NTU Journal for Renewable Energy (2023) Vol. 5 (1): 47-60
DOI: https://doi.org/10.56286/ntujre.v5i1.518

IRAQI Academic Scientific Journals

ISSN: 2788-9912 (print); 2788-9920 (online)
NTU Journal for Renewable Energy
Available online at:
https://journals.ntu.edu.iq/index.php/NTU-JRE

Evaluation of the performance of the photovoltaic Trombe wall in the Iraqi conditions

Ateka K. Ibrahim[1], Omer K.Ahmed[2]

[1,2]Kirkuk Technical College, Northern Technical University, Iraq.

Article Information

Received: 03 June 2023
Received in Revised form: 20 June 2023
Accepted: 11 August 2023
Published: 28 August 2023

Corresponding Author:
Ateka K. Ibrahim

Email:
ateka.khalel@ntu.edu.iq

Keywords:
PV/Trombe Wall , Performance, Iraqi conditions

ABSTRACT

An experimental study was conducted to assess the affect of cooling technologies on the effectiveness of the PV/Trombe wall system. The solar panel's cooling system included a DC fan. and water flows via the heat exchanger that is situated behind the photovoltaic panel was used. The results showed that when cooling with both air as well as water, the temperature of the photovoltaic panel decreased, reaching (25.60°C) at 12 p.m. The electrical efficiency was recorded as its highest value when employing water for cooling, as it reached (13.75%). As for the thermal efficiency, it reaches its highest rate employing air and water for cooling because of the thermal energy that air and water gain, as it reached (45.83%).

Nomenclatures

A	Area(m^2)	$T_{inwater}$	Water temperature at the heat exchanger inlet [K]
V	Voltage [V]	$T_{outwater}$	Water temperature at the heat exchanger outlet [K]
TW	Trombe wall	T_{inair}	The temperature of the air at the PV/TW inlet [K]
PV	Photovoltaic	T_{outair}	The temperature of the air at the PV/TW exit [K]
L	Length [m]	$\dot{m}_{air}$	Mass flow rate of air [kg/s]
I_{solar}	solar radiation [W/m^2]	Q_{air}	Heat gain [W]
I	Current [A]	V_{air}	Velocity of air inside the duct [m/s]
H	Height [m]	η	Efficiency
G	Gravitational [m/s^2]	ρ	Density [kg/m^3]
DC	Direct current [A]	β	Volumetric expansion coefficient [1/K]

1. Introduction

One source of solar energy passive is the Trombe Wall. technology that converts solar radiation into useful thermal energy. Because as an easy structure system that doesn't require cutting-edge technologies, the Trombe wall is now widely used in various nations [1]. The Trombe wall's surface has been colored black to boost its capacity to absorb solar energy. However, the TW's visible black matte surface makes it challenging to adhere to building aesthetic standards that restrict the TW use being constrained. The blue-dark color of photovoltaic cells can significantly improve the TW's exterior appearance. when they are attached to the cover glass. is among the most interesting renewable energy forms is photovoltaic. Building a combined PV hybrid solar system generates power and heat concurrently to save energy[2][3]. The photovoltaic Trombe wall contributes to the environment by lowering the consumption of fossil fuels. It is appropriate for residential buildings and does not produce noise. It causes no harm and produces no pollutants that harm the environment[4].

Many theoretical and experimental studies for the (PV/TW) system are being done recently. Chenglong et al. [5] invented a novel (PV/TW) system that utilizes the phase-change material to address the issue of the system overheating in the summer, this kind of system is referred to as PV-PCM-Trombe. The findings demonstrate that the system effectively decreases the photovoltaic cells' temperature and that the PCM panels coated with lacquer can reduce the photovoltaic cells' temperature. Ahmed et al. [6] conducted an experiment of the (PV/TW) making utilization of a porous medium According to the results, the glass cover, DC fan, and porous medium together improve by approximately 20% and 5% improvement in thermal and electrical Efficiency, respectively .combining a direct current fan and a medium that is porous also raises both the electrical and thermal efficiency by 4% and 13%, respectively.

Ahmed et al. [7] presented a study on the examination of(PV/TW) by employing (binary fluid), the single-pass air duct serves as the element that heats the air, while the water is heated using serpentine-shaped copper tubes. by employing 300 L/day, according to the results, the highest daily medians for electric and thermal efficiency were, respectively, 10.69% and 79.89%. Abed et al. [8] proposed an investigation to assess how the (PV/TW) system is affected by nanofluid performances. According to the results, under operational circumstances (fan and nano 0.5% and 300 L/day), 62.99% and 9.2% of the greatest thermal and electrical efficiency were attained. when boosting coolant flow in the heat exchanger and utilizing nano-fluids are not good options for heating the place. Abed et al. [9] tested the influence of employing air and water to cool photovoltaic panels to improve the (PV/TW) performance. The temperature as well as the cover of glass of a photovoltaic panel affect the efficiency of a system. As a result, the cover glass optimizes the efficiency of both the electrical and thermal by (4%-13%). The performance of the system has to be enhanced. by incorporating a DC fan into the system to assist with air movement in the experimental chamber and solar panel cooling. Abed et al. [10] exhibited the influence of a glass cover on PV/TW effectiveness as well as the utilization of (Al2O3/water) for cooling. nano-particle concentrations of 0.5% and 1% were investigated. The findings demonstrate that the outside glass elevates the photovoltaic cells' temperature and the chamber, and lowers the electrical efficiency while increasing the system's thermal efficiency, the best system's thermal efficiency of 80% was achieved by using (glass cover and 0.5% nanofluid). Abdullah et al. [11] examined four operating circumstances: water and air for cooling, cooling by water, not employing any cooling techniques, and cooling by air. to assess the influence of photovoltaic cells' cooling on the effectiveness of (PV/TW), According to the data, the cooled solar panel that uses both water and air has the greatest system's daily electrical efficiency (11.69%), while when uses water only the greatest daily thermal efficiency (39.81%). and maximum total efficiency of 51.40% was recorded for the cooling by water. Bendong et al. [12] proposed a purified (PV/TW) system to investigate electrical and thermal efficiency, offer winter room warming, degrade gas formaldehyde, and provide sustainable power. When this proposed system had been compared to other PV/T systems, the system's thermal and electrical efficiencies for air averaged 36.6% and 11.9%, respectively. Jie et al. [13] exhibited an analysis of the PV/TW system employing a DC fan or without a DC fan, The findings show that with similar solar exposure, the interior temperature increases by 0.50°C on average where as the pv cells' temperatures drop by 1.28°C. This displays that the additional DC fan may assist in both cool the solar panels and boosting the temperature indoors of the entire space. Yuan et al. [14] developed the Mediterranean photovoltaic Trombe Wall (MPVTW). Using a solar panel that is situated in the very middle of the air channel for MPVTW has an electrical efficiency of 12.0% and a thermal efficiency of 38.2%, according to the results. System MPVTW has a 10.83% higher average efficiency than the total efficiency of the EPVTW system. The aim of this article is to study the impact of different cooling technologies on the performance of the PV / TW system in terms of providing warm air to improve comfort conditions inside the room, in addition to providing hot water.

2. Methodology:

In order to clearly grasp how these kinds of systems should be used for household purposes, this article will examine the impact of the cooling approach on the efficiency of the PV/TW system. by employing water that flowed via the heat exchanger on the solar cell's back side. and air as the working fluid to obtain heat from the solar cell. Different experiments were achieved for a month (February -2023), with a volume flow rate (0.3) liter/min, each test starts at 8 A.M. and ends at 4 P.M., Section 3 contains a description of the experimental model together with its components and tools utilized. Calculating performance and system efficiencies will be covered in Section 4. Section 5 will offer the findings, and section 6 will include the conclusions.

3. Experimental work:

Several tests were conducted for the experimental model as shown in the Fig. (1)

To illustrate the impact of operating standards, design, and weather effects on the effectiveness of the PV/TW. The functional tests of this study were carried out in Hawija, northern Iraq, (35.19°N, 43.46°E) for the month of February, the two experimental room dimensions with the subsequent measurements (1.25 m wide, 1.25 m deep, and 2 m high). To minimize heat loss, insulating sandwich panels were used in the design of each testing room. Polycrystalline photovoltaic panels are used.

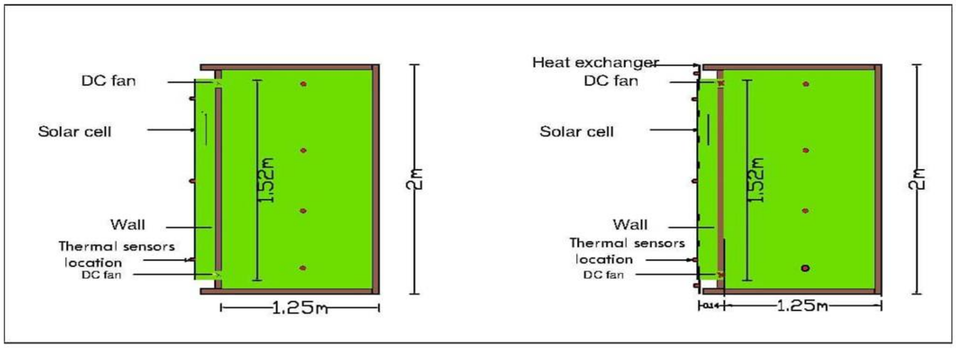
Table No. (1) details the specifications of photovoltaic panels.

The photovoltaic panels were put on the southern facades of the experiment room, as depicted in Fig. (1), The first system consisted of the solar panel in the frontal, and air channel is attached wall. On top of the wall and at its base, there were two DC fans installed. The fan at the highest part of the wall take air from the channel and circulate it into the room, while the fan at the lowest part of the wall move air from the room into the duct as depicted in (Fig. 2-a). while in the second system, a heat exchanger is placed behind the photovoltaic panel and then, the duct was attached to the wall. As depicted in (Fig. 2-b), The water utilized to cooler the PV cell is circulated by a pump, where the heat travel from the PV cell to the water in the serpentine-type heat exchanger, which has a length of 16.9 m, an inner tube diameter of 0.05, and an outer tube of 0.07 mm. Both systems have 24 temperature sensors. There are 11 sensors in the system utilizes air for cooling and 13 in the system employs water as a cooling medium. on the photovoltaic panels, there are six sensors mounted, three on each solar panel for each system. There are each room in the system has four sensors set up. eight duct sensors were used for both systems, two in the lower vents and the upper vents in each duct. two sensors were used for the water-cooled model for the purpose of calculating the water's temperature going into and out of the system. The water is driven by a pump placed in a 200-liter water tank with a volumetric flow rate of about 300ml/min. Polycrystalline photovoltaic panels are used. Table No. (1) details the specifications of photovoltaic panels. Arduino software was used to collect information about fan speed, voltage, and current. At every clock, data is collected and saved in the microcontroller's internal memory, where it is later retrieved by a specific memory via (USB) port.

Table 1 solar cell Specification.

The measured physical quantity	Measuring unit	The measured physical quantity	Measuring unit
Standard Condition Maximum Power	150W	Operating Temperature	25°C
Maximum Power voltage	17.9V	Dimensions(m)	(1.48*0.68*0.035) m
Maximum Power Current	8.38A	Cell Type	Polycrystalline
Short Circuit Current (Isc)	8.81A	Tolerance	± 3%

Fig. 1 Picture of two experimental room



a b

Fig. 2 A diagram of the experimental model. (a) the system cooled by air (b) the system cooled by water

4. Performance calculation:

Thermal and electrical efficiency have an important part in a PV/TW's performance. By evaluating the heat gain rates in the ducts and the heat exchangers, the thermal and electrical efficiency of the (PV/ TW) system was assessed in this study [15].

4.1. The heat gained from the air moving through the duct It computes by a formula as follows[16].

$$Q_{air} = \dot{m}_{air}\, Cp_{air}(T_{outair} - T_{inair}) \quad [1]$$

where (Q_{air}) the heat gain, (Cp_{air}) the air's specific heat, ($T_{outair} - T_{inair}$) temperature differences between the air entering and leaving the air duct.

$\dot{m}_{air}$ represents the air mass flow rate as indicated in the formula as follows [8]

$$\dot{m}_{air} = \rho_{air}.A_{duct}.V_{air} \quad [2]$$

air velocity was determined for two situations:

1-The first situation: velocity of airflow within duct is computed by natural convection applying the equation below [17].

$$V_{air} = \sqrt{\frac{0.5.g.\beta.H(T_{outair} - T_{inair})}{C_{losin}\left(\frac{A_{duct}}{A_{in}}\right)^2 + C_{losout}\left(\frac{A_{duct}}{A_{out}}\right)^2 + C_d\left(\frac{H}{D_H}\right)}}$$

[3]

D_H is hydraulic diameter of air duct, and can be described by the formula D_H=2(W+D). (g) acceleration, (H) height, (A_{in}-A_{out}) upper and lower vent area, C_{losin}, C_{losout}, (C_d) are the loss coefficients of the duct, and indicate modulus of loss at the vent inlet, modulus of loss at the vent outlet and friction factor. The calculation method for each of these variables is shown in the expression below. [14].

$C_{out} = 0.3$, $C_{in} = 0.25$,

$$C_d = 0.3 \times 1.368 \times G_{rx}^{0.084} \quad [4]$$

G_{rx} the following is stated as Grashof's law [18] .

$$G_{rx} = g.\beta.(T_P - T_{f1}).\frac{L^3}{\nu_{f1}^2} \quad [5]$$

β :Volumetric expansion coefficient [1/K] and is determined by the formula below [19]

$$\beta = \frac{1}{T_f} = \frac{2}{T_{outair} + T_{inair}} \quad [6]$$

2-The second situation: velocity of airflow within duct is computed by forced convection. (with the fan present) [6]:

$$V_{air} = C_{fan}.I_{solar} \quad [7]$$

whereas C_{fan} constant value =0.0006 m^3/J [20]

The thermal efficiency (η_{th})are It is the ratio of useful energy output to absorbed solar energy [21].

$$\eta_{thermal} = \frac{\dot{m}_{air}\, Cp_{air}(T_{outair} - T_{inair})}{I_{solar} A_{pv}} \quad [8]$$

The electrical efficiency (η_elec) it is dependent on the photovoltaic cell's temperature. and solar radiation concentration. [22].

$$\eta_{elec} = \frac{P_{max}}{A_c\, I_{solar}} \times 100\% \qquad [9]$$

$$P_{max} = V.I - P_{consumed} \qquad [10]$$

P_{max} = is the electrical power produced by the conversion

$P_{consumed}$ is the power consumed by the fan to move air [10]

3.2. The water gains heat as it flows through the heat exchanger:

This equation was used to compute the thermal gain of the heat exchanger water [23].

$$Q_{water} = \dot{m}_{water}\, Cp_{water}(T_{outwater} - T_{inwater}) \qquad [11]$$

$$\eta_{thermal} = \frac{\dot{m}_{water}\, Cp_{water}(T_{outwater} - T_{inwater})}{I_{solar} A_{pv}} \qquad [12]$$

The relation shown below is used to determine the overall efficiency. [10]

$$\eta_{overall} = \eta_{electrical} + \eta_{thermal} \qquad [13]$$

the uncertainty of each device used in the study, as shown in Table 2. and the uncertainty of the experimental data as shown in Table 3. The equation that follows is utilized to determine the Uncertainty of the results [24].

$$\omega_R = \sqrt{\left(\frac{\partial\varphi}{\partial X_1} \times \Omega_1\right)^2 + \left(\frac{\partial\varphi}{\partial X_2} \times \Omega_2\right)^2 + \cdots \left(\frac{\partial\varphi}{\partial X_n} \times \Omega_n\right)^2} \qquad [14]$$

Table 2 Uncertainty of the experimental device.

Equipment	Measurement	Error
Sensor SRD-05VDC-SL-C	Voltage DC	± (0.1%)
Sensor SRD-05VDC-SL-C	Current DC	± (0.1%)
Sensor DS18B20	Temperature	± (0.5 ◦C)
Davis Vantage Pro2 Plus 616	Solar radiation	(±10 W/ *m2*)
Sensor GM8903	wind speed	± (0.1%)

Table 3 Uncertainty of the experimental data

Parameter	Relative Uncertainty %
Intensity of solar radiation	±3.31
Electrical efficiency	±0.89
Thermal efficiency	±2.26
Temperature	±3.6

5. Results and discussion

1-The system is without any cooling

(13)

2- Cool the system by employing water only

3- Cool the system by employing air only

4-Cool the system by employing (water and air)

5.1 PV panel temperature

Fig. (3) showed the influence of various cooling techniques on the photovoltaic cell's temperature. When cooling techniques are not employing, the greatest temperature of the photovoltaic panel (46.27°C) was recorded at 12 p.m., caused by a rise in the value of solar radiation. When utilizing

(15)

water as a cooling, the temperature of the solar cell dropped significantly, reaching (27.5°C), as water passing via the heat exchanger positioned after the photovoltaic panel helped to cool the photovoltaic panel due to the high thermal capacity of the water, which led to an increase in the thermal energy gained from the solar panel. When air-cooled, a solar panel achieves its maximum temperature (33.27°C) at about 12 p.m. When water and air are employing applied, the PV panel reached its highest temperature (25.60°C) at 12 p.m. from the results it was found when used water and air for cooling. photovoltaic cell's temperature is dropped which was caused by the thermal energy gained from the PV panel.

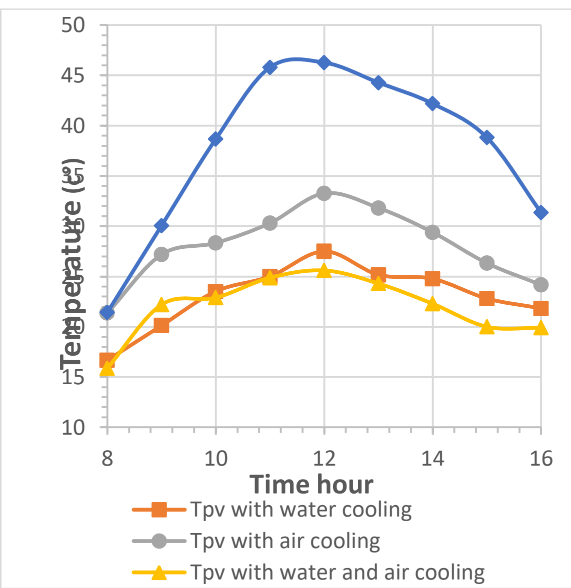


Fig .3 The impact of various cooling techniques on the temperature of the PV cell

This behavior is consistent with many previous studies, When cooling techniques are not used, the photovoltaic cell's temperature reached (66°C) , in the case of using water for cooling photovoltaic cell's temperature reached (44°C), When employing air for cooling, a solar panel achieves its maximum temperature (65°C) When water and air are employing applied, the PV panel reached its highest temperature (43°C) at 12 p.m. [11].

5.2 the electric power for the (PV/TW) system

As depicted in Fig. 4, if no cooling techniques are employed. the amount of electrical energy reaches (72.5W) at 12 p.m., electric power is improved when only water cooling is used, Due to the drop photovoltaic cell's temperature, at 12 p.m., achieved the max value (94.83W). When using a DC fan for cooling, The value of electrical power was (77.25 W) at 12 p.m., and when both water and air were used for cooling, the percentage of electrical energy was (91.5 W) at 12 p.m., the results reveal when cooling with water and air , Where the amount of electrical energy increases with a reduction in the solar cell's temperature, in comparison with a system that uses fans for cooling only, where the electrical energy decreases to a lesser extent because operating the fans alone consumes part of the energy that is produced.

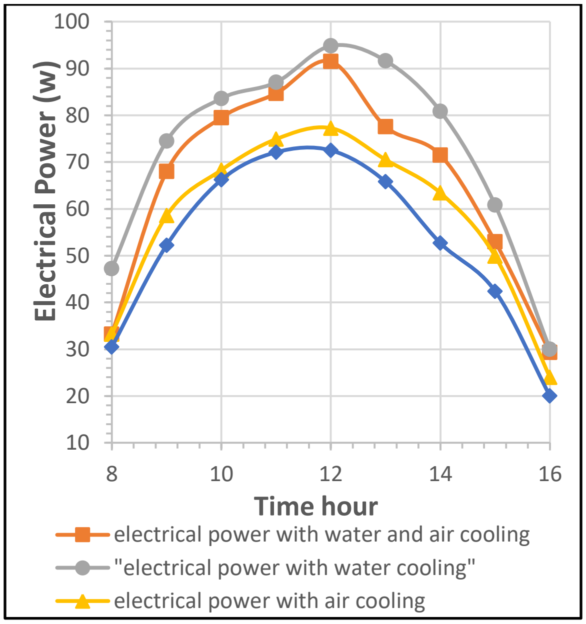


Fig .4 The impact of various cooling techniques on the electric power

5.3 impact Variation in water temperature on a (PV/TW)

Fig (5) depicts the temperature differential between the water that enters and exits the system, as the variation in the system's water temperature was measured as it reached (6.99°C) at 8 a.m. when the fans were not working. When the value of solar radiation rises, the quantity of variation starts increasing to the temperature reaches (14.1°C) at 12 pm. When the fans were turned on, the change in the system's water temperature was recorded at 8 a.m. (5.4°C), and the greatest temperature is measured at 12 p.m., (13.2°C) as because of the elevated level of solar radiation. The variation in the water's temperature drops at about 4 p.m., achieving (2.81°C) as the amount of solar radiation declines. it is clear from the results that the variation in the system's water temperature is less in the case of operating the fans compared to the case without fans, as the operation of the fans helps to cool the water flow via t the heat exchanger positioned after the photovoltaic cell, and thus the temperature of the water leaving the system decreases.

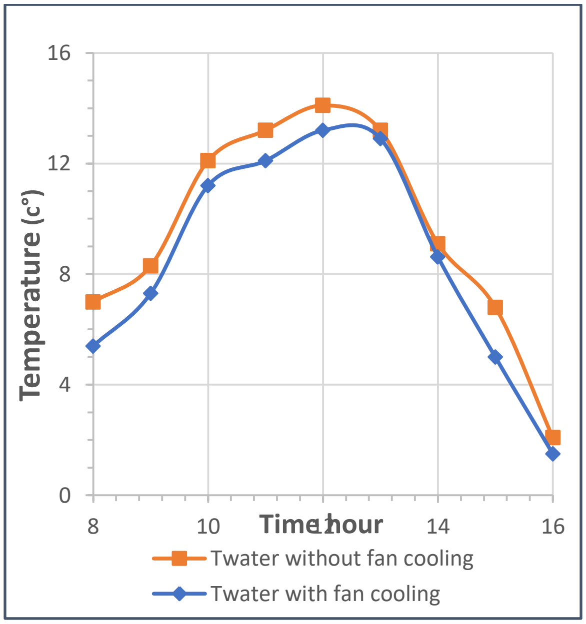


Fig.5 Change in water temperature with and without the fan operating

This behavior is consistent with many previous studies, When the fans were turned on the variation in the system's water temperature was recorded (24°C). when the fan were not working the variation in the system's water temperature was recorded (30°C) at 12 pm. [11].

5.4 The thermal and electrical efficiency of the system

Fig (6-7) depicts the influence of various cooling approaches on electrical and thermal efficiency. in the absence of cooling, the daily average electrical efficiency was (11.54%). In the situation of cooling with water, the daily rate of electrical efficiency was (13.75%), when utilizing water for cooling, the electrical efficiency rises as the photovoltaic panel temperature lowers, which has a favorable influence on the electrical efficiency. In terms of thermal efficiency, the daily average when no cooling methods were used was (30.57%). While it reaches thermal efficiency when only water cooling is used (37.77%). it is clear from the results the water lowers the photovoltaic cell's temperature, and thus the acquired thermal energy from the water that goes flow via the heat exchanger is boosted, resulting in thermal efficiency than the system without cooling, In the instance of air cooling (operating fans), the average daily electrical efficiency was (10.76%). however, the average day of electrical efficiency was achieved (12.56%) when employing a water and air cooling combination. In the situation of working fans, the average daily thermal efficiency was (33.62%). The daily rate of thermal efficiency was (45.83%) when water and air cooling were used. results show that employing water increases electrical efficiency because water lower the photovoltaic cell's temperature and therefore boost electrical efficiency. As for the thermal efficiency, it reaches its highest rate using water and air cooling due to the heat energy gained by air and water it rises in the noon, then begins to fall as the value of solar radiation decreases, which corresponds with the findings of the research, the daily rate of electrical efficiency was (7.77%), when utilizing water for cooling . the daily rate of electrical efficiency was achieved (8.01%) when employing a water and air cooling combination. the daily rate of thermal efficiency was (46.50%), when utilizing water for cooling. the daily rate of thermal efficiency was achieved (49.78%) when employing a water and air cooling combination [8].

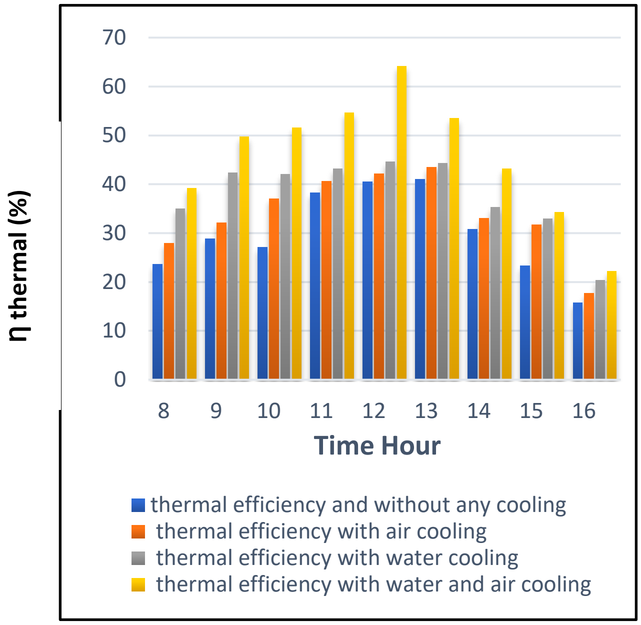


Fig.6 The impact of various cooling techniques on thermal efficiency

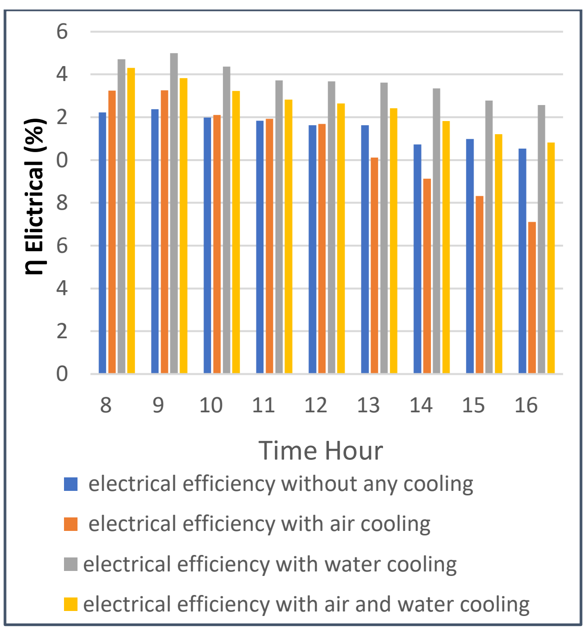


Fig.7 The impact of various cooling techniques on electrical efficiency

References

[1] O. K. Ahmed, K. I. Hamada, A. M. Salih, and R. W. Daoud, "A state of the art review of PV-Trombe wall system: Design and applications," *Environ. Prog. Sustain. Energy*, vol. 39, no. 3, p. e13370, 2020.

[2] [2] B. Agrawal and G. N. Tiwari, "Optimizing the energy and exergy of building integrated photovoltaic thermal (BIPVT) systems under cold climatic conditions," *Appl. Energy*, vol. 87, no. 2, pp. 417–426, 2010.

[3] [3] T. T. Chow, "A review on photovoltaic/thermal hybrid solar technology," *Appl. Energy*, vol. 87, no. 2, pp. 365–379, 2010.

[4] [4] W. G. J. van Helden, R. J. C. van Zolingen, and H. A. Zondag, "PV thermal systems: PV panels supplying renewable electricity and heat," *Prog. photovoltaics Res. Appl.*, vol. 12, no. 6, pp. 415–426, 2004.

[5] [5] C. Luo, W. Zou, D. Sun, L. Xu, J. Ji, and M. Liao, "Experimental Study of Thermal Effect of Lacquer Coating for PV-Trombe Wall System Combined with Phase Change Material in Summer," *Int. J. Photoenergy*, vol. 2019, 2019, doi: 10.1155/2019/7918782.

[6] [6] O. K. Ahmed, K. I. Hamada, and A. M. Salih, "Enhancement of the performance of Photovoltaic/Trombe wall system using the porous medium: Experimental and theoretical study," *Energy*, vol. 171, pp. 14–26, 2019.

[7] [7] O. K. Ahmed, K. I. Hamada, and A. M. Salih, "Performance analysis of PV/Trombe with water and air heating system: an experimental and theoretical study," *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 44, no. 1, pp. 2535–2555, 2022, doi: 10.1080/15567036.2019.1650139.

[8] A. A. Abed, O. K. Ahmed, M. M. Weis, and K. I. Hamada, "Performance augmentation of a PV/Trombe wall using Al2O3/Water nano-fluid: An experimental investigation," *Renew. Energy*, vol. 157, pp. 515–529, 2020, doi: 10.1016/j.renene.2020.05.052.

[9] A. A. Abed, O. K. Ahmed, and M. M. Weis, "Performance analysis of a bi-fluid photovoltaic/trombe wall under Iraqi climate," *AIP Conf. Proc.*, vol. 2213, no. March, 2020, doi: 10.1063/5.0000049.

[10] A. A. Abed, O. K. Ahmed, M. M. Weis, A. K. Ahmed, and Z. H. Ali, "Influence of glass cover on the characteristics of PV/trombe wall with BI-fluid cooling," *Case Stud. Therm. Eng.*, vol. 27, no. March, p. 101273, 2021, doi: 10.1016/j.csite.2021.101273.

[11] A. Abdullah, F. Attulla, O. K. Ahmed, and S. Algburi, "Effect of Cooling Method on the Performance of PV/Trombe Wall: A Case Study[1] A. Abdullah, F. Attulla, O. K. Ahmed, and S. Algburi, 'Effect of Cooling Method on the Performance of PV/Trombe Wall: A Case Study,' SSRN Electron. J., pp. 1–17, 2022, doi: 10.," *SSRN Electron. J.*, pp. 1–17, 2022, doi: 10.2139/ssrn.3994435.

[12] B. Yu, X. Liu, N. Li, S. S. Liu, and J. Ji, "The performance analysis of a purified PV/T-Trombe wall based on thermal catalytic oxidation process in winter," *Energy Convers. Manag.*, vol. 203, no. June 2019, p. 112262, 2020, doi: 10.1016/j.enconman.2019.112262.

[13] J. Jie, Y. Hua, P. Gang, J. Bin, and H. Wei, "Study of PV-Trombe wall assisted with DC fan," *Build. Environ.*, vol. 42, no. 10, pp. 3529–3539, 2007, doi: 10.1016/j.buildenv.2006.10.038.

[14] Y. Lin, J. Ji, X. Lu, K. Luo, F. Zhou, and Y. Ma, *Thermal and electrical behavior of built-middle photovoltaic integrated Trombe wall: Experimental and numerical study*, vol. 189. Elsevier B.V., 2019. doi: 10.1016/j.energy.2019.116173.

[15] A. H. A. Al-Waeli, K. Sopian, J. H. Yousif, H. A. Kazem, J. Boland, and M. T. Chaichan, "Artificial neural network modeling and analysis of photovoltaic/thermal system based on the experimental study," *Energy Convers. Manag.*, vol. 186, no. February, pp. 368–379, 2019, doi: 10.1016/j.enconman.2019.02.066.

[16] N. Zhu, S. Li, P. Hu, F. Lei, and R. Deng, "Numerical investigations on performance of phase change material Trombe wall in building," *Energy*, vol. 187, p. 116057, 2019.

[17] L. Xu, K. Luo, J. Ji, B. Yu, Z. Li, and S. Huang, "Study of a hybrid BIPV/T solar wall system," *Energy*, vol. 193, p. 116578, 2020.

[18] L. Xu, J. Ji, K. Luo, Z. Li, R. Xu, and S. Huang, "Annual analysis of a multi-functional BIPV/T solar wall system in typical cities of China," *Energy*, vol. 197, pp. 1–30, 2020, doi: 10.1016/j.energy.2020.117098.

[19] N. Islam, K. Irshad, M. H. Zahir, and S. Islam, "Numerical and experimental study on the performance of a Photovoltaic Trombe wall system with Venetian blinds," *Energy*, vol. 218, p. 119542, 2021.

[20] H. Yi, J. Jie, H. Hanfeng, J. Aiguo,

H. Chongwei, and L. Chenglong, "Optimized simulation for PV-TW system using DC fan," *ISES Solar World Congress 2007, ISES 2007*, vol. 3. pp. 1617–1622, 2007. doi: 10.1007/978-3-540-75997-3_332.

[21] A. N. Al-Shamani, K. Sopian, S. Mat, H. A. Hasan, A. M. Abed, and M. H. Ruslan, "Experimental studies of rectangular tube absorber photovoltaic thermal collector with various types of nanofluids under the tropical climate conditions," *Energy Convers. Manag.*, vol. 124, pp. 528–542, 2016.

[22] G. Vokas, N. Christandonis, and F. Skittides, "Hybrid photovoltaic-thermal systems for domestic heating and cooling-A theoretical approach," *Sol. Energy*, vol. 80, no. 5, pp. 607–615, 2006, doi: 10.1016/j.solener.2005.03.011.

[23] Y. Zhou and C. Wah Yu, "The year-round thermal performance of a new ventilated Trombe wall integrated with phase change materials in the hot summer and cold winter region of China," *Indoor Built Environ.*, vol. 28, no. 2, pp. 195–216, 2019.

[24] J. P. Holman, "Experimental Methods for Engineers, Experimental Thermal and Fluid Science." 1994.