailhi and O. Zeitoun. Investigating the cooling of solar photovoltaic modules under the conditions of Riyadh. Journal of King Saud University-Engineering Sciences 2021; 1-14. Available online on 26 March 2021. https://doi.org/10.1016/j.jksues.2021.03.007.