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RESEARCH ARTICLE
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Effect of Winter Operating Conditions on the Performance of a PV/Trombe Wall: An Experimental Evaluation

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Abstract. A photovoltaic Trombe wall is well known for its ability to supply the building with thermal and electrical energy at the same time. The increase in the temperature of the solar panels leads to a decrease in electrical efficiency. The use of DC fans and water as a medium for cooling the panels improved thermal and electrical efficiency and enhanced the comfort conditions inside the building. The results showed that the Trombe wall with DC fans could reduce the demand for the rudder by Increasing the heat inside the building, as it reached the highest thermal efficiency at 37.5% . As for the system equipped with a heat exchanger recorded the highest electrical efficiency of 14%. Finally, the results showed that the use of DC fans improves the overall efficiency of the photovoltaic Trombe wall system.

Keywords: PV/Trombe wall; Performance; DC Fan; Effect; Water.

1-Introduction:

A significant increase in energy consumption has been observed in recent years due to the increasing population worldwide. Therefore, the interest in solar energy has begun greatly, and it is considered clean energy and reduces environmental pollution and global warming[1]. Solar energy was the optimum solution provided by scientists to address the energy crisis around the world[2][3]. Using solar energy to generate electric power has become an important issue because of recent renewable energy regulation laws[4]. According to statistics, humans spend 90% of their lives indoors, so providing comfortable conditions for these residents is critical[5]. Photovoltaic cells convert sunlight into electrical energy as the temperature of photovoltaic panels increases in hot climates, especially in the eastern region, which is one of the most important disadvantages[6]. The increase in temperature of the solar cells reduces their electrical efficiency[7]. Currently, renewable energy is the most widely used way to reduce energy consumption in buildings and improve the indoor environment[8]. A Trombe wall reduces energy consumption in buildings and is a passive solar system that converts solar energy into thermal energy and electrical energy[9]. Trombe wall in its traditional form consists of a glass layer, an airflow duct, and a black painted wall facing south, as shown in **Fig. (1)** [10][11]. In recent years, photovoltaic panels have been used in the south facade, and the new design is called Photovoltaic Trombe Wall[12]. This technology increases the aesthetic of the building, generates electrical energy, and increases

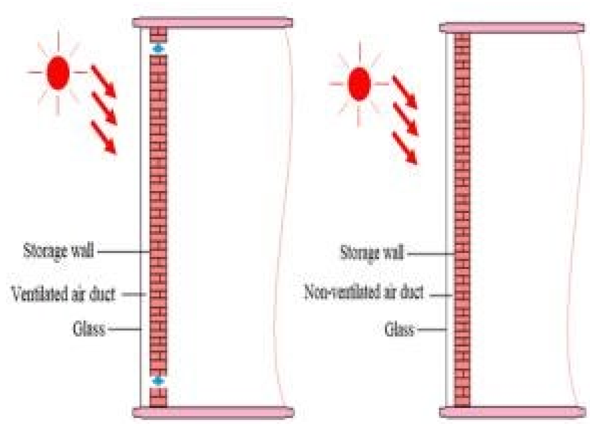


Fig. (1) The fundamental design of a PV Trombe wall.

NOMENCLATURES

APV	The area of a photovoltaic panel [m^2]
A_{duct}	Duct area [m^2]
A_{out}	The area of the upper vent [m^2]
A_{in}	The area of the lower vent [m^2]
cp_{air}	The heat capacity of air [J/kg.K]
D_H	Hydraulic duct diameter [m]
g	Gravitational acceleration [m/s^2]
H	Duct Height [m]
MPC	Maximum Power Current [A]
VMP	Voltage of Maximum Power [V]
VOC	Voltage in an open circuit [V]
Isc	Short Circuit Current [A]
PV	Photopholtaic
I	Current [A]
I_{solar}	The amount of solar radiation [W/m^2]
ii air	A flow rate of mass air [kg/s]
$P_{consumed}$	Consumed energy [W]
$P_{electrical}$	Net electric power [W]
Q_u	Gain of heat [W]
T_{outair}	The temperature of duct outlet air [K].
Tinar	The temperature of duct inlet air [K].
V	Voltage [V]
V_{air}	Inside the duct, air velocity [m/s]
β	Coefficient of volumetric expansion [1/K]
ρ_{air}	The density of the air [kg/m^3]
$\eta_{thermal}$	Thermal efficiency [%]
$\eta_{electrical}$	Electrical efficiency [%]
η_{total}	Total efficiency [%]
C_{fr}	the friction loss factor
C_{losin}	the resistance factor of the air inlet
C_{losout}	the resistance factor of the air outlet

thermal comfort inside the building[13]. [13]. In this system, the thickness of the wall is increased to meet the requirements of excessive thermal loads, as the heat is stored inside the wall for the longest possible period[14]. This heat energy is transmitted through the wall surface[15][16]. Then the heat is transmitted to the building through convection and radiation[17]. A PV Trombe wall system is affected by several factors; these factors must be taken into account when designing the system. Ji et al. [16] Analyzing the thermal and electrical performance of the PV Trombe wall for buildings, the results showed an increase in room temperature when the width of the PV Trombe wall system was increased. Sun et al. [18] A test was conducted on the PV Trombe wall, and a building with a south-facing window, where the thermal efficiency of the south-facing building was higher, while the efficiency of the PV Trombe wall was 27%, and the electrical efficiency was less effective, reaching 11.6%. Ji J. et al. [19] Use DC fans with a photoelectric Trombe wall. Then they conducted theoretical analysis and experimental work on the system. It was found that the use of DC fans improves thermal comfort inside the building and reduces the temperature of solar panels. Feng et al. [20] Use fresh air and a heat exchanger for the photovoltaic Trombe wall system. Note the improvement of comfort conditions inside the building and provide the building with warm water. Othman et al. [21] He conducted an experimental study of the electrical and thermal efficiency of the photovoltaic Trombe wall system using water and air. The results showed that the highest electrical and thermal efficiency was 17% and 76%, respectively. In the summer, the ventilated photovoltaic Trombe wall system is idle, but in the winter, the photovoltaic Trombe wall system, which uses water, faces the problem of freezing water, so it was proposed to use ventilation in the winter season and use water in other seasons[22]. Dehra. [23] Studied the energy performance of the photovoltaic Trombe wall to evaluate ventilation systems equipped with a DC fan. The results showed that the highest thermal and electrical efficiency was 37% and 31.4% of the system equipped with a DC fan. Jie et al. [24] verification of the effect of the DC fan when the use of the fan reduces the temperature of the photovoltaic panels to 1.28°C, while the room temperature is increased to 0.5°C. In this study, the PV Trombe wall was designed and installed. The experiments were conducted in December and January for a full day to show the effect of the experimental parameters on the electrical and thermal performance.

2- Methodology

The experimental work was conducted in the city of Hawija, northern Iraq (35.19°N, 43.46°E) under different operating conditions. The experimental data were recorded from 8 am to 4 p.m. For the months of December and January. At level 3, the practical work was described; at level 4, the mathematical model was presented. At level 5, the results were clarified and interpreted, while at level 6 and the last, conclusions were presented.

3- Experimental work

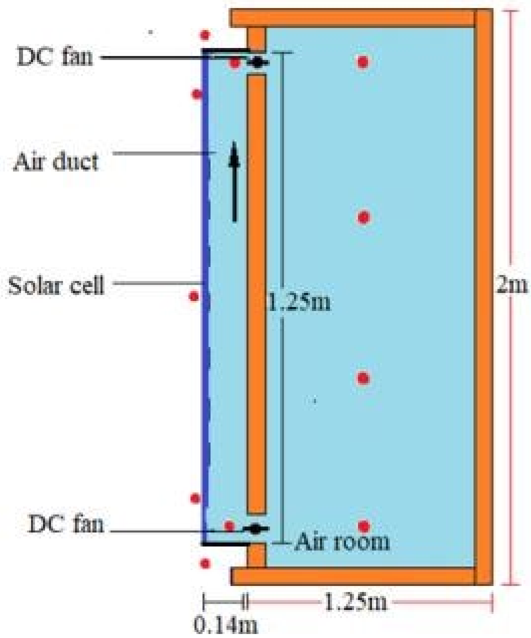
In this study, two test models were built on knowing the effect of experimental parameters on the thermal and electrical performance of the photoelectric Trombe wall in Winter. Figure 2 shows the design of the PV Trombe wall system from the outside to the inside. The system consists of a photovoltaic panel, a heat exchanger, an airflow duct, DC fans, and an experimental room comprised of the following dimensions 1.25 m wide, 1.25 m deep, and 2 m in height. Figure 3 shows the different operating modes of the system. Figure (3 - a) shows the air-cooled only model, while Figure (3- b) shows the water-cooled only model. The fans cool the solar panels and remove heat from the panels by drawing heat and transferring it to the test room, improving comfort conditions in Winter, where the fan operates

at a flow rate of 3 m/s. While the other model contains a heat exchanger in which the heat exchanger is installed at the back of the solar panel, the heat exchanger is used to cool the solar panels by drawing the heat generated from the solar panel and heating the water flowing inside the heat exchanger and benefiting from it for domestic use. The dimensions of the heat exchanger are shown in Figure 4. Solar panels installed to the south receive solar radiation to generate electricity. Table 1 shows the advantages of the photovoltaic panel.

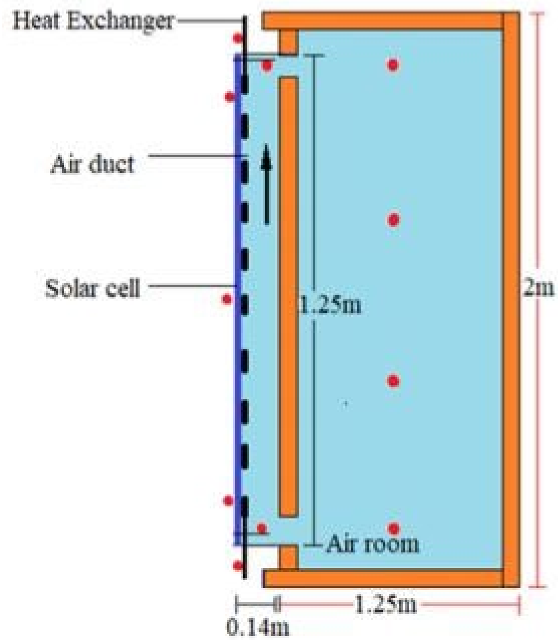
Fig. (2) The test room's experimental appearance**.**

Table 1 Specification of solar cell

Parameters	**Unit**	**Parameters**	**Unit**
Operating Temperature	25 ^{o}C	Maximum power under normal conditions	150 W
Mpc	8.38 A	Isc	8.81 A
Voc	22.4 V	Dimensions (mm)	1.48*0.68 * 0.035 m
Vmp	17.9 V	PV Type	Polycrystalline



(a) Cooled only by air



(b) Cooled only by water

Fig. (3) The system's schematic diagram

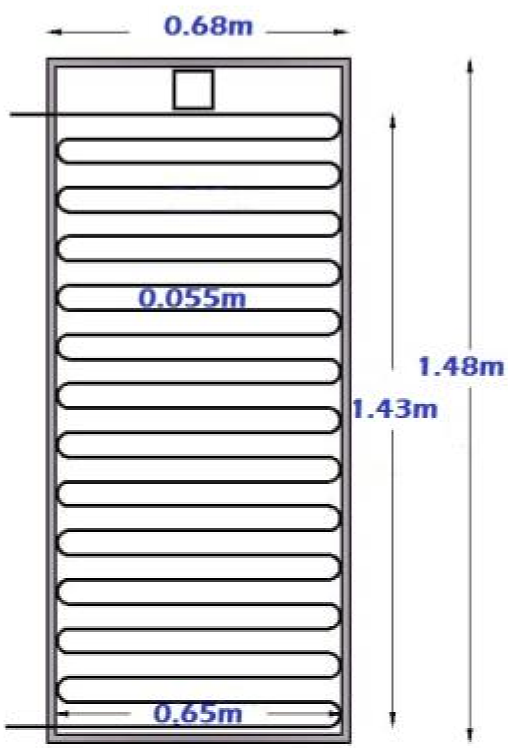


Fig. (4) schematic diagram of a heat exchanger

To evaluate the thermal performance of the system. Sensors were used to measure the temperature on the front face of the photovoltaic panel. The air duct temperature, the experimental room temperature, water inlet, and outlet temperature were also measured. A weather station also measured ambient parameters (Davis vantage pro 2). Sensors were used to measure voltage and current. A battery was also used to store the electricity produced by the photovoltaic panel. Use an MPPT device to control the electrical output. A water pump operating at a flow rate of 0.18 liters/hour and an external water tank was used. Table 2 shows the characteristics of the DC fan and water pump. Table 3 shows the accuracy of the measurement tools used in the experiment.

Table 2 Characteristics of the fan and pump

Parameters	DC Fan	Pump
Model	SDF8025M12S	JT-500
Input Voltage	12V	6-12V
Input Current	1.68W	17W
Flow Rate	3 m/s	110 L/H

Table 3 The accuracy of the devices used in the measurement

Equipment	Measurement	Error
Sensor JQC-3ff-s-z	Electrical power	±(0.8%)
Sensor JQC -3ff-s-z	Current Voltage	±(0.5%)
Sensor DS18B20	Temperature	± (0.5 °C)
Rotameter	The mass flow rate of water	± (3%)
Davis vantage pro 2	Solar radiation	(±10 W/m^2)

4-Mathematical model development

In this paper, the daily performance of the photovoltaic Trombe wall system was evaluated, and the thermal efficiency of the system was calculated as follows[25].

$$\eta_{thermal} = \frac{\dot{m}_{air} Cp_{air} (T_{outair} - T_{inair})}{I_{solar} A_{PV}} \quad (1)$$

The following equation yields the air mass flow rate:

$$\dot{m}_{air} = \rho_{air} . A_{duct} . V_{air}$$

(2)

The air flow velocity in the air duct can be calculated as follows The first method When DC fans are not used, the air velocity is given by the following equation [26].

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

(3)

C;=0.3x1.368x□"

cipsin=0.25, ciuseur=0.3

The second method, if the fans are working, calculate the airspeed from the following equation [27].

$$V_{air} = C_{fan} . I_{Solar}$$

(4)

The thermal efficiency of a PV panel that is cooled by both water and air can be calculated using the equation below[27]:

$$\eta_{thermal} = \frac{\dot{m}_{water} Cp_{water} (T_{outwater} - T_{inwater}) + \dot{m}_{air} Cp_{air} (T_{outair} - T_{inair})}{I_{solar} A_{PV}}$$

(5)

The electrical efficiency is given by [28]

$$\eta_{electrical} = \frac{I\,V}{I_{solar} A_{PV}}$$

(7)

The following equation gives the overall efficiency[29].

$$\eta_{overall} = \eta_{electrical} + \eta_{thermal}$$

(8)

5- Results and discussion:

5-1 System temperature

Fig. (5) shows the variation in ambient temperature. Fig. (6) shows the temperature change of solar panels for the PV Trombe wall system using air and water cooling. Experimental results showed a gradual rise in temperature during the day depending on the intensity of solar radiation. The cooling methods used show a temperature low if only the heat exchanger is used or the DC fans and heat exchanger are used together. The highest rise in the temperature of the solar panels was recorded in the absence of any cooling method, and the maximum temperature was 46°C at 12 p.m. In contrast, the lowest rise in the temperature of the solar panels was recorded using the heat exchanger (water-cooling) only, where the temperature reached a maximum of 28°C at 12 p.m.

Fig. (7) shows the temperature duct and the effectiveness of different cooling methods on the airway. We note that the temperature rises in the absence of any cooling way. The maximum temperature reached 44°C at 12 p.m. while cooling with water showed an apparent effect on the airway temperature, where the temperature decreased significantly and reached 26°C at 1 p.m.

Fig. (8) shows the temperature change and the effect of different cooling methods on the room temperature. Experimental results show a decrease in the temperature in the first morning hour to below zero Celsius. The temperature begins to rise gradually due to the increase in the intensity of solar radiation. The presence of DC fans led to the rise in the temperature inside the experimental room, which improved the comfort conditions inside the room. The highest temperature inside the room was recorded at 31°C at 2 p.m in the case of using DC fans. In comparison, the lowest rise in the experimental room temperature was 20°C at 2 p.m in the case of using water cooling only.

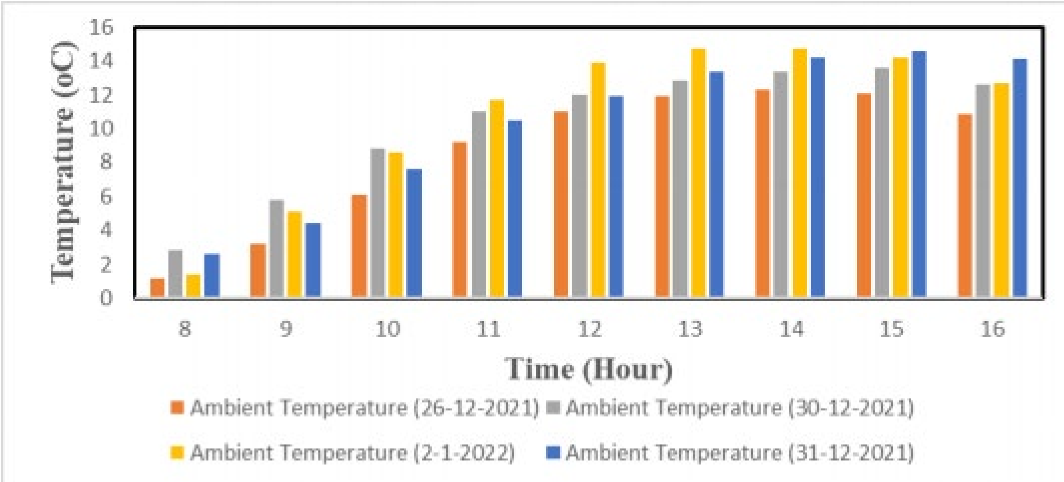


Fig. (5) Variation in ocean temperature

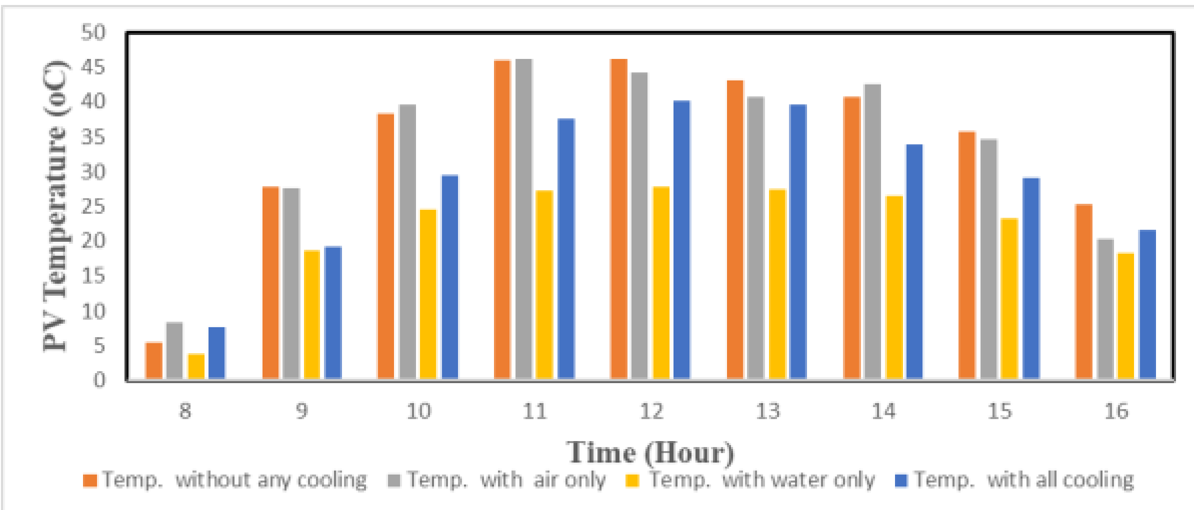


Fig. (6) Variation in solar cell temperature for four experimental days.

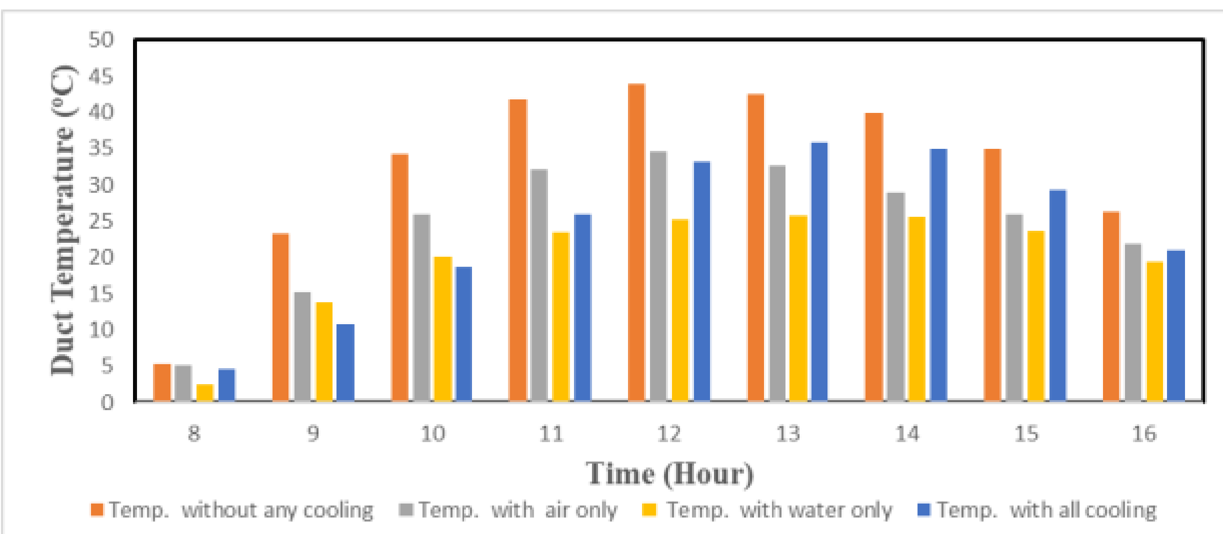


Fig. (7) Variation in airway temperature for four experimental days.

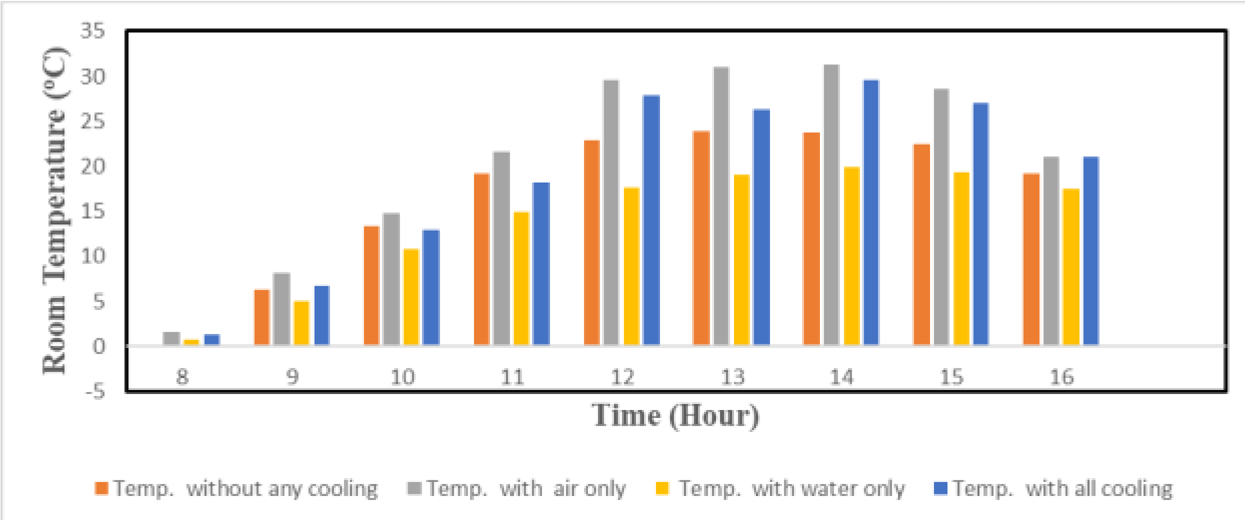


Fig. (8) Variation in room temperature for four experimental days.

5-2 System efficiency

Fig. (9- 11- 11) shows the thermal, electrical, and total efficiency of the photovoltaic Trombe wall system. The experimental results showed a gradual increase in thermal efficiency during the day in all different operating conditions due to the rise in the intensity of solar radiation. The presence of DC fans helped increase thermal efficiency. The increase in thermal efficiency when using DC fans was only 4.12%. When using DC fans with water cooling, the increase in thermal efficiency was 3.67%. The presence of water cooling reduced the thermal efficiency Because part of the heat gained from the solar cell is transferred to the heat exchanger. As for electrical efficiency, it improved during the day. The use of water cooling led to an improvement in electrical efficiency. The increase in electrical efficiency in the case of using water cooling only compared to not using any cooling method was 0.9%. When using water cooling with DC fans, the increase in efficiency amounted to 0.6%, compared to the case of using DC fans only.

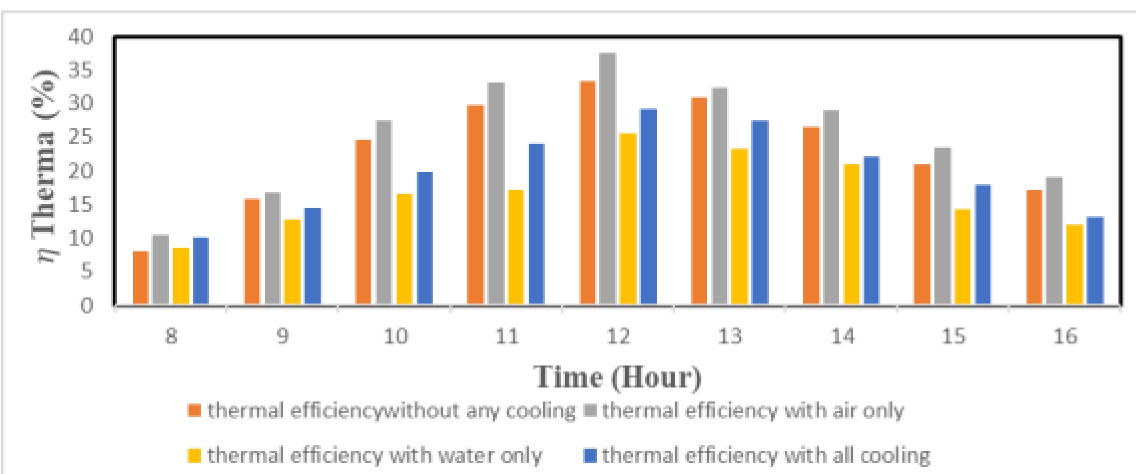


Fig. (9) Thermal Efficiency of PV Trombe Wall System

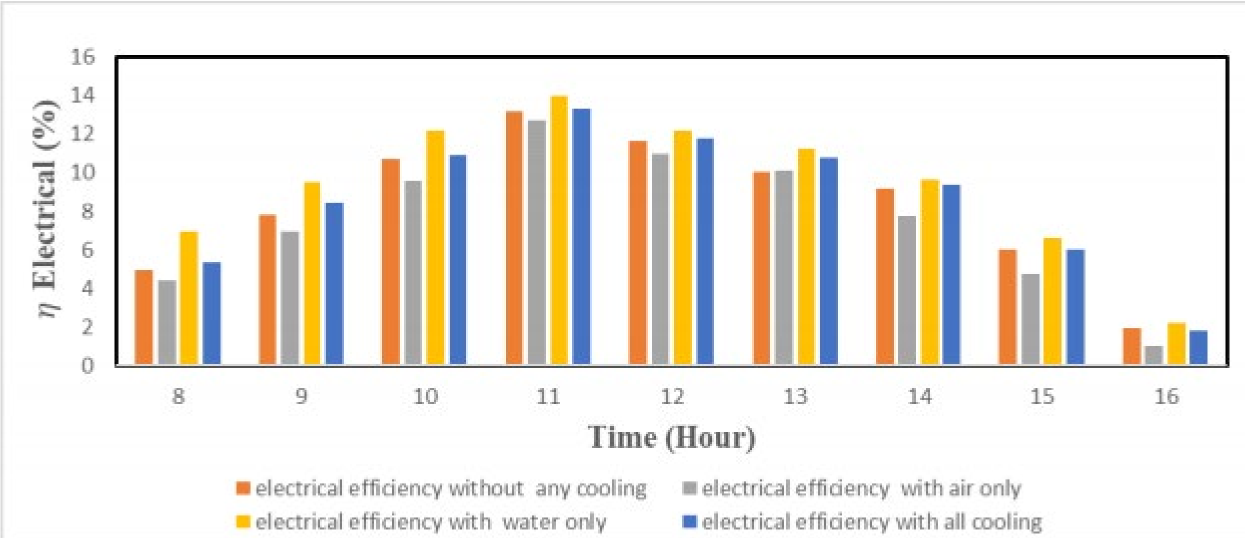


Fig. (11) Electrical Efficiency of PV Trombe Wall System.

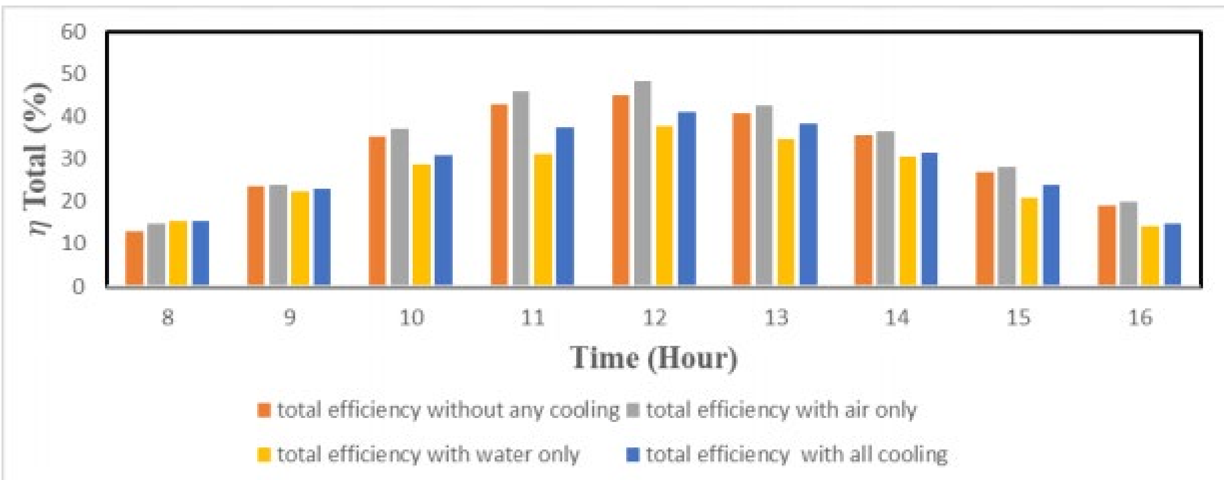


Fig. (11) Total Efficiency of PV Trombe Wall System.

6- Conclusion:

This article assesses the performance of the photovoltaic Trombe wall by studying the operating conditions and knowing their effect on electrical and thermal efficiency.

1- The presence of DC fans increases thermal efficiency and improves comfort inside the building, as the fans reduce the solar panel's temperature.
2- The heat exchanger is used to heat water for domestic use and cool the solar panel to increase electrical efficiency.
3- The high thermal efficiency of the system was recorded at 37.5% when the medium used for cooling was DC fans.
4- The highest electrical efficiency of the system was recorded at 14% when the medium used for cooling was water.

Reference:

[1] O. K. Ahmed, R. W. Daoud, S. M. Bawa, and A. H. Ahmed, "Optimization of PV/T solar water collector based on fuzzy logic control," *Int. J. Renew. Energy Dev.*, vol. 9, no. 2, pp. 303–310, 2020, doi: 10.14710/ijred.9.2.303-310.

[2] O. K. Ahmed, S. Algburi, Z. H. Ali, A. K. Ahmed, and H. N. Shubat, "Hybrid solar chimneys : A comprehensive review," *Energy Reports*, vol. 8, pp. 438–460, 2022, doi: 10.1016/j.egyr.2021.12.007.

[3] A. A. M. Omara and A. A. A. Abuelnuor,

"Trombe walls with phase change materials: A review," *Energy Storage*, vol. 2, no. 6, pp. 1–28, 2020, doi: 10.1002/est2.123.

[4] J. Long, R. Zhang, J. Lu, and F. Xu, "Heat transfer performance of an integrated solar-air source heat pump evaporator," *Energy Convers. Manag.*, vol. 184, no. January, pp. 626–635, 2019, doi: 10.1016/j.enconman.2019.01.094.

[5] A. N. Saleh, A. A. Attar, O. K. Ahmed, and S. S. Mustafa, "Improving the thermal insulation and mechanical properties of concrete using Nano-SiO2," *Results Eng.*, vol. 12, no. June, p. 100303, 2021, doi: 10.1016/j.rineng.2021.100303.

[6] O. K. Ahmed and S. M. Bawa, "Reflective mirrors effect on the performance of the hybrid PV/thermal water collector," *Energy Sustain. Dev.*, vol. 43, pp. 235–246, 2018, doi: 10.1016/j.esd.2018.02.001.

[7] O. K. Ahmed and Z. A. Mohammed, "Influence of porous media on the performance of hybrid PV/Thermal collector," *Renew. Energy*, vol. 112, pp. 378–387, 2017, doi: 10.1016/j.renene.2017.05.061.

[8] M. Rabani, V. Kalantar, and M. Rabani, "Heat transfer analysis of a Trombe wall with a projecting channel design," *Energy*, vol. 134, pp. 943–950, 2017, doi: 10.1016/j.energy.2017.06.066.

[9] A. Ahmed, O. Khalil, M. Mustafa, A. Khalil, and Z. Hussein, "Influence of glass cover on the characteristics of PV / trombe wall with BI-fluid cooling," *Case Stud. Therm. Eng.*, vol. 27, p. 101273, 2021, doi: 10.1016/j.csite.2021.101273.

[10] C. A. Buckner *et al.*, "We are IntechOpen , the world ' s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %," *Intech*, vol. 11, no. tourism, p. 13, 2016, [Online]. Available: https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection-in-biometrics.

[11] Z. Hu, W. He, J. Ji, and S. Zhang, "A review on the application of Trombe wall system in buildings," *Renewable and Sustainable Energy Reviews*, vol. 70, no. 2017. Elsevier, pp. 976–987, 2017, doi: 10.1016/j.rser.2016.12.003.

[12] 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.

[13] 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, doi: 10.1016/j.energy.2019.01.001.

[14] 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, doi: 10.1016/j.energy.2019.116057.

[15] K. Irshad *et al.*, "Parametric analysis and optimization of a novel photovoltaic trombe wall system with venetian blinds: Experimental and computational study," *Case Stud. Therm. Eng.*, vol. 34, no. April, p. 101958, 2022, doi: 10.1016/j.csite.2022.101958.

[16] O. K. Ahmed, K. Hamada, and A. Salih, "Thermal and Electrical Performance Analysis of PV/Trombe Wall System," *Proc. 5th Int. Eng. Conf. IEC 2019*, pp. 68–73, 2019, doi: 10.1109/IEC47844.2019.8950524.

[17] T. Bajc, M. N. Todorovid, and J. Svorcan, "CFD analyses for passive house with Trombe wall and impact to energy demand," *Energy Build.*, vol. 98, pp. 39–44, 2015, doi: 10.1016/j.enbuild.2014.11.018.

[18] S. Y. Wu, L. Xu, and L. Xiao, "Performance study of a novel multi-functional Trombe wall with air purification, photovoltaic, heating and ventilation," *Energy Convers. Manag.*, vol. 203, no. July 2019, 2020, doi: 10.1016/j.enconman.2019.112229.

[19] Y. Zhu, T. Zhang, Q. Ma, and H. Fukuda, "Thermal Performance and Optimizing of Composite Trombe Wall with Temperature-Controlled DC Fan in Winter," *Sustain.*, vol. 14, no. 5, 2022, doi: 10.3390/su14053080.

[20] G. Feng, S. Liu, K. Huang, Y. Pan, and R. Niu, "Simulation for a New Type of Photovoltaic (PV) Fresh Air and Domestic Hot Water System," *Procedia Eng.*, vol. 121, pp. 1428–1434, 2015, doi: 10.1016/j.proeng.2015.09.055.

[21] M. Y. Othman, S. A. Hamid, M. A. S. Tabook, K. Sopian, M. H. Roslan, and Z. Ibarahim, "Performance analysis of PV/T Combi with water and air heating system: An

experimental study," *Renew. Energy*, vol. 86, pp. 716–722, 2016, doi: 10.1016/j.renene.2015.08.061.

[22] 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.

[23] H. Dehra, "An investigation on energy performance assessment of a photovoltaic solar wall under buoyancy-induced and fan-assisted ventilation system," *Appl. Energy*, vol. 191, pp. 55–74, 2017, doi: 10.1016/j.apenergy.2017.01.038.

[24] D. Singh, R. Chaudhary, and A. Karthick, *Review on the progress of building-applied/integrated photovoltaic system*, vol. 28, no. 35. Environmental Science and Pollution Research, 2021.

[25] J. Ji, C. Guo, W. Sun, W. He, Y. Wang, and G. Li, "Experimental investigation of tri-functional photovoltaic/thermal solar collector," *Energy Convers. Manag.*, vol. 88, pp. 650–656, 2014, doi: 10.1016/j.enconman.2014.09.030.

[26] 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. November, 2020, doi: 10.1016/j.enconman.2019.112262.

[27] A. A. Abdullah, F. S. Attulla, O. K. Ahmed, and S. Algburi, "Effect of cooling method on the performance of PV/Trombe wall: Experimental assessment," *Therm. Sci. Eng. Prog.*, vol. 30, no. December 2021, p. 101273, 2022, doi: 10.1016/j.tsep.2022.101273.

[28] O. K. Ahmed and A. S. Hussein, "New design of solar chimney (case study)," *Case Stud. Therm. Eng.*, vol. 11, pp. 105–112, 2018, doi: 10.1016/j.csite.2017.12.008.

[29] O. K. Ahmed and S. M. Bawa, "The combined effect of nanofluid and reflective mirrors on the performance of PV/Thermal solar collector," *Therm. Sci.*, vol. 23, no. 2, pp. 573–587, 2019, doi: 10.2298/TSCI171203092A.