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INVESTIGATION OF HYBRID PHOTOVOLTAIC /THERMAL SOLAR SYSTEM PERFORMANCE UNDER IRAQ'S CLIMATE CONDITIONS

Raad H. Abed[1] and Nabeel A. ghaydh[2]

[1] Master's degree student Department of Mechanical /College of Engineering, University of Kufa, Republic of Iraq. Email: raadhamza1983@gmail.com

[2] Asst. prof. Dr. Department of Mechanical /College of Engineering, University of Kufa, Republic of Iraq. Email: nabeel.ghayadh@uokufa.edu.iq

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ABSTRACT

The research investigates the use of fins fastened to a solar panel's rear surface for passive cooling. The research compared solar modules with air cooling against modules with connected fins acting as a heat sink. The comparison was based on the former. The research studies the cooling of modules with fins using two different types of air: ventilation air and still air. By comparing the heat transmission by photovoltaic panels with and without fins, the research sought to analyses the effects of the environment and solar radiation on the performance of solar cells. The inquiry was done hypothetically. According to the findings, using fins for cooling reduced cell temperature and improved electrical and thermal efficiency. The estimated performance values of the PVT solar cell obtained by using the COMSOL program and the experimental measurements carried out during the daytime were reasonably in accord. The biggest reduction in cell temperature is (3.7ºC at noon), while the greatest increases in electrical and thermal efficiency are (16.54% and 58.3%, respectively). There is good agreement between experimental and numerical results.

KEYWORDS: Key words: photovoltaic; electrical efficiency; thermal efficiency; temperature.

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1. INTRODUCTION

Renewable energy sources rely on natural and eco-friendly resources one such source is solar energy, which requires incident solar radiation of 3.8 million watts per year. Among the various applications of renewable energy, hybrid photovoltaic (PV/T) systems are considered superior due to certain advantages. The process involves the simultaneous production of both electricity and thermal energy, The Heat recovery ventilation (HRV) system offers ways to recycle heat from exhausted air by mixing it with fresh air from the outside. The technology behind a photovoltaic/Thermal (PV/T) device is the ability of a single PV module to generate both energy and heat, which can be used to heat water. When used in conjunction with an air-type PV/T, preheating air from the PV/T can be used by the heat recovery ventilation system, allowing for more effective airflow. Low temperature air due to frost and dew condensation can be remedied using heated air from an air-type PV/T collector (Ahn et al., 2015). This study proposed an air-type single-pass PV/T collector system with heat-dissipating thin rectangular fins. Temperature characteristics were measured and compared to various operating circumstances and setups to calculate PV/T system efficiency (Mojumder et al., 2016). The PV/T system without an absorber plate was studied computationally and tested experimentally. COMSOL Multiphysics was used to analyze the system in 3D and Malaysian weather was used for outdoor experiments. The PV/T thermal performance was comparable to that with 1000 W/m2 irradiation and 34 Co inlet and ambient temperatures, with 84.4% numerical efficiency and 80% experimental efficiency. The simulation model can be used for various thermal collector designs and materials (Nahar et al., 2017). The study examined the air prejudiced PV/T trend for two cases: case one (completely covered PV modules) and case two (partially covered glass). Experimental and numerical findings showed that the PV/T device should operate at a modest air flow rate of 0.013 kg/s. The highest exit temperature of the air and electric power was 44.3 Co and 26.6 W. Case 1 had 34% thermal and 10% electrical efficiency, while case 2 had 48.9 and 9.1% (Jalil et al., 2020). This study designed a Hybrid Photovoltaic-Thermal (PVT) double-pass counter-flow device with mixed-mode solar dryer. This technology saves tons of fuel and improves the dried product's color, flavor, and taste. The system is used to dry 300g of banana slices from 43.2 to 60.2°C to test its efficacy and resilience. MATLAB 2015b calculates PVT with dryer room temperature distribution, usable gain of heat, and thermal efficiency (Jadallah et al., 2020). Experimentally investigated the influence of cooling on the performance of a PV panel. One PV module was utilized without a heat sink while the other was used with one. Data from both panels was recorded at 15-minute intervals over 11 hours. The inclusion of a heat sink increased solar to electrical conversion efficiency by 35% and power production by 55%, while decreasing temperatures by 9% in the front and 11% in the rear (Wisam et al., 2020). The experiment studied the efficiency of two alternative configurations of the locally created passive cooling approach, namely rectangular fins and circular fins placed to the back surface of mono-crystalline photovoltaic (PV) modules. The results showed that the PV module with bigger cross-sectional and surface area wasted 155% more heat and produced 10.8% and 4% more power, while also reducing module temperature by 10.6% and increasing module efficiency by 14.5%. The module with round fins dissipated just 27% warmer than the standard module (Amber et al., 2021). This study evaluated the daily and yearly performance of a cooled by air PVT collector with triangle-shaped obstacles to a standard one. A computational model was built and verified using Ulsan, Korea weather data. The PVT collector with triangle-shaped obstacles had daily mean thermal, electrical, and total energy and exergy efficiencies of 24.73%, 15.59%, 62.83%, and 15.57%. The PVT collection with triangle-shaped barriers had 12.84% and 1.98% higher yearly energy and exergy outputs than the air-cooled PVT collector (An et al., 2022). The PVT air collector with a triangular barrier was found to have a greater thermal performance than the collector without one, indicating that it could better use solar energy. Air mass flow rate affects thermal, total energy, and electrical efficiency, and the collector with a triangular block had a greater thermal performance than the collector without one, indicating that it could better use solar energy (Choi et al., 2022). The study studied the photovoltaic/thermal air collector in Tetouan, Morocco, which focuses solar radiation using two movable mirrors to boost electrical and thermal energy. To demonstrate the mirrors' impact on the collector's thermal and electrical output, simulated findings and experimental investigations showed good agreement. The technique estimates the hybrid collector's daily solar energy and searches for the ideal daily angle of tilt of the two mirrors to increase the collector's solar radiation. The tilt angles rely on the sun's elevation angle and azimuth angle on ordinary days (Benkaddour et al., 2022). Previous experiments confirmed a 2D, steady-state simulation system that included the convective flow of air flowing within the PVT system and radiant and convection heat losses from the front PV surface. The findings showed that surface zigzags are preferable for air flow rates of 0.06 kg/s or less, while fins are preferred for greater air flow rates. The fin–surface zigzag combination was the most beneficial, improving electrical and thermal efficiency by 26% and 3%, respectively (Ghanim & Farhan, 2022). This article discusses the efficiency and durability of solar photovoltaic (PV) devices and collectors for solar thermal energy. It also discusses how to cool the solar collector, including air cooling, water cooling, and other techniques. The efficiency of photovoltaic cells was improved using these techniques and tested in a variety of environments. The research showed how using solar energy is helping in crucial ways (Saleh et al., 2022). This study is concerned with both theoretical, experimental studies on the PV/T solar system and examination the effect the climate of middle of Iraq on air PV/T solar system. It represents a possibility increasing the benefit of solar energy by cooling solar cell. The desired objectives can be an achieved in this thesis. Improvement in the performance of solar cells and electrical efficiency of solar cells by cooling them by air. And the heat dissipation from the surface of the cell to heated air and can be used in process applications such as drying launch, Crops (such as tea, corn and coffee), and other drying applications.

2. METHODOLOGY

The studied involved maintaining a constant air velocity while entering a tunnel with identical conditions in both the back sheet without fins and back sheet with fins. Fin with Thermal Conductivity (164W/m K). Additionally, variable solar radiation was applied for eight hours each day from 8 am to 4 pm. The inlet air inside the tunnel at a velocity of (3.1 m/s). and external wind velocity of air, and the solar cell was taken into account, as it affects the coefficient of heat transfer of the cell's external surface and its outer condition. The air temperatures varied for each hour of the day with a total of eight hours during the day. The tunnel was also utilized in the experiment. The duct is constructed from an acrylic material that has good heat insulation properties. The PV/T module's performance was analyzed through numerical simulation. The analysis was conducted using parameters that remained constant throughout the process. The experiment involved maintaining a constant air velocity while entering a tunnel with identical conditions in both the back sheet without fins and back sheet with fins. Additionally, variable solar radiation was applied for eight hours each day from 8 am to 4 pm. The external wind velocity of air the solar cell was taken into account as it affects the coefficient of heat transfer of the cell's external surface and its outer condition. The air temperatures varied for each hour of the day, with a total of eight hours during the day. The tunnel was also utilized in the experiment. The duct is constructed from an acrylic material that has good heat insulation properties. The PV module is composed of five solid domains, namely the front cover made of glass, encapsulation consisting of ethyl vinyl acetate (EVA), photovoltaic (PV) cells, back sheet made of Tedlar as shown in Table 1, and thermal paste which serves as a heat conductor. The flow channel is comprised of two distinct domains namely a solid domain composed of aluminum and a gas domain consisting of air.

Table 1. Material properties and thickness of each layer of PV Panel (Leow et al., 2020)

No.	Material (Layer)	Thickness (cm)	Thermal Conductivity (W/m°C)	Specific Heat Capacity (J/kg°C)	Density (kg/m3)
1.	Glass Covering	0.3	1.8	500	3000
2.	EVA	0.05	0.35	2090	960
3.	PV Cell	0.04	148	677	2330
4.	Tedlar	0.01	0.2	1250	1200

The PV/T module panel is composed of five layers, which include both solid and gas materials. The user employs COMSOL Multiphysics software which is based on the finite element method (FEM) to solve the governing equations. The simulation has achieved unsteady state conditions in 3D. The software is used to extract data on the mean cell surface temperature shown in Fig. 1 and Fig. 2. and average air outlet temperature This data is then used to create graphs using Microsoft ExcelTM.

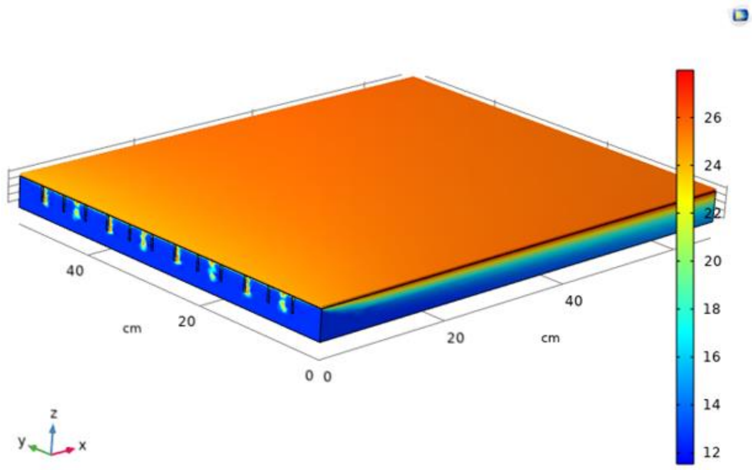

Fig.1. Domain temperature with fin

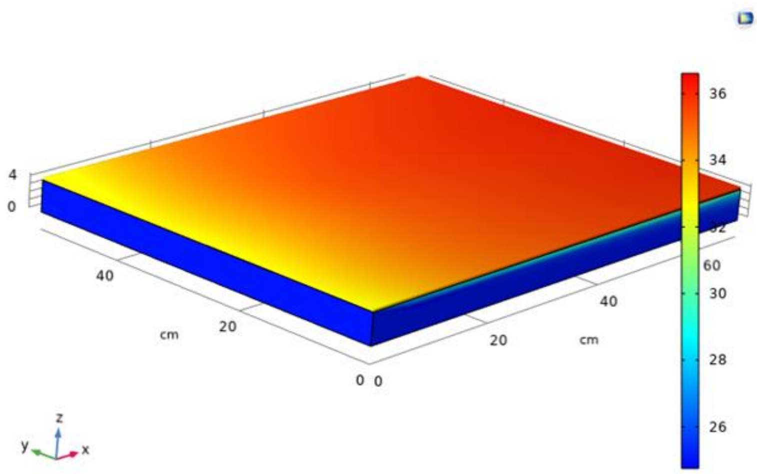

Fig.2. Domain temperature without fin

3. CONTINUITY EQUATION

The continuity equation, represented by the conservation of mass, is given in a three-dimensional flow in terms of time-averaged compressible flow (Benkaddour et al., 2022).

$$\partial\rho / \partial t + \partial /\partial x (\rho u) + \partial /\partial y (\rho v) + \partial / \partial z (\rho w) = 0. \quad (1)$$

This can be re-formulated in a vector form:

$$\partial\rho/(\partial t) + \nabla \cdot \rho \vec{V} = 0, \quad (2)$$

where ρ is the density of air (kg m-3), del (∇) refers to the vector gradient operator and $\vec{V}$ is the fluid velocity vector defined as follows:

$$\nabla = \partial /\partial x\, i + \partial / \partial y\, j + \partial / \partial z\, k, \quad (3)$$

$$\vec{V} = ui + vj + wk. \quad (4)$$

4. MOMENTUM EQUATION

For single-phase laminar flow, a compressible Newtonian fluid including the effect of gravitational forces, under transient conditions (Benkaddour et al., 2022), the general momentum equation in a three-dimensional Cartesian coordinate form as:

X-direction

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\rho g_x-\left(\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{yx}}{\partial y}+\frac{\partial \tau_{zx}}{\partial z}\right), \quad (5)$$

Y-direction

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\rho g_x+-\left(\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{xy}}{\partial z}\right), \quad (6)$$

Z-direction:

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial y}+\rho g_x+-\left(\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}\right), \quad (7)$$

5. ENERGY EQUATION

The rate of heat addition from solid to fluid particles owing to heat conduction across element boundaries is the general conductive energy equation with a heat source and translational motion between the layers (Benkaddour et al., 2022).

$$D(\rho cT)/ Dt . \nabla T = \nabla.(kx, y, z /\nabla T) + Q\dot{v} \quad (8)$$

X-direction:

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\rho g_x+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \quad (9)$$

Y-direction:

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\rho g_x+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \quad (10)$$

z-direction:

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\rho g_x+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \quad (11)$$

where ρ is the density of PV layers (kg. m-3), c is the heat capacity of PV layers at constant pressure (J. kg-1. K-1), kx, y, z is the thermal conductivity of the PV layers (W. m-1. K-1) x, y and z, directions and assumed isotropic ($kx = k = kz$). u, v and w are the velocity components in x, y and z directions, respectively, $Q\dot{}v$ is the volume heat source or sink.

6. ELECTRICAL AND THERMAL EFFICIENCY SYSTEMS

Equation (12) can be used to calculate the amount of useful heat gained by air (Amber et al., 2021).

$$Qu = \dot{m}cp\ (T_o - T_i) \quad (12)$$

where Qu represents the amount of heat transferred, ṁ is the mass flow rate, cp is the specific heat capacity, to is the outlet temperature, and Ti is the inlet temperature. One method for determining thermal efficiency is through evaluation.

$$\eta_{th} = \dot{m}\ c_p\ (T_o - T_i)/\ G * A_s \quad (13)$$

The equation (13) relates the thermal efficiency (ηth) of a system to the mass flow rate (ṁ), specific heat capacity (cp), temperature difference between the outlet (To) and inlet (Ti), and the heat transfer area (As) and solar radiation (G) of the sun.

The equation for calculating heat gain from a collector involves several variables, including Qu, To, Ti, Ac, and G. Qu represents the usefulness of the heat gained, while To and Ti refer to the outlet and also inlet temperatures of the heat transfer fluid. Ac is the area of the collector, and G represents the amount of radiation on the collector surface.

Equations (14) and (15) provide information on the power generation and photovoltaic efficiency (Amber et al. 2021). The power of a solar cell is commonly described using two main parameters: the circuit current (I), circuit voltage (V),

$$Pe = V * I \tag{14}$$

$$\eta e = Pe / G * A_{pv} \tag{15}$$

represents the efficiency of a system, where ηe is the electrical efficiency, Pe is the power output, G is the solar radiation, and Apv is the product of the area and pressure difference. The user has provided a formula that relates electrical efficiency (ηe) to electrical power output (Pe) and the area of PV modules (Apv).

7. EXPERIMENTAL SETUP

The practical side consists of installing three photovoltaic cells identical in terms of dimensions and quality , and these cells are characterized by the specifications, the wind tunnel is installed below twice cell with the fins placed in the second cell , where the wind tunnel is made of acrylic material , which is characterized by good thermal insulation , the height of the Wind Tunnel (4 cm) and length (53 cm), in addition to installing DC fans with the wind tunnel to draw cooling air inside the tunnel at a speed of (3.1 m/s). leaving the third cell without an air tunnel and without cooling fans, the fins are installed below one of the photovoltaic cells with a good heat-conducting resin, The fin consists of the following dimensions (2 cm) height, (53 cm) length and (0.3 mm) number of fin (12) to fix the fins tightly with the cell surface from below and avoid air gaps ,the fin had made of aluminum material with high thermal conductivity thereby increasing thermal conductivity and we get the highest heat dissipation of the fins. this study was conducted in Najaf in Iraq (32.0107 N, 44.3265 E) from May 2023. The experiments last for 8 hours from 8: 00 AM to 4: 00 pm where readings, The temperature is on the back of each of the photovoltaic modules , the results are recorded for three panels at once for analysis and correct comparison , the devices used in it are a K-type temperature sensor for measuring temperatures installed in (5) different areas of the same panel and identical to the three panels shown in Fig. 3a and Fig. 3b , a solar radiation intensity meter for measuring the intensity of solar radiation with a unit (W/m^2).

3a (back sheet with fin)

3b (back sheet without fin)

Fig. 3. Experimentally state for PV panel.

8. RESULTS AND DISCUSSIONS

A photovoltaic (PV) system's thermal and electrical efficiency is examined in the experimental findings together with the effects of different meteorological factors, such as sunshine, wind speed, ambient temperature, and input air temperature. To do this, the projected PV/T system's output power for both electrical and thermal energy was measured.

9. EXPERIMENTAL RESULTS

The experimental results encompass an examination of the impact of various weather conditions, including sunlight, wind speed, the surrounding temperature, and inlet air temperature, on the thermal and electrical efficiency of a photovoltaic (PV) system. This was achieved by measuring the resulting electrical power and thermal energy output power of the proposed PV/T system.

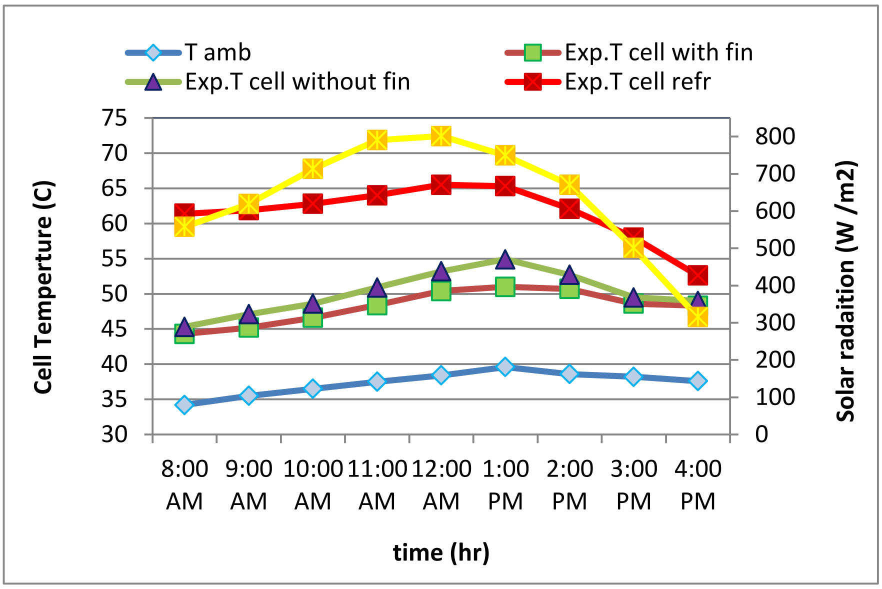

Fig. 4. The experimental variation of PV temperature with time day for 15 May 2023, for PV module, PV/T module and PV /T module with fin

Fig. 4 shows the variation of cell temperature with time day for 15 May 2023, for PV module, PV /T module and PV /T module with fin, the cell temperature increase through day due to the solar radiation increase and ambient temperature increases, and the cell temperature for PV /T module with fin decreases compared with other cases due to dissipation heat in temperature because increases the convection surface area. the maximum temperatures of the PV panel are (65.5) in May. the maximum temperature of PV/T system without fins are (66.6) in May. the maximum temperature of PV/T system with fins are (76) in May.

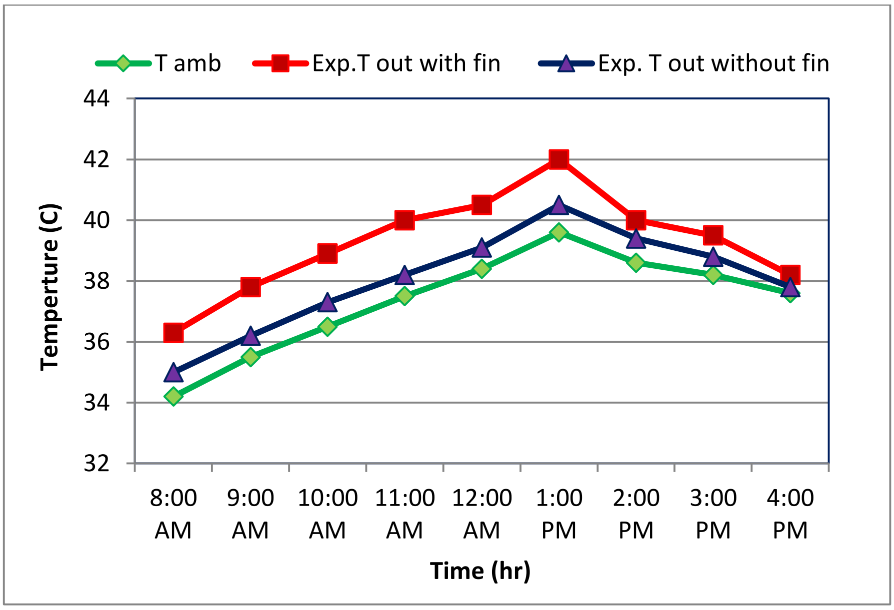

Fig. 5. the variation of outlet temperature with time day for May 2023, for PV /T module and PV /T module with fin.

Fig. 5 show the variation of outlet temperature with time day for May 2023, for PV /T module and PV /T module with fin, the outlet temperature increase through day due to the solar radiation increase and ambient temperature increases, and the outlet temperature for PV /T module with fin higher from PV /T module without fins due to the increase in the contact surface and thus the heat transfer air increases.

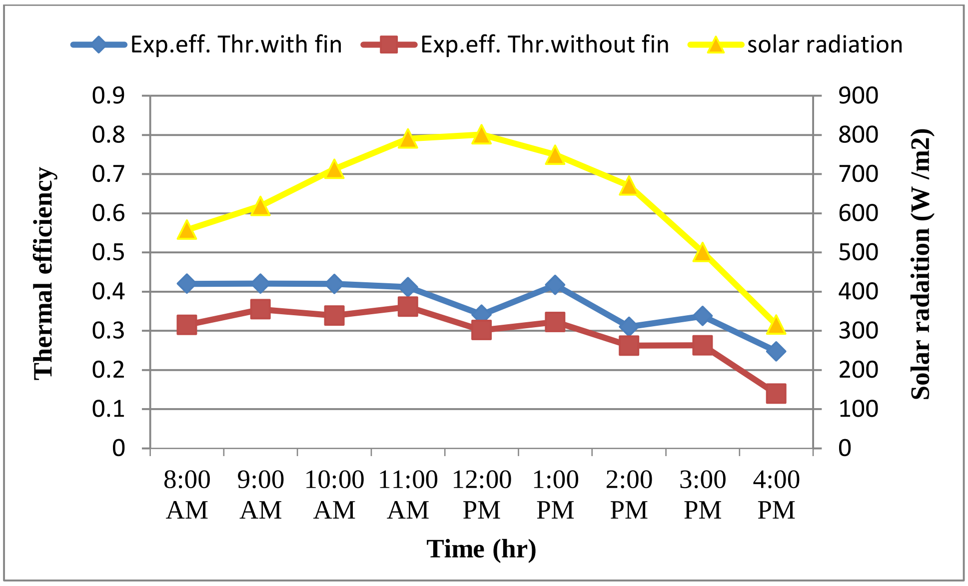

Fig. 5. the variation of thermal efficiency with time day for May 2023, for PV /T module without fins and with fins.

Fig. 5 show the variation of thermal efficiency with time day for May, June and July 2023, for PV /T module and PV /T module with fin, respectively. the Thermal efficiency increase through day due to the solar radiation increase and ambient temperature increases, and Thermal efficiency for PV /T module with fin higher from PV /T module without fins due to the increase in the contact surface and thus the heat transfer air increases.

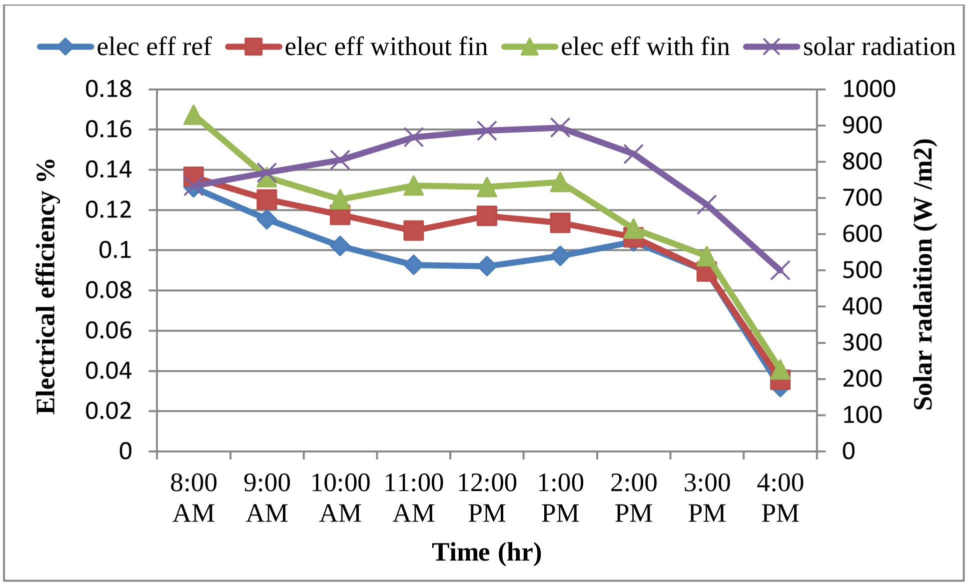

Fig. 6. The experimental Electrical efficiency and solar radiation for May 2023, for PV module and PV/T module without fins and with fins.

The figures presented in Fig. 6 illustrate the time variation of electrical efficiency for three different types of solar modules: PV module, PV/T module, and PV/T module with fin. These comparisons are specifically focused on the month of May in the year 2023. The instantaneous electrical efficiency decreases as solar irradiance increases due to the rise in temperature of PV cells. This increase in temperature leads to a reduction in the production of electrical power relative to the amount of solar irradiance. The electrical efficiency of a PV/T module with a fin system surpasses that of other cases, primarily due to the reduction in temperature of PV cells. This decrease in temperature contributes to the enhancement of the module's electrical efficiency.

10. THEORETICAL RESULTS FOR COOLING BY AIR

The utilization of the COMSOL Multiphysics software is employed. The models are being compared in this analysis .The measurements were conducted in an open ambient environment within the mid-climate region of Iraq, specifically in Najaf.

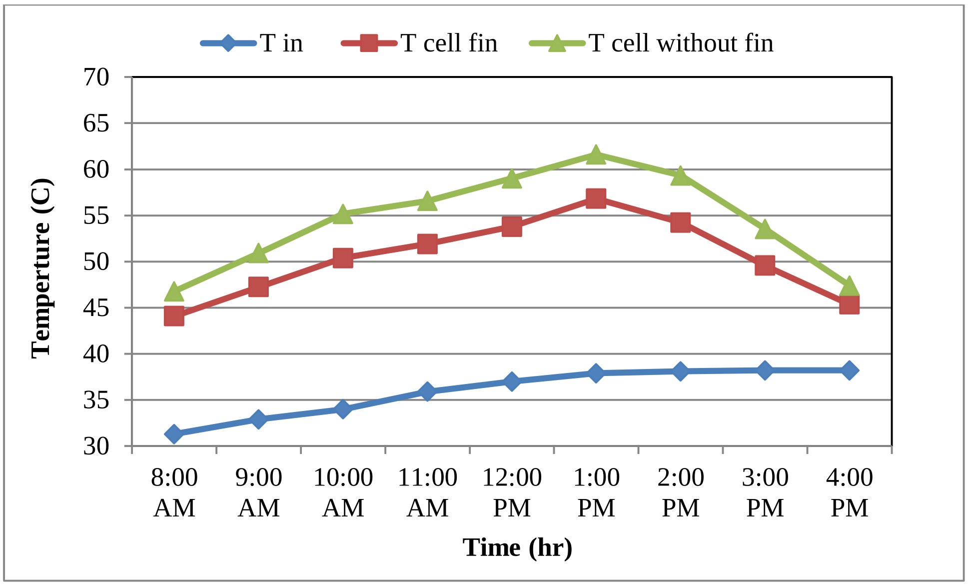

Fig. 7. the theoretical variation of Cell temperature with time day for May 2023, for PV /T module and PV /T module with fin.

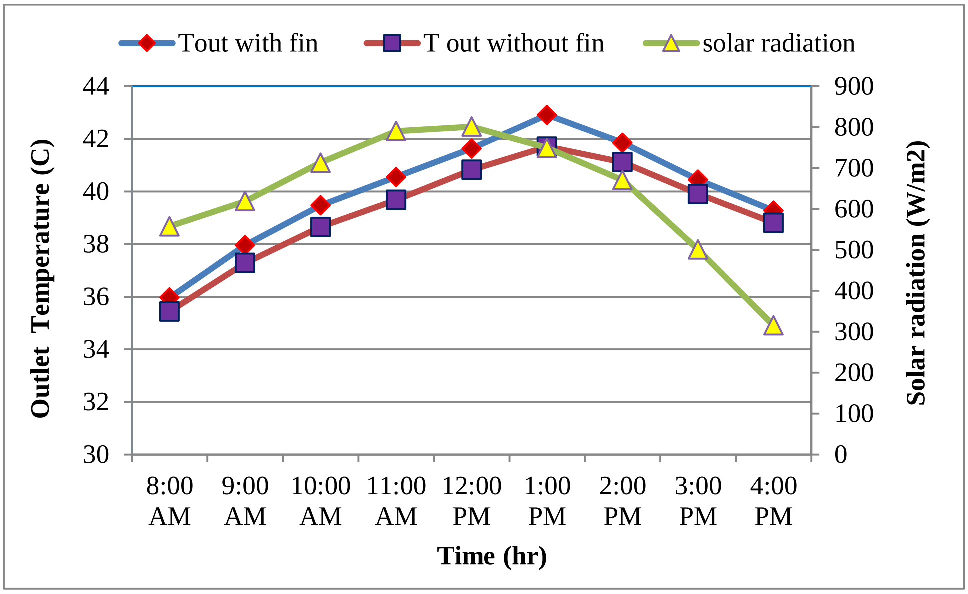

Fig. 8. the variation of outlet temperature with time day for May 2023, for PV /T module and PV /T module with fin.

Fig. 7 shows cases the exciting potential for the average Cell temperature to vary throughout the day for both the PV/T module and the PV/T module with fin in May 2023. The average Cell temperature increases throughout the day because of the increase in solar radiation and ambient temperature. Additionally, using fins on the PV/T module helps dissipate heat, increasing the convection surface area.

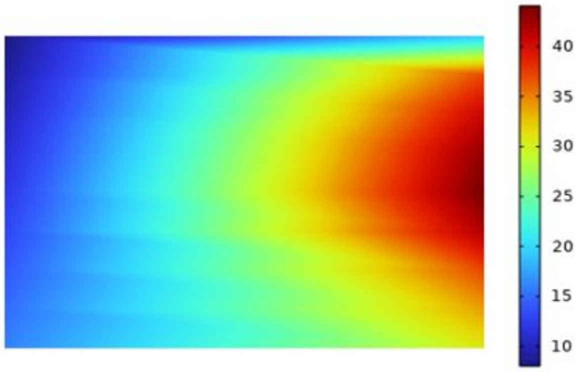

Fig. 9a back sheet surface temperature without fins.

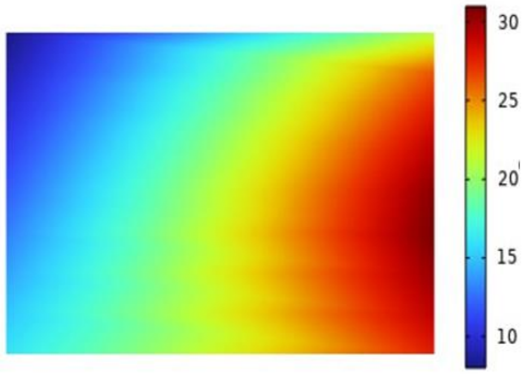

Fig. 9b back sheet surface temperature with fins.

The temperature variation of the back surface of the photovoltaic cell was analyzed over the course of one day from 8:00 am to 4:00 pm. The results showed that the average temperature distribution in the soft plate was higher than that in the plate with fins, which indicates that the heat distribution in the soft plate was lower as shown in Fig. 9 a and b and the reason here is the presence of fins that will increase the area of heat dissipation for solar cells.

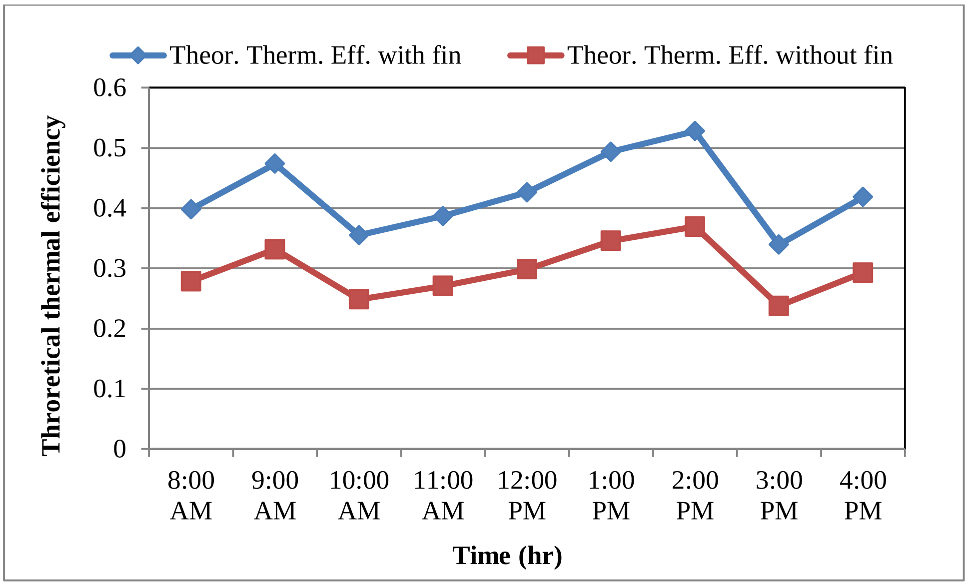

Fig. 10 Theoretical and Experimental Results of Outlet Temperature for May 2023, for PV /T module without fin.

11. THEORETICAL AND EXPERIMENTAL RESULTS FOR AIR

The COMSOL program are developed to solve governing equations to predicate the all above measured parameter. The predicated results are compared with experimental results to validate its correctness; in addition, it has been calculating the percentage deviation of theoretical about of experimental results and choosing samples of result to illustrate the difference between them as below:

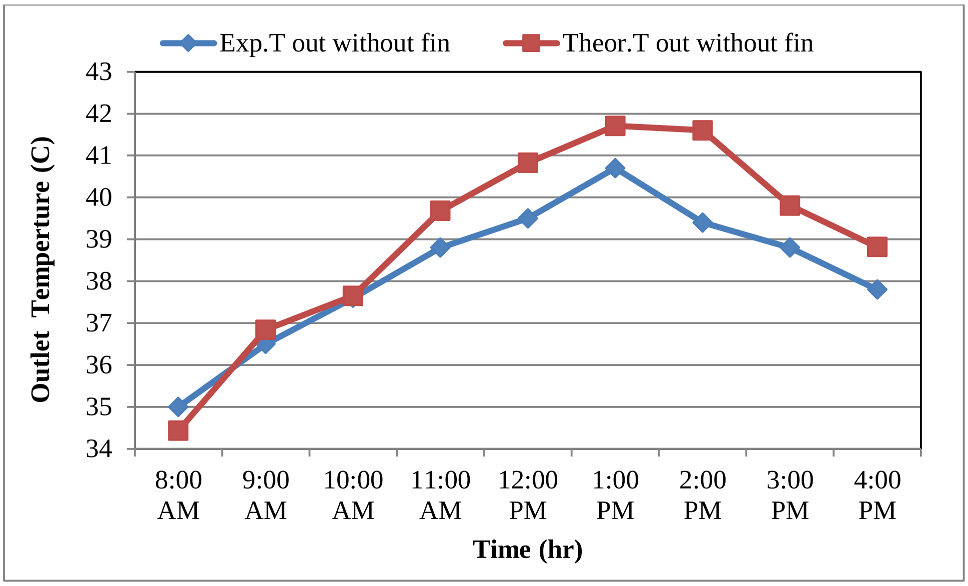

Fig. 11 Theoretical and Experimental Results of Outlet Temperature for May 2023, for PV /T module without fin.

Fig.11 presents a good agreement between theoretical and experimental results of Outlet Temperature for May 2023, for PV /T module and PV /T module with fin, respectively. The Outlet Temperature of maximum deviation percentage is 10.10% for PV /T module and 13.94 % PV /T module with fin. The reasons of deviation, thermal insulation is not efficient 100 % of, where ambient temperature more than back sheet temperature that leads to transfer additional heat during the back and the side of solar system, in addition to uncertainty in measurements.

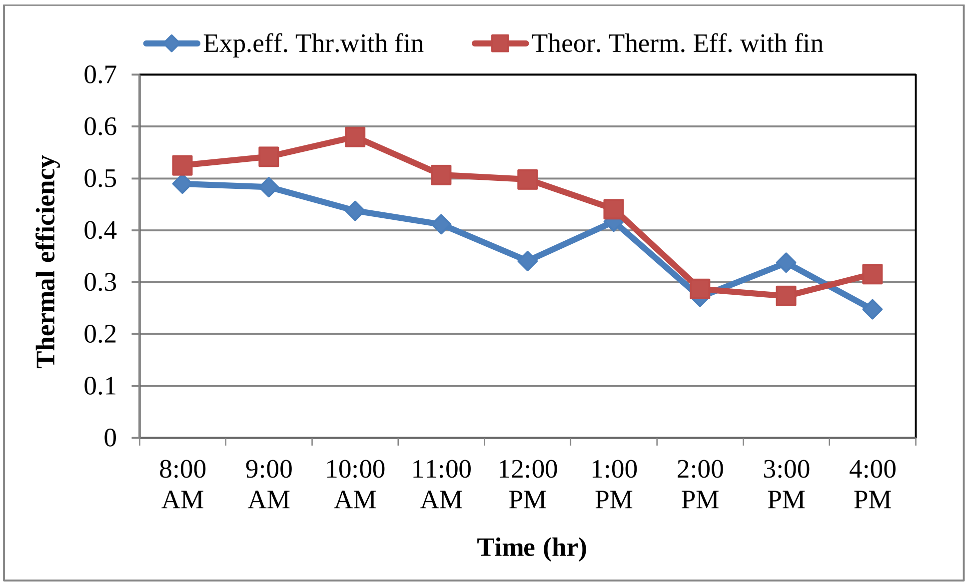

Fig. 12. Theoretical and Experimental Results of Thermal efficiency for May 2023, for PV /T module with fin.

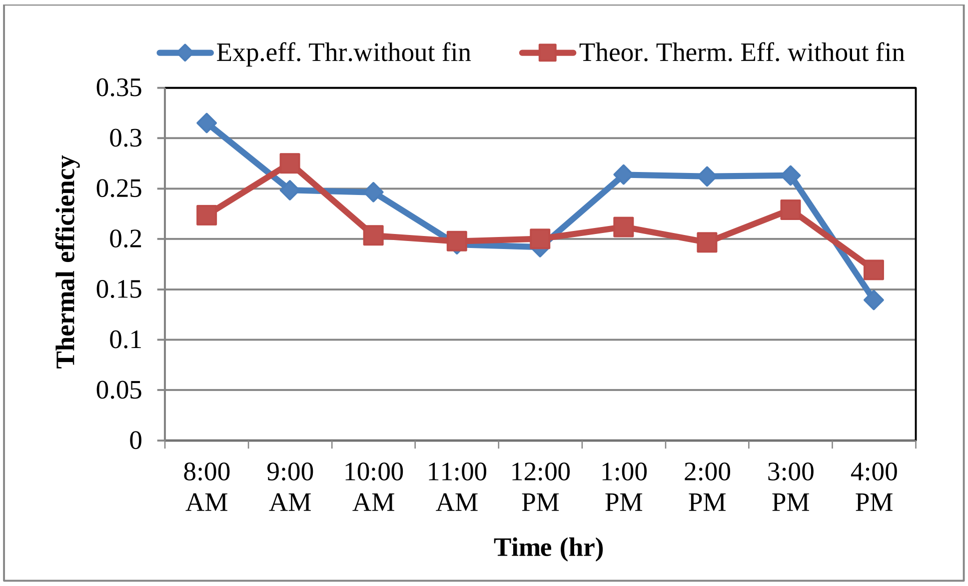

Fig. 13. Theoretical and Experimental Results of Thermal efficiency for May 2023, for PV /T module without fin.

Figs. 12 and 13 depicts the comparison between the theoretical and experimental outcomes of thermal efficiency for the PV/T module during the month of May 2023. The findings demonstrate a satisfactory level of agreement, with an average deviation percentage of 16.54 % observed in the month of May. There are several factors that contribute to the observed deviation. One factor is the incomplete effectiveness of thermal insulation, which does not achieve a 100% efficiency. Additionally, the thermal efficiency of the experimental results is calculated based on readings from multiple instruments, which introduces a high level of uncertainty.

12. CONCLUSION

Through the employment of fins linked to the module's back surface, passive cooling of the solar module is effectively accomplished. For comparison with solar modules strengthened by attached fins, which provide effective heat dissipation, an air-cooled solar module was chosen as the base model. Air at a steady speed and the cooling air around the plate work together to effectively cool the finned components. To investigate how variations in the outside temperature and solar radiation affect the predicted performance of solar cells, an intriguing theoretical investigation was carried out. The research focused on heat transport through solar modules, including those with and without fins. It may be possible to use this study to reveal how to improve the efficiency and performance of solar cells. The cooling of the fins contributed to the findings, which showed a beneficial conclusion with a drop in cell temperature and a discernible rise in electrical and thermal efficiency. With those tested experimentally throughout the day, the estimated solar cell performance values produced by the COMSOL Multiphysics program showed encouraging consistency. At midday, the largest drop in cell temperature is a manageable 3.7ºC at noon, while the maximum gains in electrical and thermal efficiency are a stunning 16.54 % and 58.3%, respectively. Statistical and empirical data are in excellent accord.

Through the employment of fins linked to the module's back surface, passive cooling of the solar module is effectively accomplished. For comparison with solar modules strengthened by attached fins, which provide effective heat dissipation, an air-cooled solar module was chosen as the base model. Air at a steady speed and the cooling air around the plate work together to effectively cool the finned components. To investigate how variations in the outside temperature and solar radiation affect the predicted performance of solar cells, an intriguing theoretical investigation was carried out. The research focused on heat transport through solar modules, including those with and without fins. It may be possible to use this study to reveal how to improve the efficiency and performance of solar cells. The cooling of the fins contributed to the findings, which showed a beneficial conclusion with a drop in cell temperature and a discernible rise in electrical and thermal efficiency. With those tested experimentally throughout the day, the estimated solar cell performance values produced by the COMSOL Multiphysics program showed encouraging consistency. At midday, the largest drop in cell temperature is a manageable 3.7ºC at noon, while the maximum gains in electrical and thermal efficiency are a stunning 16.54 % and 58.3%, respectively. Statistical and empirical data are in excellent accord.

13. REFERENCES

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