Increasing the Photovoltaic Efficiency by Using Air guide in Cooling System: A New Practical Study

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Abstract- **Reducing cell temperature is very important to improve cell efficiency and increase electrical output. This study indicates the need to reduce losses in the process of cooling the PV cell by controlling the air flow rate where the highest electrical efficiency of the cell at the airflow rate (0.049 kg/s). The results showed that the rate of reduction of the temperature of the cell reached (37.22%), and the temperature of the cell decreased by (22.2782 °C) as a result of cooling using air guides. The heat generated by the cooling process can be utilized in multiple applications as the difference between the inlet and outlet temperature of the air duct reached (13.717°C), and the increase in the thermal efficiency of the PV cell (68.7%).**

Keywords – Photovoltaic efficiency, Air guide model, solar energy ,Air cooling technique

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I. INTRODUCTION

The population suffers from an increase in greenhouse gas emissions and is looking for models and sources of low-carbon or zero-emission energy[1].The investment of abundant and unlimited solar energy sources at present has met with great demand for the damage caused by fossil fuels to the environment[2]. Photovoltaic cells have several advantages, including the production of electrical energy directly through solar radiation without the need to follow the engines[3].(PV) are solar thermal systems,

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a solar energy design with high reliability, but their high initial cost makes it difficult for many to use in a large number of developing countries[4].In spite of the advantages of photovoltaic cells, there are a number of influences that face the work and performance of the photovoltaic cell and reduce its productivity of electrical energy, the efficiency of the photovoltaic cell directly affected by the temperature of the photovoltaic cell.The production of electrical energy by photovoltaic cells is influenced by a fundamental factor, which is the temperature of the cell[5]. The temperature of the PV base and the surface of the PV cell reaches a temperature above 70^0C[6]. Consequently, the productivity of the photovoltaic cell of electrical energy falls at a rate of 0.55 - 0.65% / K per increase in cell temperature due to low conversion efficiency (conversion of solar radiation to energy) by 0.08% / K, for each rise in temperature of the cell one temperature[7]. Increasing the temperature of one photovoltaic cell reduces electrical efficiency by more than 0.5% and the cell operates at its highest efficiency at a standard operating temperature of 25-28 °C[8] .In fact, what is converted to electrical energy from solar radiation by photovoltaic cells does not exceed 20% and more than 80-85% of the value of solar radiation is absorbed as waste energy and waste is not useful for the cell, one of the most important reasons for the rise of the temperature of the photovoltaic cell[9] . A modern and practical method used to reduce the cell temperature by forced air cooling. Air guidesfor the first time used in the PV cooling system to direct the airflow towards the cell base in order to cool and improve the productivity of PV cells. The air guides were designed by numerical simulation software and gave excellent results by directing the air and reducing the cell temperature[10].

The objective of this study is getting the high power output from PV cell Within the weather conditions for Iraq and increasing the cell efficiency to the highest possible amount with the lowest costs and the simplest possible methods and manufacture of a test model can be easily applied . a clear perception of the amount of waste heat that can be used by important applications. Use of air guide was not discussed by another researcher within the previous literary reviews in the techniques of cooling the photovoltaic cell by using forced air.

2-Experimental Method

2-1 Experimental Set-up

A Polycrystalline photovoltaic cells were used in the experimental system to cool it by forced air . The PV cell were installed in Iraq, the city of Najaf Ashraf - Technical College of Engineering in Najaf south at a fixed inclination of (31^o) degrees to gain the largest amount of solar radiation falling[11] and produce the largest amount of electrical energy from these cells. Characteristics and specifications of the used photovoltaic cells are shown in Table (1).Figure (1) shows an illustration of the parts of the photovoltaic cooling system where the system consists mainly of the photovoltaic cell and the duct installed on the rear side of the photovoltaic cell dimensions (1956 mm long and 992 mm wide and 100 mm channel height). Air guides are installed inside the duct, and at the top of the duct and air fan is installed on the top of the air duct. In addition to the devices used to operate the system and measuring devices. Air is pulled from the bottom of the channel upward by the density of the hot air through the air intake fan. Air guides direct the largest amount of air to the base of the cell to increase heat exchange

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between the base of the cell and air. The air absorbs the largest amount of heat generated at the base of the cell to cool the cell and reduce the temperature of the cell.

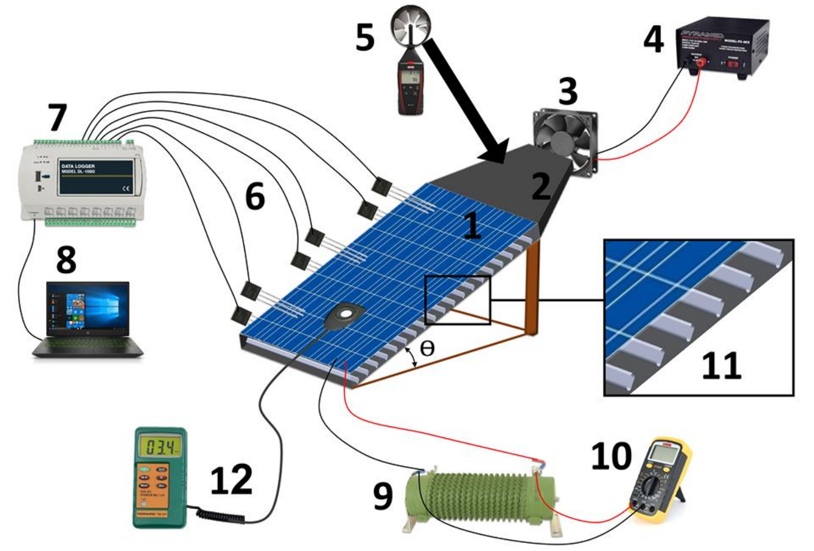


Fig.1: Schematic diagram of the PV cell cooling system with the whole parts of the system

1-A photovoltaic cell	5-Anemometer	9- Variable load
2- Nozzle duct	6- Thermocouple	10- Voltmeter
3-Dc fan	7-Data logger	11- Air guides
4-Power supply	8-Computer or U.S.P	12- Solar radiation.

Table 1. Characteristics of the PV cell.

Model type	BSM330P-72
Solar cell type	Poly 156*156 cell
Size	1956*992*40 mm
Maximum power	330 W
Maximum voltage (Vmp)	37.57 V
Maximum current (Imp)	8.78 A
Open circuit voltage(Voc)	46.34 V
short circuit current(Isc)	9.29 A
Weight	25 kg
Output tolerance	0-3%
Standard test condition	1000 W/m^2 ,25 °C
Operation Temperature	-40 °C to +85 °C

Figure (2) shows a real picture of the experimental work of the PV cooling system by using air guides. Eighteen air guides were used and installed inside the air duct at equal distances at a location of 70 mm from the air duct base and at angle 45 degrees inside the air duct to direct the largest amount of air towards the base of the cell .

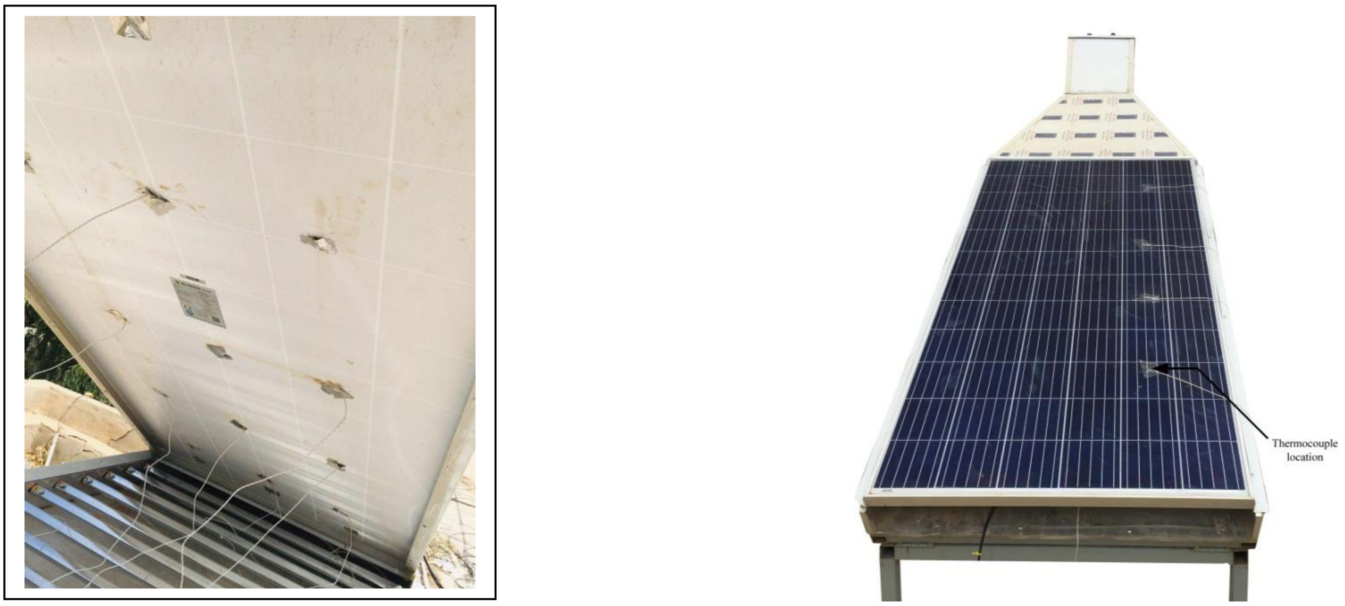


Fig. 2.Photo of the experimental set-up for PV cell with air guides cooling system.

2-2 Measuring devices

To get results that will be achieved through the work system, a set of measuring devices had been used to suit the working conditions, and complete calibration procedures for each device are shown in figure.1. Experimental work on the photovoltaic cells is carried out from 6:00 to 18:00 (during the day). The cell surface temperature, the temperature of the base of the cell, the temperature of the air entering the air duct, the temperature of the air coming out of the air duct and the ambient air temperature are taken by K-type thermocouples. The thermocouples are carefully installed at specific points in the experimental system. Also, the intensity of the incident solar radiation is measured using a measuring device (solar power meter device) called (Pyranometer).

Ambient airspeed, fan speed, and air velocity are measured using an anemometer AM-4206M. The voltage and current produced by the cell are measured using a voltmeter and variable resistance.

3-PV/T System analysis

Fig. (3) shows the schematic of hybrid PV/T system. It contains a glass to glass PV module, flat absorber plate, and insulation. The PV module and absorber plate provide a channel where the flowing air is heated by the backside of the PV module and from the absorber plate[12]. Heat transfer coefficients and equivalent thermal networks are illustrated in Fig. (4).

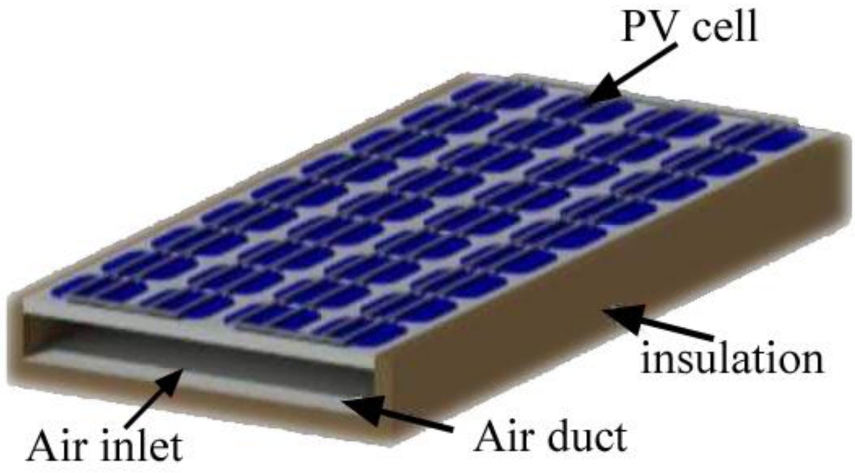
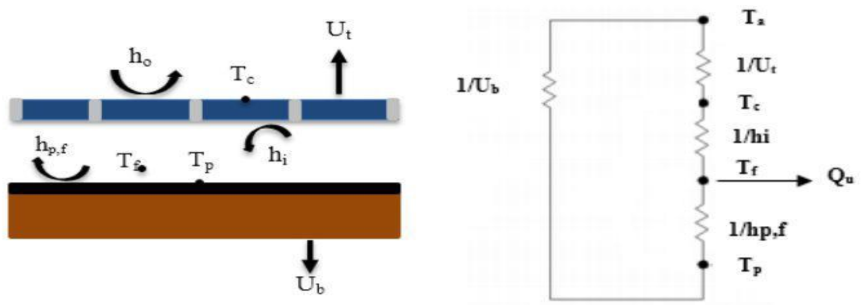


Fig.3: PV/T air cooling system



(a) coefficients of Heat transfer (b) thermal resistance Equivalent

Fig.4 : Analysis of PV/T thermal system[13].

Energy balance equations for each component of the system per unit area can be written as:

- **Solar cells of the PV module**

The total solar energy absorbed by solar cells can be calculated by the sum of the total thermal losses from the upper surface of the solar cell, the rate of heat transfer from the backside of the solar cell to the air, and the rate of production of electrical energy from the photovoltaic cell[14].

$$\alpha c \tau g \text{ PF G (t)} = Ut\,(Tc - Ta) + hi\,(Tc - \overline{Tf}) + \tau g \text{ PF } \eta c \text{ G (t)} \quad (1)$$

From Eq. (1), cell temperature (Tc) can be obtained as

$$Tc = \frac{(\tau\alpha)eff\ G + UtTa + hi\,\overline{Tf}}{Ut + hi} \quad (2)$$

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Where αc: Cell absorptive is 0.9 [9].

- **Air channel**

The heat energy transferred to the air flowing below the base of the photovoltaic cell can be calculated by the sum of the rate of convection transferred from the rear of the solar cells to the air as well as the rate of convection transferred from the base of the air channel to the air.

$$Qu= hi\,(Tc - \overline{Tf}) + hp,f\,(Tp - \overline{Tf}) \quad (3)$$

And equation (3) can become:

$$Qu=hi\,(Tc - \overline{Tf}) \quad (4)$$

As a result of the use of air guides that direct air to the base of the cell, there is a small amount of air is moving towards the base of the photovoltaic cell. Because the PV base is completely isolated from the outside environment, the heat transfer coefficient can be neglected by the load between the air and the base of the air duct. The heat energy transferred to air can be calculated by the following relationship:

$$Qu = \dot{m} * Cp\,(T_o - T_i) \quad (5)$$

$$\dot{m} = \rho * A * Vf \quad (6)$$

The PV/T thermal efficiency system is described as follows:

$$\eta_{th} = \frac{Q_u}{GA_c} \quad (7)$$

While the overall thermal efficiency (ηov) of the PV/T system can be obtained by converting the electrical efficiency to equivalent thermal efficiency then adding it to thermal efficiency as follows:

$$\eta_{ov} = \frac{\eta_e}{C_f} + \eta_{th} \quad (8)$$

Where Cf is the thermal conversion factor. It lies between (0.29 - 0.4) Conversion factor value that is adopted in this work is 0.36 [15]and electrical Cell efficiency (ηc) represents the maximum power of the solar cell to thesolar irradiance receiving by the solar cell:

$$\eta c = \frac{pmax}{G*A_c} \quad (9)$$

Fill factor (FF) represents the ratio of maximum power divided by the open-circuit voltage and short circuit current

$$FF=\frac{Pmax}{Voc*Isc} \quad (10)$$

One of the most important factors that affect the performance and efficiency of the cell is the mobilization factor (PF), which is known as the proportion of cell area (Ac) (the number of cells (Nc) multiplied by the cell area without structure) to module area (Am). (PF) it is often less than one

$$PF=\frac{Ac*Nc}{Am} \quad (11)$$

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In this study Ac= (72cells*.156m*.156m)=1.7522 m^2
Am = (1.956m*.992m)=1.940352 m^2
PF=0.903

Module efficiency (ηm) is defined as the product of cell efficiency (ηc) bypacking factor :

$$\eta m = \eta c * PF \quad (12)$$

The radiation heat transfer coefficient in the lower air channel as follows[16]:

$$hr,pb = \frac{\sigma\,(Tp^2 + Tb^2)(Tp + Tb)}{\frac{1}{\varepsilon p} + \frac{1}{\varepsilon b} - 1} \quad (13)$$

where σ: Stefan Boltzmann’s constant is ($5.67*10^{-8}$W/m^2.K^4).

εp: Emittance of the plate is (0.92).

εb: Emittance of the bottom plate is (0.92).

and the Convective heat transfer coefficient from the top surface of the solar cell to the ambient can be determined by following equation[17]:

$$ho = 5.7 + 3.8\,Vw \quad (14)$$

Convective heat transfer coefficient from the back surface of the solar cell to fluid is calculated by:

$$hi = 2.8 + 3\,Vf \quad (15)$$

It is assumed that the convective heat transfer coefficient in PV/T system equals to convective heat transfer coefficient from absorber plate to fluid in a channel and from back plate and fluid in a channel ($h_{p,f}$= h)

can be calculated by using the following relation:

$$h = \frac{Nuka}{De} \quad (16)$$

The mode of heat transfer is based on the value of the Reynolds number (Re), which is written as[13]:

$$Re = \frac{\rho aVfDe}{\mu a} \quad (17)$$

where the equivalent diameter of the channel (De) is as follows:

$$De = \frac{4(HchWC)}{2(Hch + WC)} \quad (18)$$

Useful energy gain that is carried away by fluid in the channel of the PV/T system can be represented by the equation [18] .

$$Qu = \dot{m}\,Cpa\,(T_{fo} - T_{fi}) \quad (19)$$

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4-RESULTS AND DISCUSSION

A variable-speed fan (dc fan) is used to operate by a DC power supply. The power consumption of the fan is controlled and the fan speed is controlled by the power supply as shown in (Figure.5). When the fan speed increases, the fan consumption of the electric current increases.

The air is pulled from the bottom up because the hot air density is low and therefore it is directed upwards.

The intensity of solar radiation is measured every ten minutes and the current and voltage of the cell, wind speed, fan speed, and electric power consumption are measured.

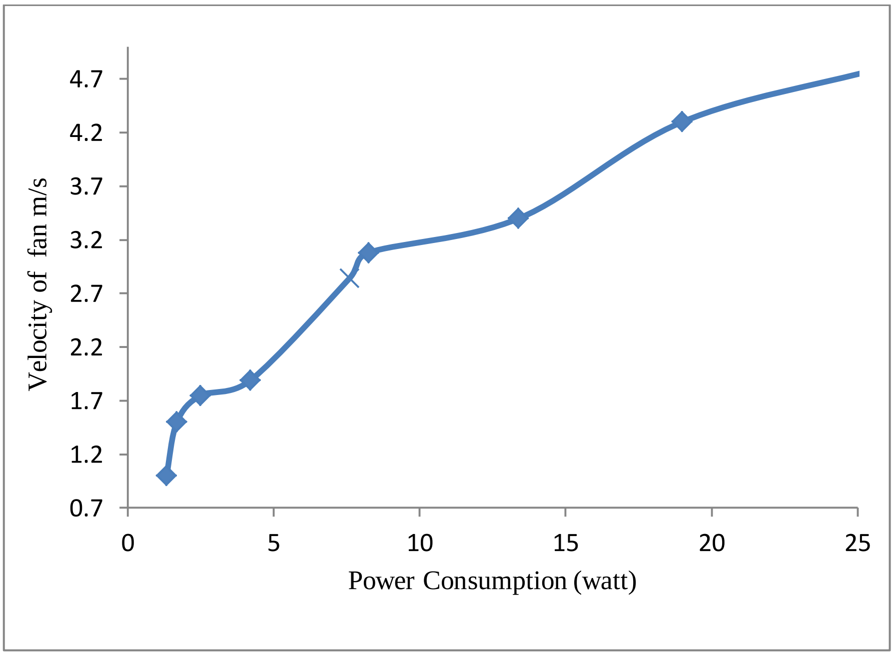

Fig. 5: The average power consumption of the air pull fan used in the system at each speed

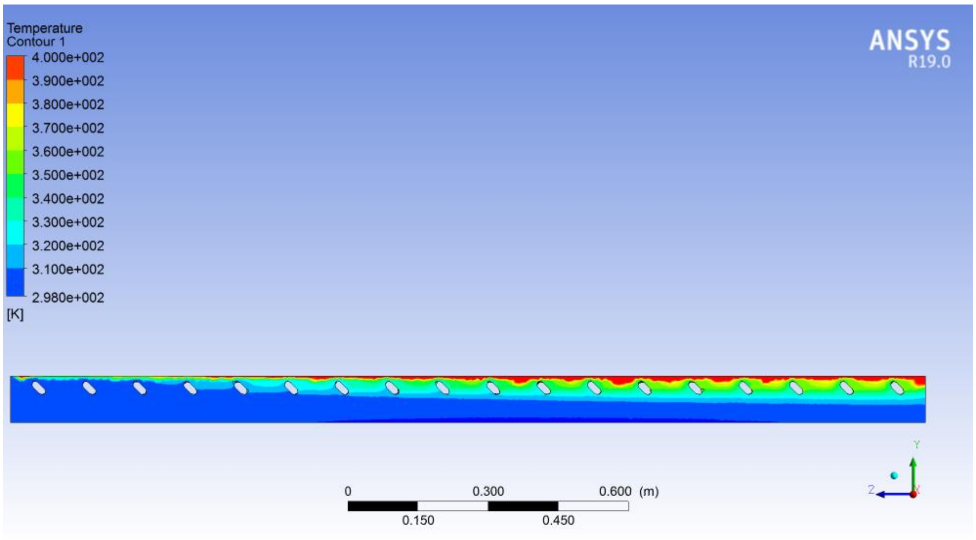

Fig. 5: Distribution temperature of the air inside the duct (one row, 18 air guide – air mass flow rate 0.01 kg/s)[10]

4-1 Weather meteorological data

Photovoltaic do not need fuel, it is directly convert solar radiation falling on them to electrical energy and therefore their work is highly dependent on the atmosphere conditions that is affected by a severity of solar radiation and the outdoor air temperature. Figure (6) shows the intensity of solar radiation during the experiment day and Figure (7) shows the change in ambient air temperature during the day. Figure (8) shows the change of wind speed during the day and observes that the rate of solar radiation during the days of experiment 920 (W / m^2) and the maximum solar radiation 1200 (W / m^2).

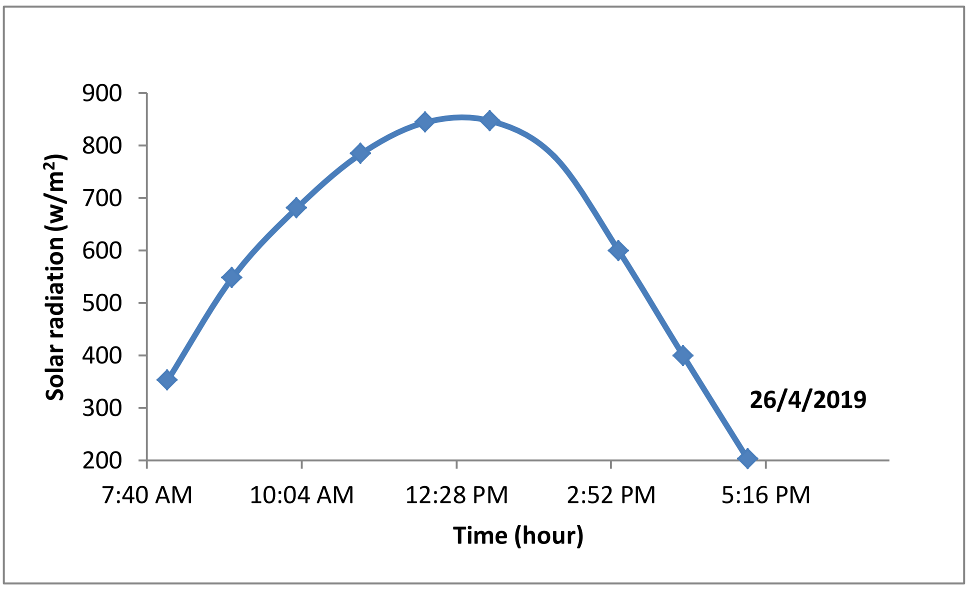

Fig.6 : Solar radiation changes during daylight hours

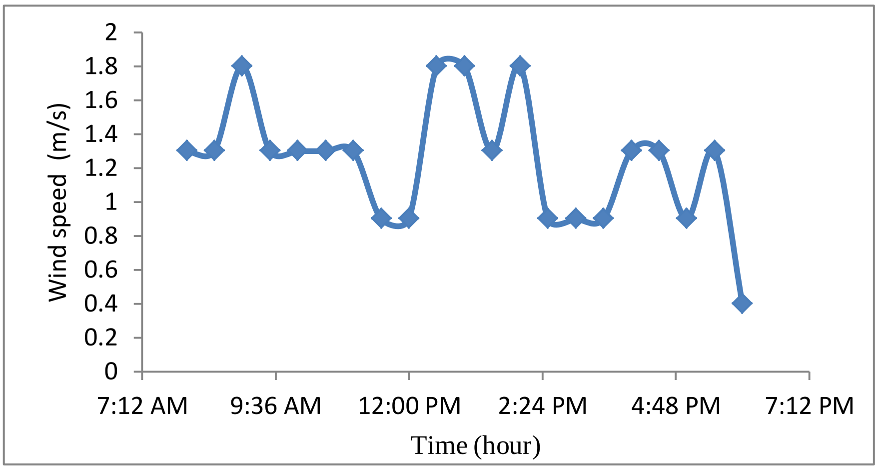

Fig.7: Wind speed changes during daylight hours

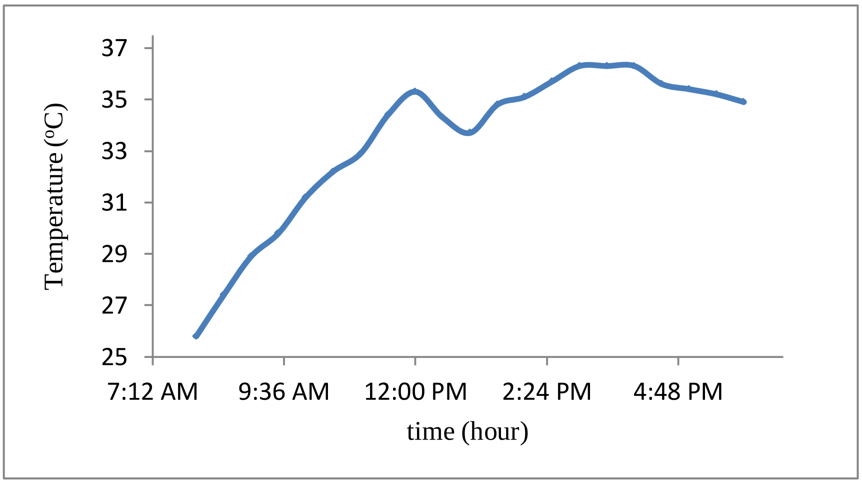

Fig.8: Ambient temperature changes during daylight hours

4-2 Effect of using air guides on the performance of PV cells

By cooling the cell base with forced air, the cell surface temperature is also reduced as a result of the cooling process, as well as the low temperature of the cell base because the cooling process reduces the converted energy into heat and is converted into electrical energy. The total decrease in cell surface temperature during the procedure (21.575 °C) while the total decrease in cell base temperature was (22.622°C).

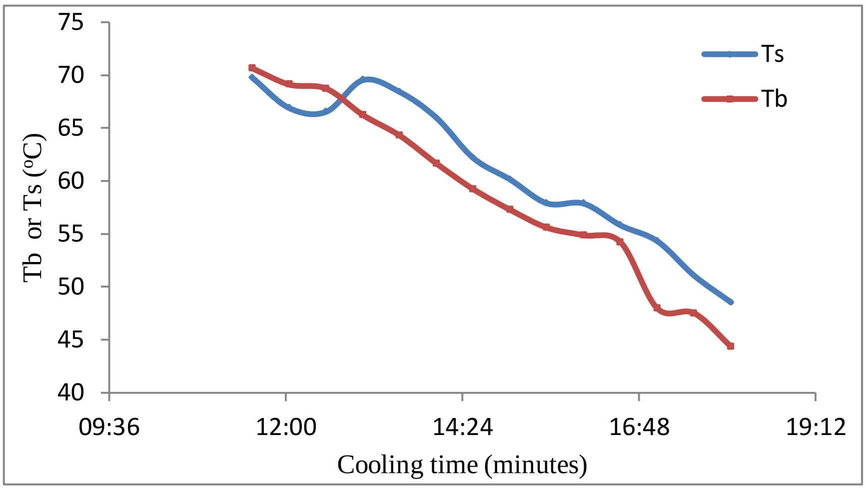

Fig. 9 :The relationship between cell surface temperature and cell-based temperature during cell cooling at 2.45 m/s

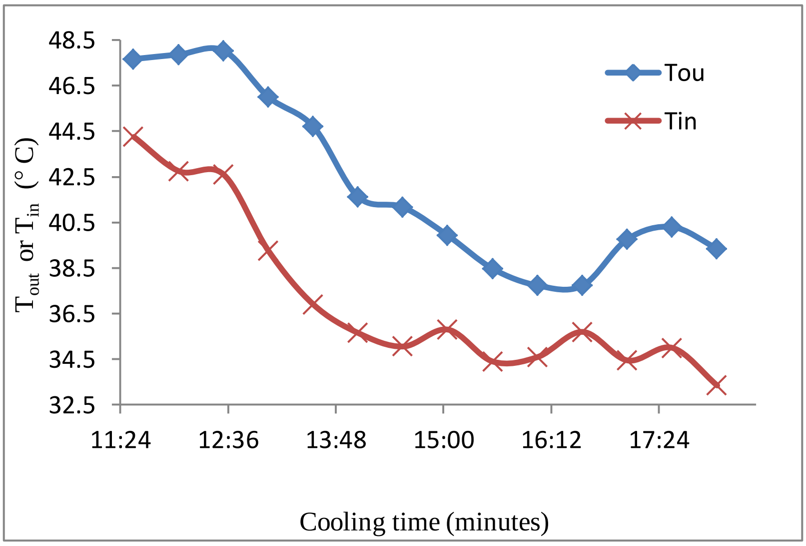

Fig.10:Effect of the cooling process on air outlet temperature and air inlet temperature

As a result of the speed of air drag, which makes the balance of air inside with the outlet air, therefore the temperature of the air inside and out are closed, and the difference between them is relatively small.

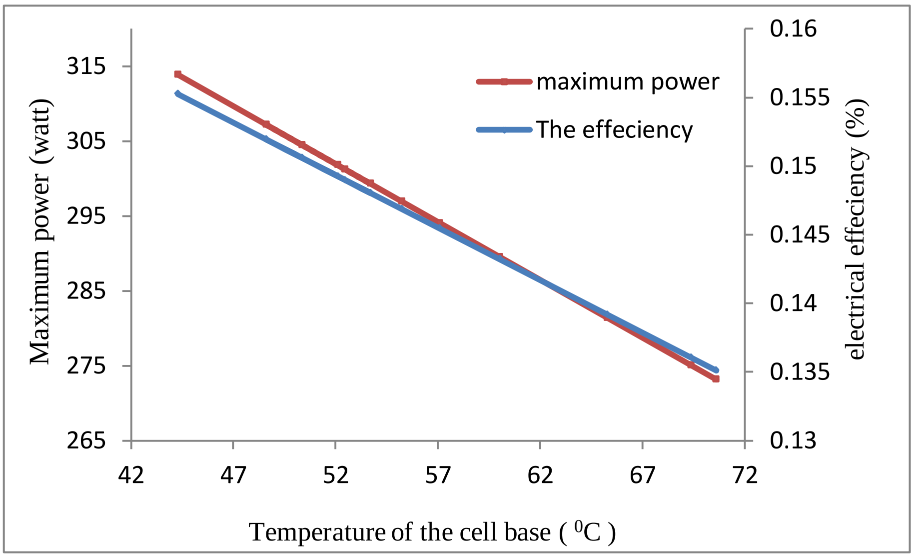

Fig. 11 :The relationship between the maximum cell power and the electrical efficiency of the cell with the temperature of the base of the cell during the cooling process at 2.45 m/s

The electrical power produced by the cell is affected by the electrical efficiency of the cell in reverse with the temperature of the cell, as shown in the above (Fig. 10) .

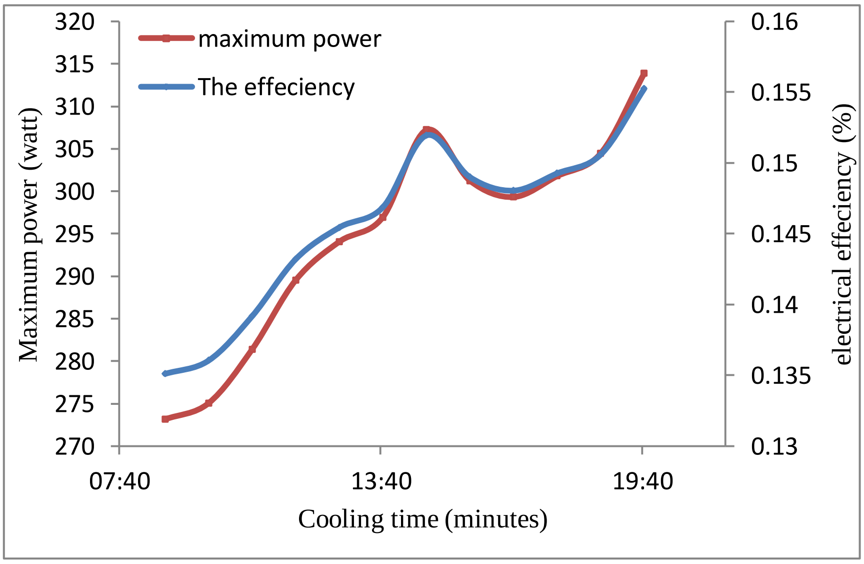

Fig.12 :The relationship between the maximum cell power and the electrical efficiency of the cell with during cooling time at 2.45 m/s .

Both the electric power produced from the cell and the electrical efficiency of the cell gradually increase with the cooling time as shown in Fig. 11**.**

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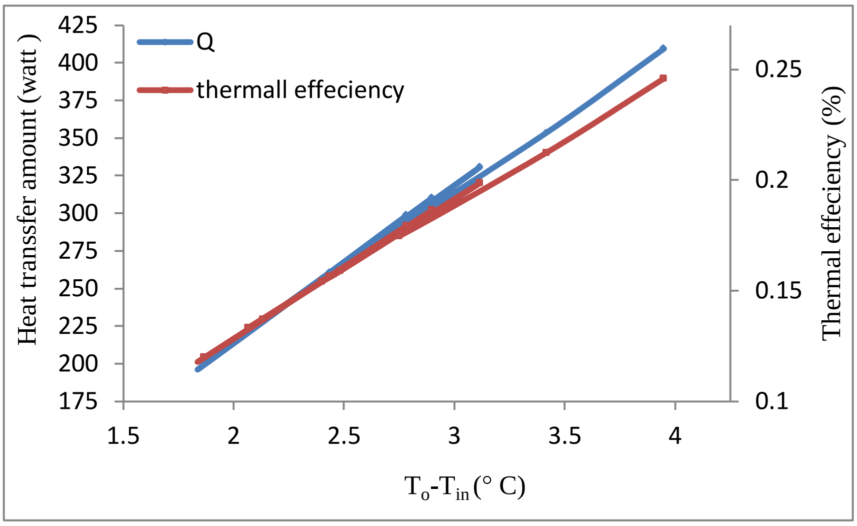

Fig. 12 :The effect of the difference between the temperature of the air inside and out on the amount of heat transferred to the air and thermal efficiency.

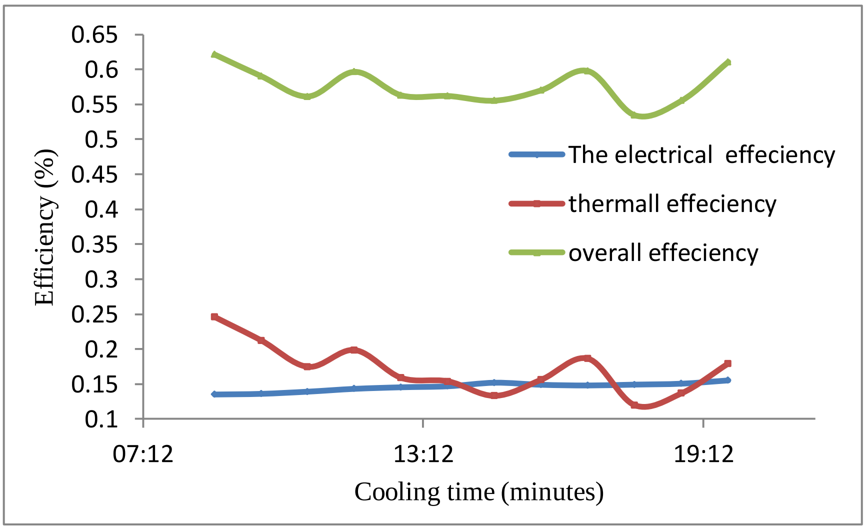

Fig.13:Effect of PV Cooling Procedure on Electrical, Thermal, and overall Cell Efficiency

It is very necessary to verify the validity of the results extracted from the theoretical study and to ensure the accuracy of the numerical simulation results by comparing them with the experimental results extracted, as well as finding the accuracy and error ratio between those two readings (experimental reading and numerical reading) .

Figure.14 shows the outlet air temperature from the PV cell cooling process with the average mass flow rate of the air. Clearly, temperatures decreased as the mass flow rate increased.

The percentage difference between the experimental and numerical results is (6.1%) and (13.2%)to equal is (9.65%).

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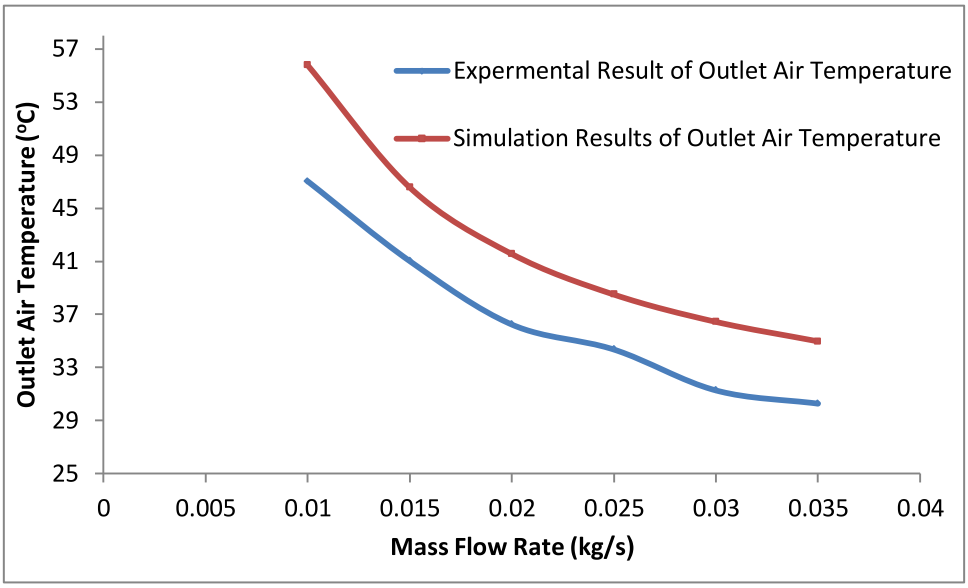
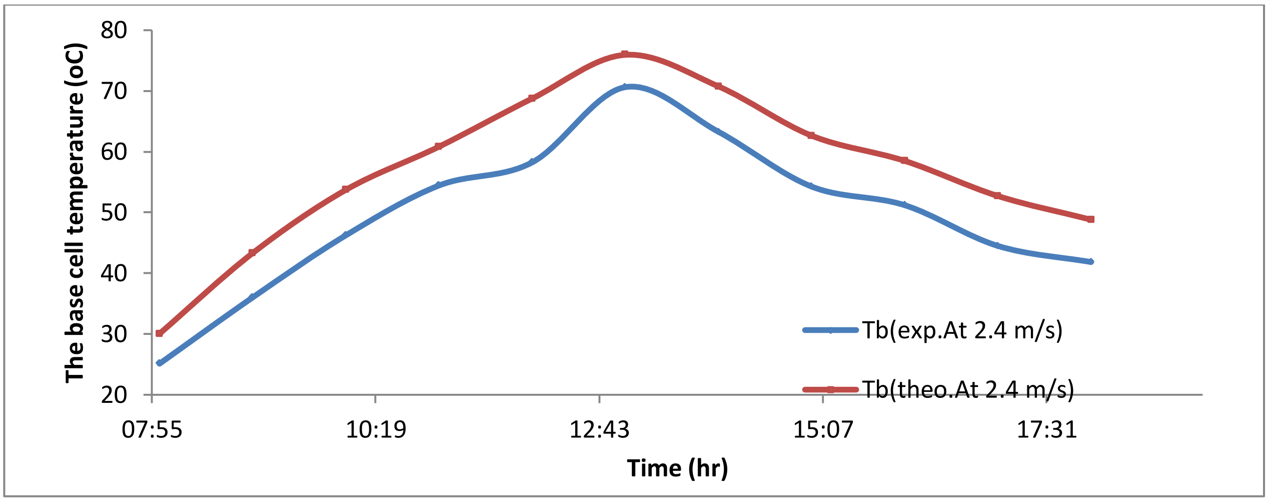


Fig.14: outlet air temperature versus air mass flow rates for the numerical validation results and experimental results[10].



- Fig. 15:Experimental and theoretical result for the base cell temperature

The above figure shows a comparison of experimental results with the analytic results of the thermal model to the PV cell cooling system to verify the accuracy of the results, and through it, it was found that the error rate is 8.45% .

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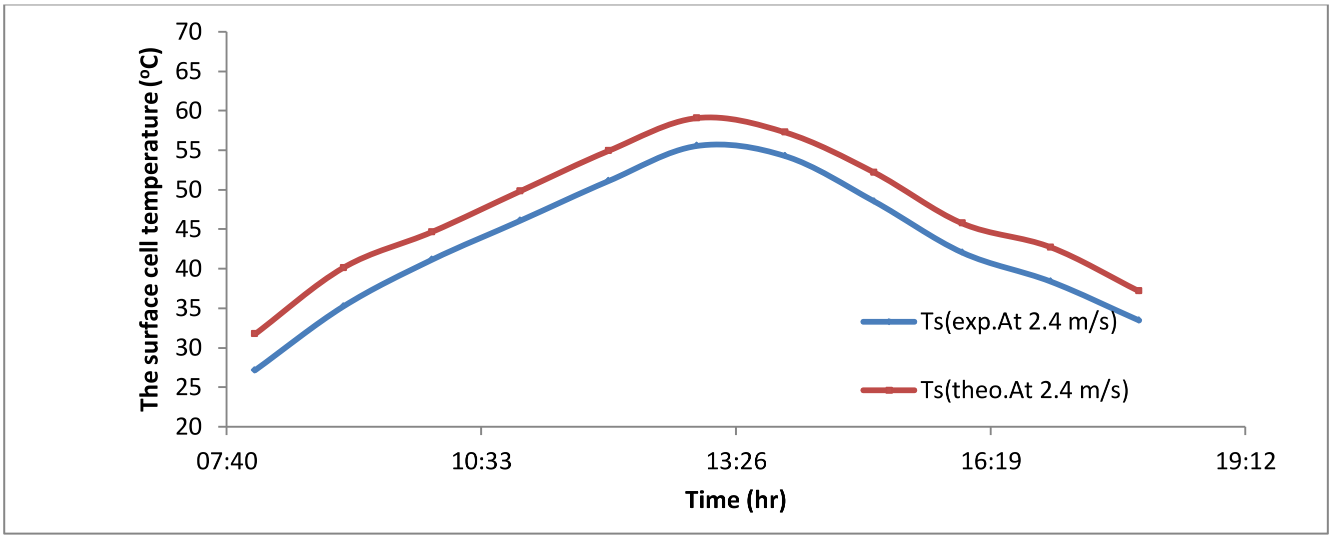

Fig.16:Experimental and theoretical result for the surface cell temperature The above figure shows a comparison of experimental results with the analytic results of the thermal model to the PV cell cooling system to verify the accuracy of the results, and through it, it was found that the error rate is 8.24% .

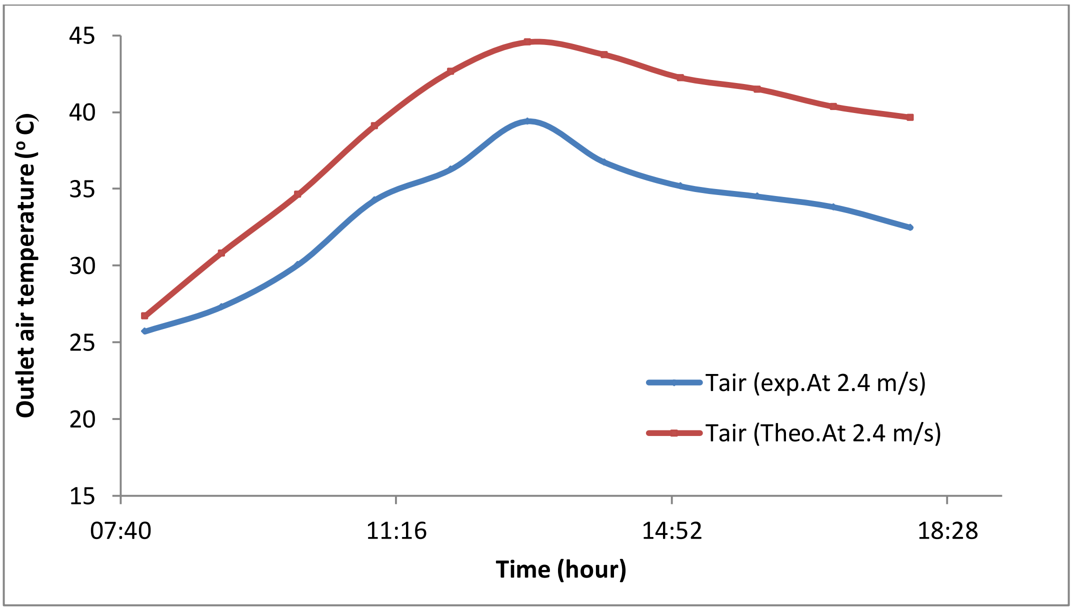

Fig.17:Experimental and theoretical result for the outlet air temperature

The above figure shows a comparison of experimental results with the analytic results of the thermal model to the PV cell cooling system to verify the accuracy of the results, and through it, it was found that the error rate is 9.46% .

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.5-Conclusions

From the above results can be summarized by experimental and theoretical results collected from the PV cell cooling system by air guide:

1- The air-cooled PV system by using air guides is an efficient and modern technology to cool the PV cell at the lowest cost to reduce the temperature of the cell base and increase the performance and efficiency of the PV cell..

2- The highest reduction in the temperature of the PV base was (37.22%) when the temperature of the base of the cell was reduced by (22.622 °C) from (70.622 °C to 48°C) .

3- Percentage increase in the maximum power of the photovoltaic cell after the cooling process by the air guides system is 14.88%.

4- The percentage increase in electrical efficiency of PV / T systems by using air guides system is (14.9%).

5- The net electric power added to the production of the PV cell after the cooling of the photovoltaic cell by using air guides was (42.3 watts).

6-The highest amount of thermal energy produced from the photovoltaic cell, which can be extracted by air flowing towards the base of the cell, was (678 watts).

7-The thermal efficiency increase rate of the PV cell is (68.7%). The temperature difference between the air outlet and the air inlet temperature was 13.717 ° C.

6-References

[1] Y. V Trofimenko, V. I. Komkov, V. V Donchenko, and T. D. Potapchenko, “Model for the assessment greenhouse gas emissions from road transport,” vol. 7, no. 1, pp. 465–473, 2019.

[2] M. H. K. Aboaltabooq *et al.*, “Effect of variable heat input on the heat transfer characteristics in an Organic Rankine Cycle system,” *Renew. Energy Environ. Sustain.*, vol. 1, 2016.

[3] M. H. K. Aboaltabooq *et al.*, “Effect of variable heat input on the heat transfer characteristics in an Organic Rankine Cycle system,” *Renew. Energy Environ. Sustain.*, vol. 1, p. 13, 2016.

[4] I. E. Maree and A. G. Ismaeel, “Experimental and Theoretical Calculation of Efficiency for Flat Plate Solar Collectors in Erbil City,” vol. 7, no. 2, pp. 786–793, 2019.

[5] P. Tudor *et al.*, “Experimental Investigation of Waste Heat Available for a Hybrid Micro-Cogeneration Group Involving a Diesel Engine Electric Generator and Organic Rankine Cycle,” pp. 1–6.

[6] R. S. Rathour, V. Chauhan, and K. Agarwal, *Cooling of Solar Photovoltaic Cell : Using Novel Technique Cooling of Solar Photovoltaic Cell : Using Novel Technique*, no. January. Springer Singapore, 2019.

[7] H. D. Walley, *Vertebrate resistance to pesticides*, vol. 129. 1964.

[8] A. Mohsin alsayah, M. Hatf, K. Aboaltabooq, M. H. Majeed, and A. A. Al-najafy, “Journal of Mechanical Engineering Research and Developments (JMERD) MULTIPLE MODERN METHODS FOR IMPROVING PHOTOVOLTAIC CELL EFFICIENCY BY COOLING : A REVIEW,” vol. 42, no. 4, pp. 52–59, 2019.

[9] T. G. Grubisić-Čabo, F., Nizetić, S., & Marco, “Photovoltaic Panels: A Review of the Cooling Techniques,” *Trans. FAMENA*, vol. 40, no. 1, pp. p63-74. 12p., 2016.

[10] M. H. M. Ahmed Mohsin Alsayah , Mahdi Hatf Kadhum Aboaltabooq, Bassam Abed Saheb

M.hussein, “CFD study to improve PV cell performance by forced air : Modern design,” *Period. Eng. Nat. Sci.*, vol. 7, no. 3, pp. 1468–1477, 2019.

[11] J. A. D. Deceased and W. A. Beckman, *Design of Photovoltaic Systems*. 2013.

[12] A. Saxena and G. Srivastava, “Performance Studies of a Multipurpose Solar Energy System for Remote Areas,” vol. 3, no. 1, pp. 21–33, 2013.

[13] M. Zohri, S. Hadisaputra, and A. Fudholi, “Exergy and energy analysis of photovoltaic thermal (Pvt)with and without fins collector,” *ARPN J. Eng. Appl. Sci.*, vol. 13, no. 3, pp. 803–808, 2018.

[14] S. Dubey, J. N. Sarvaiya, and B. Seshadri, “Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world - A review,” *Energy Procedia*, vol. 33, pp. 311–321, 2013.

[15] K. Amori and H. Al-Najjar, “Analysis of thermal and electrical performance of a hybrid (PV/T) air based solar collector for Iraq,” *Appl. Energy*, vol. 98, pp. 384–395, Oct. 2012.

[16] L. Aelenei, R. Pereira, H. Gonçalves, and A. Athienitis, “Thermal performance of a hybrid BIPV-PCM: Modeling, design and experimental investigation,” *Energy Procedia*, vol. 48, pp. 474–483, 2014.

[17] A. Tiwari, M. S. Sodha, A. Chandra, and J. C. Joshi, “Performance evaluation of photovoltaic thermal solar air collector for composite climate of India,” *Sol. Energy Mater. Sol. Cells*, vol. 90, no. 2, pp. 175–189, 2006.

[18] S. Wang *et al.*, “Cooling design and evaluation for photovoltaic cells within constrained space in a CPV/CSP hybrid solar system,” *Appl. Therm. Eng.*, vol. 110, pp. 369–381, 2017.