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Research Article

The effect of operating conditions and climate change on the performance of the photopholtaic Trombe wall: An empirical estimate

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ABSTRACT

Due to its significance and effect on interior spaces, photovoltaic Trombe walls are regarded as sustainable technologies. This is because they use solar energy to heat the building and give thermic comfort without requiring the use of cooling equipment to reduce power consumption. not to mention supplying the structure with electricity. To investigate how operational conditions and climatic change affect PV/TW, two empirical models—one with DC fans and the other without—were developed. The two models were compared with each other. To demonstrate their impact on system competency, operating conditions for both dusty and non-dusty days have been examined. When DC fans are used on a dust-free day, the system's electrical and thermal competence is 10.2 percent and 17.6 percent, respectively. The system's electrical and thermal competence levels were 8.4 percent and 40.1 percent, respectively, on a day when there was no dust and when the DC fans were not operating. The system that had fans had a higher thermic and electrical efficiency than the other two systems, with values of 11.9 percent and 6.6 percent, respectively, on the dusty days. The system's thermic and electrical efficiency were 34.1 percent and 3.5 percent, respectively, without fans. This suggests that dusty days have an impact on the experimental system's electrical and thermic efficiency.

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INTRODUCTION

Finite fossil fuel supplies are being depleted faster than the rate at which our economy and standards of life are rising, and the fact that we are heavily dependent on fossil fuels due to climate change poses serious concerns. Therefore, it becomes crucial to research into renewable energy sources with low carbon emissions in order to alleviate carbon emissions and energy scarcity [1]. In the fight against climate change and the expansion of sustainable renewable energy sources, solar energy is becoming more

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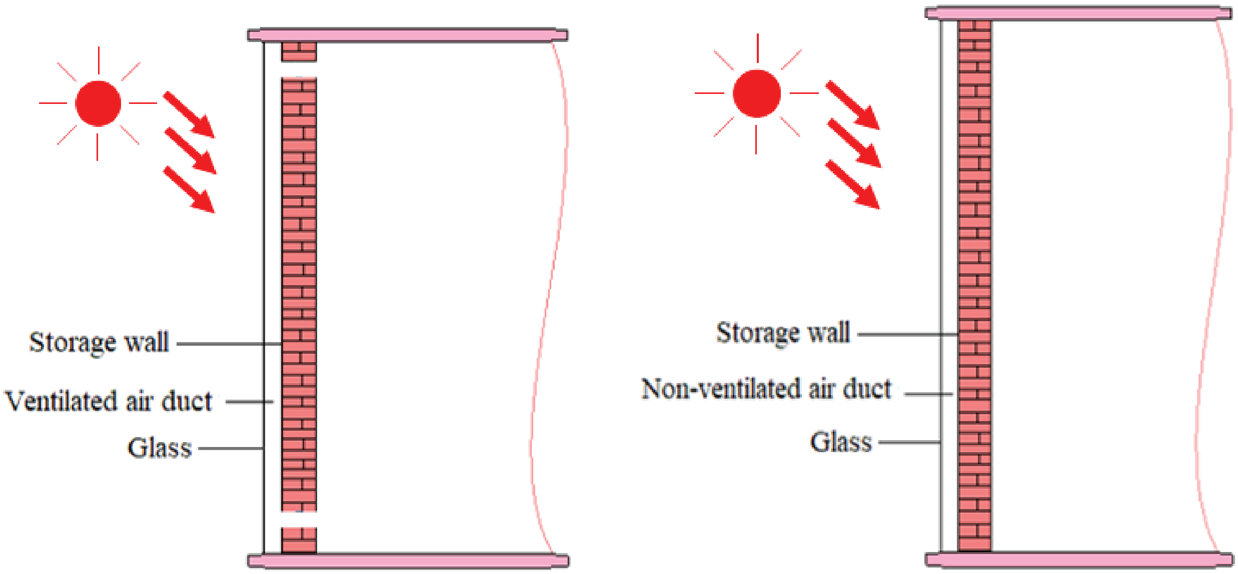
and more significant. As a result, research and development on solar energy is currently focused on a number of construction applications, including as photovoltaics, hot water delivery, heating, and cooling [2]. It is projected that using solar energy on building rooftops and facades will drastically lower energy consumption [3]. Due to its ease of construction, low cost, and excellent efficiency, the Trombe wall has been used as a solar heating system for a while [4]. The TW is made of a large black wall, a clear glass cover, and an air channel between them [5]. In a thermal wall made of materials with a high thermal capacity, such stone, brick, concrete, or sand, heat is produced by the absorption of sunlight. Additionally, the Trombe wall has apertures at the top that allow heat from the air duct to be sent into the building, and openings at the bottom that allow cold air from the building to be transferred to the air duct so that it can be heated again [6]. Also, the Trombe wall was improved by the addition of DC fans. As illustrated in Figure 1, a wall with fans is referred to as a ventilated Trombe wall, and a wall without fans is referred to as a non-ventilated Trombe wall. Heat is transmitted either by conduction and convection or by forced convection (fans) [7]. By removing the generated heat and using it to warm the building on cool days, adding fans boosts the solar panels' production capacity [8]. In order to lessen the building's reliance on fossil fuels, enhance its aesthetics, produce energy, and utilize the heat produced by the solar panels to heat the structure, the Trombe wall was additionally upgraded by utilizing solar panels and covering them with a glass covering [9]. One of the most significant problems with solar panels is that they are less effective due to dust accumulation on their surface or excessive heat [10]. This is because the dust accumulation stops solar radiation (SR) from reaching the silicon photovoltaic (SP). Consequently, dust accumulation alters the thermal balance of the system and raises the temperature over the normal rate, necessitating the cleaning of solar panels in order to maximize their electrical capacity [11].

As a result, numerous studies have concentrated on enhancing the photovoltaic Trombe wall's performance. Xiao et al. [12] simulated the low-ventilation glass Trombe wall system and compared it with the traditional wall using the Energy Plus tool. The findings demonstrated that the low-ventilation glass Trombe wall system may reduce heating by 11.1 percent in comparison to the classic wall and by 61.4 percent in comparison to the typical wall when paired with air conditioning. Wang et al. [13] investigated how adding heat pipes, which cool the PV Trombe wall with air and refrigerant gas, would affect its performance. The impact of elements influencing the system during the winter was also investigated. The system's electrical and thermal efficiency increased as a result of these techniques, as evidenced by the average daily thermal efficiency of 56.76 percent. The maximum internal system temperature was 21.46°C, and the average daily electrical efficiency was 13.52 percent. Additionally, 3.12 MJ of total power were generated. On chilly days, a comparison was made by Yadav et al. [14] between an opaque photovoltaic Trombe wall and a semi-transparent one. The findings demonstrated that air flow and wall thickness affect comfort levels. Additionally, the semi-transparent Trombe wall outperformed the opaque wall in terms of effectiveness, as evidenced by the fact that the semi-transparent system's temperature boost by 15 degrees Celsius over the opaque



(a) Ventilated system

(b) Unventilated system

Figure 1. Ventilated and non-ventilated Trombe walls.

wall's duration. Abdullah et al. [8] investigated the effects of cooling techniques on the PV Trombe wall system's performance using DC fans and a heat exchanger. The results show that the system with the heat exchanger and DC fans for cooling had the best electrical competence (11.69%), while the system's thermal efficiency was 39.81%. Siddique et al. [15] created two experimental models, one of which was a photovoltaic Trombe wall system and the other a photovoltaic wall system facing south. Each wall's performance was assessed in relation to a reference room. The heat gain of the photovoltaic Trombe wall system was 3.2 times greater than that of the south-facing photovoltaic wall system, and the average daily efficiency of the two systems was 39.67 percent and 13.16 percent, respectively. These results demonstrated the superior overall performance of the PV/TW system. Yao et al. [16] investigated the impact of various elements that result in dust collection being removed from solar panels, including (wind direction and speed, amount of rain, and the optimal angle). The amount of dust accumulation was 1.90 percent lower in the south than in the east for 30 days at a 45-degree angle, and 11.95 percent and 7.32 percent higher than in the north and west, respectively, indicating that solar panels facing the south are more susceptible to wind direction and speed than other panels. Rainfall also reduces dust collection and raises solar panel efficiency. Fatima et al. [17] investigated how dust gathering affects solar system performance, including how much less electricity is generated, how much less SR is absorbed, and when it is best to clean solar panels. Because the panels were cleaned every two weeks, the results demonstrated that regular cleaning of the panels reduced wasted energy to 7% when compared to unclean solar panels. Liu et al [18] gave a recent study on the use of electrostatic absorption to remove dust from solar panels. According to experimental data, when compared to the efficiency of regular solar panels on a clean surface, solar panels' power production capability can reach 94–97 percent. When the electric field intensity is 6 kV/cm, different membranes can achieve a dust removal rate of more than 98.6%. The results in the dust removal region also demonstrate that the optimal effect of dust removal shows at higher relative humidity levels. For example, at relative humidity levels of 70%, 2.46 kV/cm of electric field intensity is required to remove dust. Long et al. [19] investigated the effects of mounting the Trombe wall on rural homes' walls. Rural homes were heated using the thermic energy held by the Trombe wall (TW), which absorbs and stored the thermic energy created by incident sun radiation. The results show that by using the Trombe wall's ideal application plan, rural residences can save 38 492 kWh of electricity yearly, 38.4 t of CO2, and 15.4 t of standard coal during the heating season. Studying the impact of mounting solar cells on the Trombe wall was Irshad et al. [20]. The best conversion efficiency for energy generation could be achieved year-round, according to the results. Furthermore, it was observed that the system offered the extra advantage of air filtration, resulting in space heating with efficiency levels of 37% in the summer and 12% in the winter. Ahmed et al. [21] made a recommendation for a new PV/TW system with a DC fan and assess how well it performs in comparison to a different PV/TW system without a DC fan. However, in order to meet the voltage requirement of the system, the DC fan was connected to a different PV module. The average room and PV panel temperatures were raised by the assisted DC fan. A study by Deepak and Malvi [22] found that dust accumulation lowers photovoltaic panel output loss by roughly 21.57 percent. additionally came to the conclusion that proper cleaning and maintenance are required to stop dust accumulation from degrading solar panels. The effect of dust deposition on the front glass of photovoltaic panels during the winter was examined by Lasfar et al. [23] demonstrate that the dust particles reduce and scatter the incident radiation on the solar modules, which lowers the conversion efficiency. The impact of dust on photovoltaic system performance was investigated by Mustafa et al. [24]. The findings indicate that dust deposition reduces efficiency by 11.86 percent and power output by 8.80 percent, respectively, and has an impact on photovoltaic current and voltage as well as the output of photovoltaic power. The impact of dust formation on solar panels due to climate conditions was investigated by Ekinci et al. [25]. The findings demonstrated that a 15% increase in energy production was achieved by cleaning the panels. The impact of dust size, wind speed, and building roof slope on the behaviors of dust deposition was studied by Peng et al. [26]. According to the experimental findings, the rate of dust deposition decreased as dust particle diameter increased. 2.54% of the dust was deposited when the particles had a diameter of 150 μm. The rate of deposition is 0.03 percent if the dust particles have a diameter of 500 μm. Regarding the tilt angle impact of 22.6° or 36.9°, respectively, the rate at which dust particles were deposited was 2.54% or 3.74%. The effects of solar panel temperature and natural dust deposition on photovoltaic system performance were investigated by Styszko et al. [27]. The results showed that the efficiency of the PV panels decreased with increasing temperature and mass deposition; the efficiency loss was 2.1% at 480.0 mg deposition rate.

Climate change is one of the most important concerns facing the globe today. Dust storms are a regular feature of Iraqi weather in the spring and summer. Consequently, the purpose of this work is to ascertain the effect of dust deposition on the thermal and electrical competence of solar panels as well as to experimentally verification the performance of the photovoltaic Trombe wall system. The study summary is described as follows.

METHODOLOGY

One of the most common uses is investing in solar energy to generate electricity in poor nations. Nonetheless, a significant factor lowering efficiency is the reduction in solar radiation intensity brought on by climatic variations and the accumulation of dust on solar panels. Consequently, periodic cleaning of the panels to keep dust from collecting on them increases their effectiveness by allowing more solar energy to be absorbed by the panels. The study site and the experimental work arrangement are described in Section 3. The computations used to estimate competence and performance are described in Section 4. In Section 5, the findings are analyzed and clarified. Conclusions and suggestions are presented in Section 6.

Experimental Work Setup

The experiments were out at the Hawija Technical Institute in northern Iraq over four days in April (35.19°N, 43.46°E). Figure 2 illustrates two models of the PV Trombe wall system that were created to demonstrate how operational factors and meteorological conditions affect system performance. The two designs consist of a SP, a duct, and a building wall. Additionally, the two designs have lower apertures that draw cold air from the building and transfer it into the duct, as well as upper holes that allow air from the duct to enter the structure. DC fans were incorporated into the top and bottom apertures of one of the experimental designs. In contrast, the second design has no fans because heat is transmitted via the vents naturally by convection. In order to minimize heat loss, the experimental models were constructed and developed using insulated panels in a closed configuration. According to Figure 3. To increase the radiation intensity on the SP, the solar panels were mounted on the southern face, as seen in Figure 4. Polycrystalline SP were employed as the absorbent surface in this investigation. Table 1 displays the photovoltaic panels' specifications (1). The airflow channel's measurements in the designed models are as follows: (width 72 cm, depth 14 cm, height 152 cm).

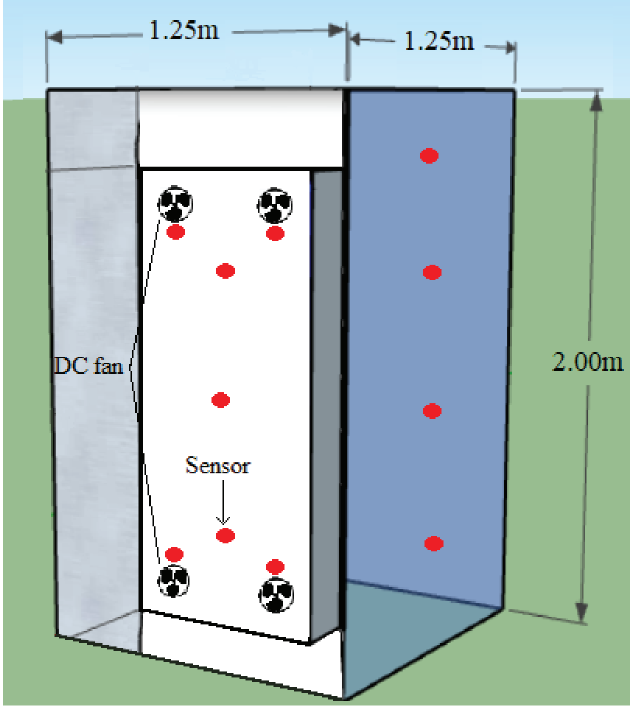
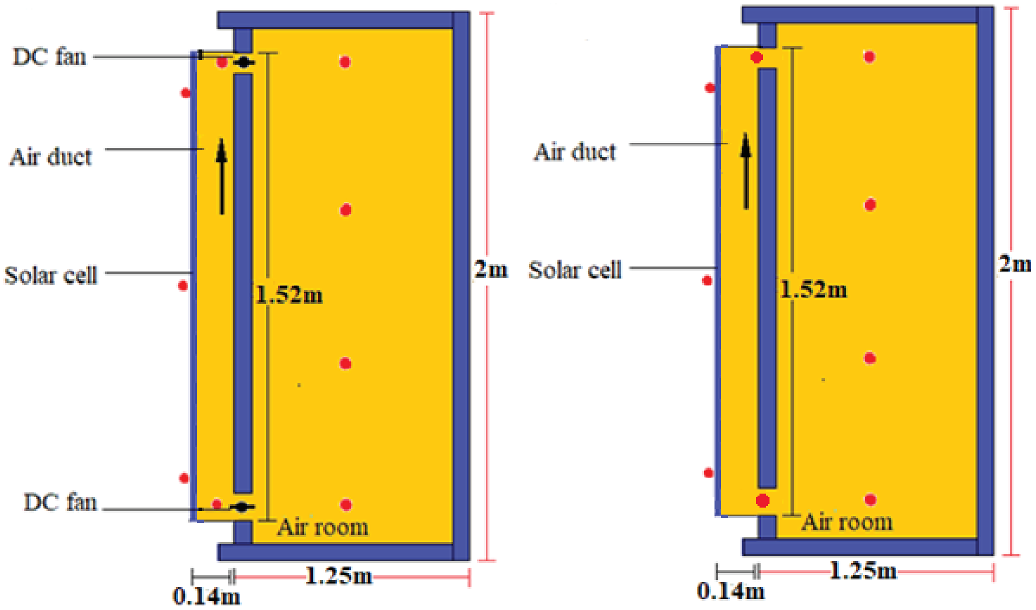


Figure 3. Diagram showing the dimensions of the insulating panels and the location of the sensors.

Figure 2. The exterior appearance of the PV/Trombe wall.



(a) With DC fan

(b) Without DC fan

Figure 4. System schematic diagram.

An essential component of competency evaluation is temperature measurement. As seen in Figure 3, eleven sensors were used in each model to detect the temperature. Two sensors were positioned on the top openings and two on the lower openings of each of the four sensors that were placed within the test room and the air channel. Additionally, three sensors were installed on the SP's front face. In addition, I used a Davis Vantage Pro 2 weather station to gauge temperature, wind speed, and sun radiation. Each embodiment measures the SP voltage and current using a sensor. Additionally, the power generated by the photovoltaic panels was stored in a battery. The electrical output can be used as the control by using an MPPT device. A water pump capable of producing 0.18 liters of water per hour was used, along with an external water tank. The DC fan and water pump specifications are listed in Table 2. The accuracy of the computation tools used in the test is shown in Table 3.

Table 1. PV panel specifications

Parameters	Unit	Parameters	Unit
Temperature	25°C	The highest capacity of the solar panel	150 W
Open Circuit Voltage	22.4 V	Dimensions of the designed system (cm)	)148*68 *3.5(cm
Maximum Power Current	8.38 A	Short Circuit Current (ISC)	8.81 A
High voltage power	17.9 V	Type of solar panel	Polycrystalline

Table 2. Properties of the pump and fan

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

Table 3. The accuracy of the measurement apparatus

Equipment	Measurement	Error
Sensor JQC -3ff-s-z	Current Voltage	± (0.1%)
Sensor JQC-3ff-s-z	Electrical power	± (0.1%)
Sensor DS18B20	Temperature	± (0.5 °C)
Rotameter	Water mass flow rate	± (3%)
Davis vantage pro 2	Solar radiation	(±10 W/m^2)

Formulation of Performance

In order to estimate the energy performance of the Trombe wall system under different operating conditions, the electrical and thermic competence of the system will be calculated. The following formula represents the heat gain of the air [28].

$$Q_{air} = \dot{m}_{air} Cp_{air} (T_{outair} - T_{inair}) \tag{1}$$

The system's thermal competence in the case of natural convection is the ratio between the amount of heat transferred, the cross-sectional area of the solar panel, and the intensity of solar radiation, which is given by the following equation [29, 30].

$$\eta_{thermal} = \frac{Q_{air}}{I_{solar} A_{PV}} \tag{2}$$

The mass flow rate is the amount of mass flowing during a cross-section of the flow system in one unit of time and is denoted by $\dot{m}$. Air flows inside the channel, and the mass flow rate of the air flowing in a duct is proportional to the air velocity and the duct's cross-sectional area and density. It can be expressed by the following equation.

$$\dot{m}_{air} = \rho_{air} . A_{duct} . V_{air} \tag{3}$$

There are two ways to calculate the air velocity inside the duct: the first is natural convection, which happens when buoyant forces cause the air to move due to differences in density brought on by temperature differences in the air. The velocity is determined using the following equation [31].

$$V_{air} = \sqrt{\frac{0.5.g.\underline{\beta}.H(T_{outair} - T_{inair})}{C_{fr}\frac{H}{D_H} + \frac{C_{losin} \cdot A^2_{duct}}{A^2_{in}} + \frac{C_{losout} \cdot A^2_{duct}}{A^2_{out}}}} \tag{4}$$

$$C_d = 0.3 \times 1.368 \times G_{rx}^{0.084} \tag{5}$$

$$\begin{gathered} C_{losin} = 0.25 \\ C_{losout} = 0.3 \\ \underline{\beta} = \frac{1}{T_f} = \frac{1}{T_{outair} + T_{inair}} \end{gathered} \tag{6}$$

The second status is forced convection, which happens when DC fans are operating and causes air flowI nside the room. The velocity is determined using the formula below [32].

$$V_{air} = C_{fan} . I_{Solar} \tag{7}$$

Whereas C_{fan} is constantly equal to 0.00073 m^3/J [32]

A portion of the power production by the SP is consumed by the load and fans, Therefore, the following formula is used to calculate the electrical power [33].

$$P_{electrical} = V . I - P_{consumed} \tag{8}$$

$P_{consumed}$ Represents the amount of power used by the fans and load.

I, V describe the current and voltage that the solar panels are producing.

Using the following formula, the electrical efficiency is calculated [34].

$$\eta_{electrical} = \frac{P_{electrical}}{I_{solar} A_{PV}} \tag{9}$$

Using the following formula, the total efficiency is calculated.

$$\eta_{overall} = \eta_{electrical} + \eta_{thermal} \tag{10}$$

RESULTS AND DISCUSSION

The System's Temperature

The experimental findings from the test days were compared between the fan-containing model and the fan-free second model, taking into account the varying weather conditions on dusty and non-dusty test days. Through the use of DC fans, which assist in cooling the SP and improving the building's interior comfort, the heat generated by the solar panels is removed. Figure 5 illustrates how climate change and DC fans impact photovoltaics' temperature. On a day without dust, the temperature of the solar panels was lower when DC fans were used. Without DC fans, the system temperature increased to 54.5°C at 11 a.m. However, the system with DC fans registered a maximum temperature of 51.5oC at noon on the SP. At 12 p.m. on a dusty (cloudy) day, the non-ventilated model without DC fans reached its maximum temperature of 48.7 °C. On a dusty (cloudy) day, the SP temperature decreased when the DC fans were on, with the highest temperature recorded at 34.6°C at 11 a.m. Dust accumulation affects the PV/ TW's performance. A substantial amount of solar radiation is reflected by dust particles that build up on the surface of photovoltaic panels. As a result, the net SR of the panels is reduced. As a result, the system's overall competence declines. The implementation of dust-gathering systems on solar panels can mitigate the problem. and clean the photovoltaic cells on a regular basis to avoid this decline and ensure that the solar radiation is at its peak. The temperature variations in the photovoltaic panels are caused by variations in solar radiation intensity; similar behavior was observed in a previous article [35].

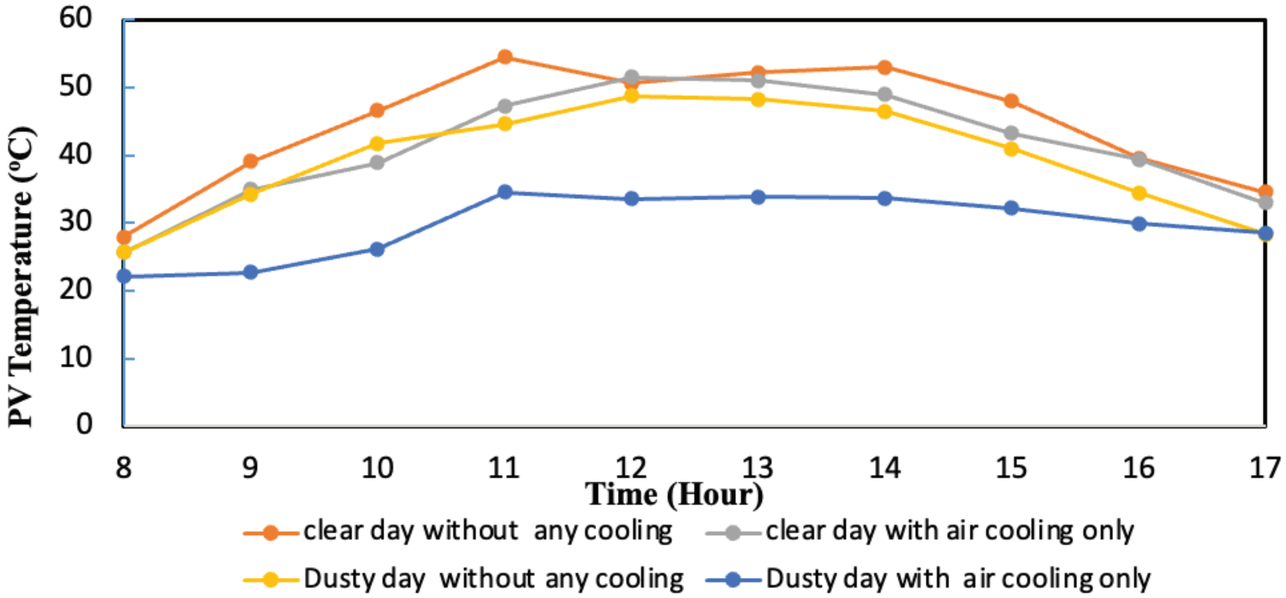


Figure 5. The change in the temperature of photovoltaic panels according to operating circumstances.

Figure 6 shows how the airway temperature changed. On a day with no dust, at 2:00 pm, the air duct's maximum temperature was measured to be 50.8°C when the air flow was without fans, that is, under natural convection. At 2:00 PM, the airflow temperature was recorded at 44.5°C on a non-dusty day when forced air flow—the presence of fans—was present. According to the results, the system's maximum temperature was recorded at 46°C at 1 p.m. and 33°C at 2 p.m. on a dusty day, respectively, under changing weather circumstances and operating circumstances. Overall, the air duct temperature was lowered by the fans' presence, which enhanced interior comfort levels.

The effects of dusty weather and DC fans on the experimental room temperature are shown in Figure 7. When the DC fans were not operating at 2:00 p.m on a non-dusty day, the room's temperature registered 39.7°C. When the DC fans are used on a non-dusty (clear) day, the room temperature rises. This is because, around 2 p.m., the maximum temperature in the room was recorded at 40.8°C, thanks to the fans' efforts to transport the heat generated by the solar panel inside. The

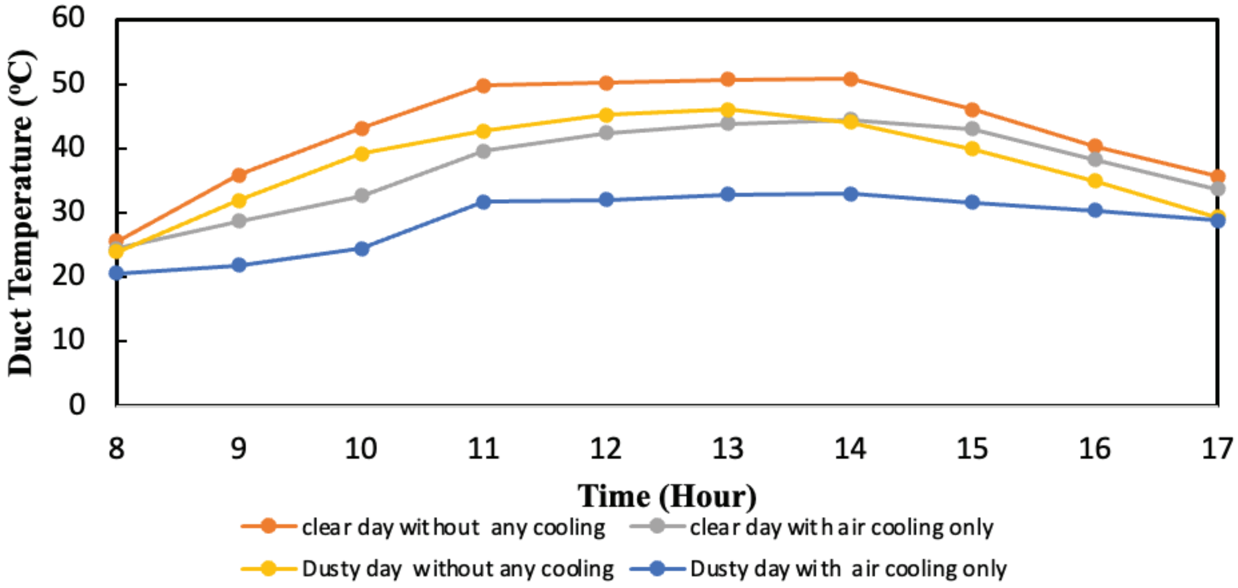


Figure 6. Temperature variation in the ducts based on operating circumstances.

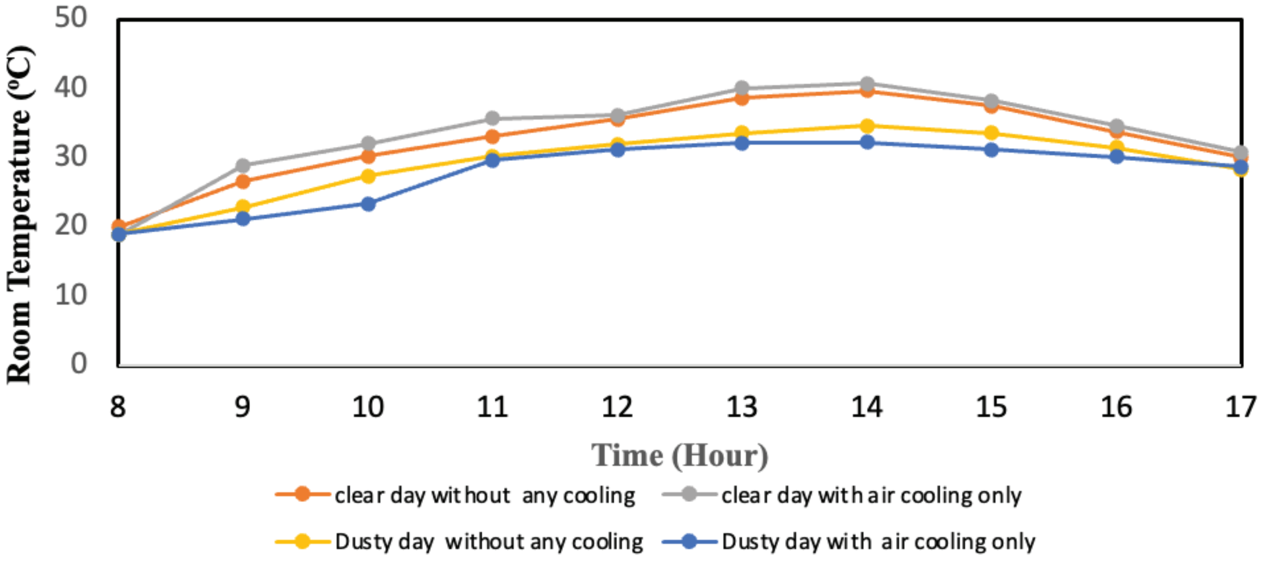


Figure 7. Variation in room temperature according to operating conditions.

highest temperature recorded in the room at 2 p.m. on a dusty day without the DC fans running was 34.6°C. At 2 p.m., the experimental system's highest temperature hit 32.3°C on a dusty day with DC fans running. Note that this time, the experiment room's temperature is lower than it was in the previous results. The reason for this is that during the day, the high dust in the building caused the interior temperature to drop for different system modes. By transporting heat from a high-temperature air duct to its lower-temperature interior, fans also improve interior thermal comfort [36].

Electrical, Thermal and Total Efficiency

Efficiency, which is impacted by operating circumstances and meteorological factors during the experiment, is the fundamental criterion for assessing the efficacy of the planned system.

Figure 8 shows how the PV Trombe wall system's electrical competence is affected by the operating and meteorological variables during the experiment. The increase in solar radiation intensity results in an increase in electrical efficiency all day long, with peak efficiency occurring around midday. Following this point, the SR declines and the electrical efficiency drops as a result. By removing the

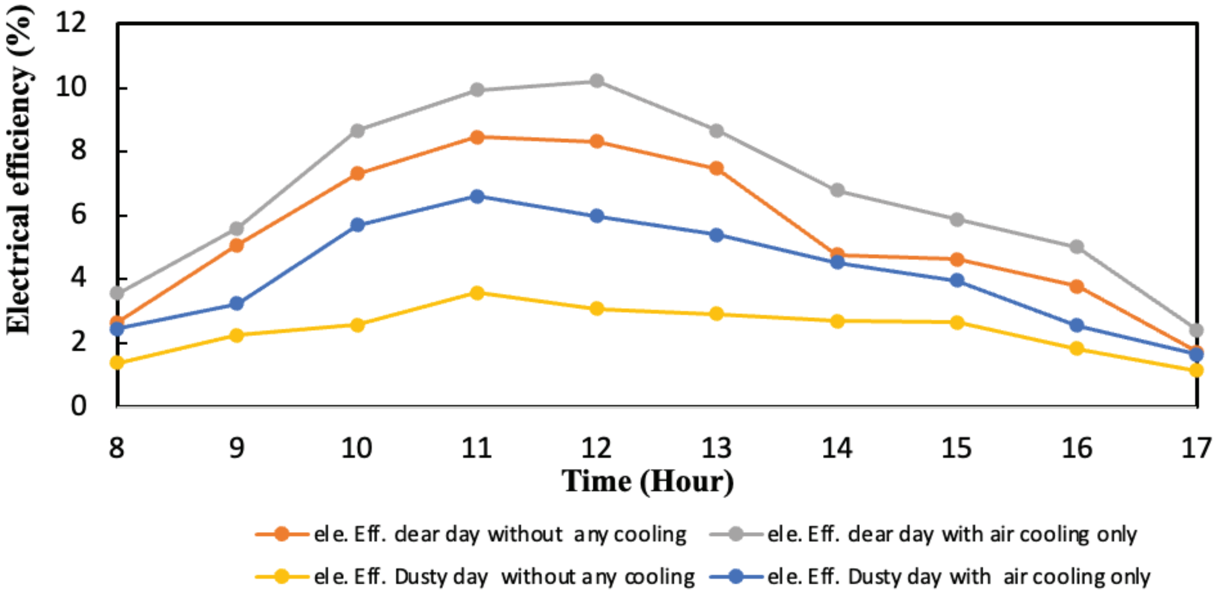


Figure 8. The electrical competence of the system varies under different operating circumstances.

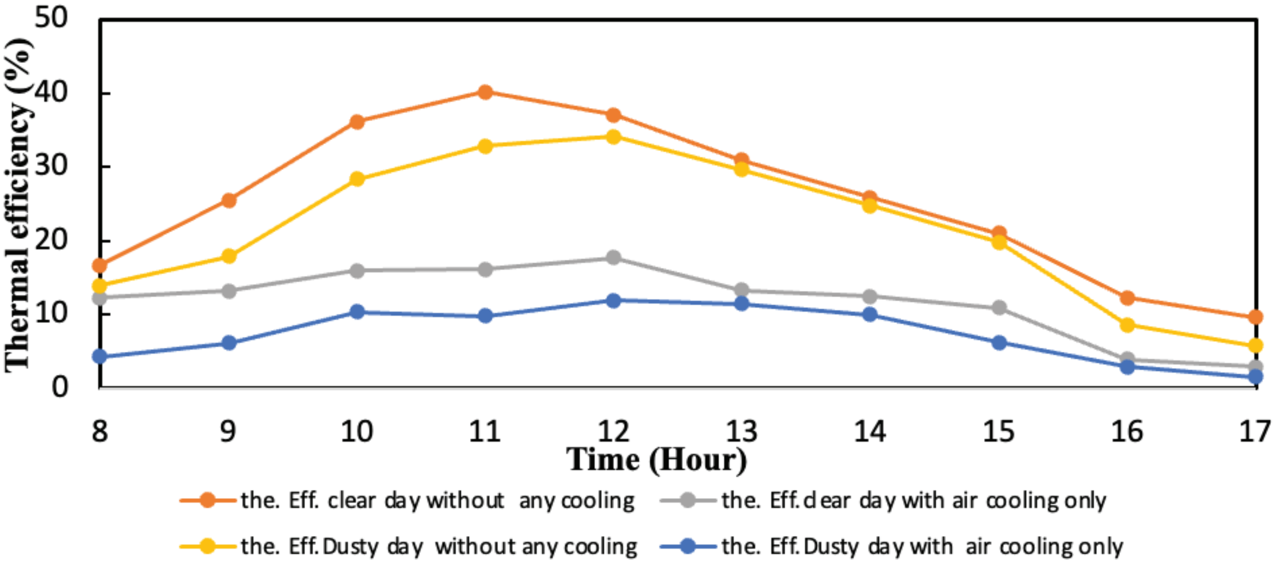


Figure 9. Variation in the thermic competence of the system under different operating circumstances.

heat produced by the solar panels, DC fans help to cool them down and increase electrical efficiency. In the first status, the top electrical competence recorded 8.2 percent at 11 a.m. when there was no dust and no air cooling, i.e., no fans to cool the solar panel. Nevertheless, around 12 p.m., the peak electrical competency recorded 10.2 percent when the photovoltaic panel was cooled with fans. In the second instance, at 11 a.m., the top electrical competence recorded 3.5 percent in the presence of dust and regular air flow—that is, without fans. At 11 a.m., the highest electrical competence recorded 6.6 percent when air-cooling (via fans) was applied. The findings showed that when DC fans were installed and the solar panels were being cooled by air, the electrical efficiency rose on non-dusty days. This is in line with earlier research [37].

The system's thermic competency is shown in Figure 9. Temperature variations and operational conditions affect thermal competency. During the day, the thermal competence increased; in the event of natural convection (without fans), it peaked at 40.1 percent at 11 a.m., but in the case of forced convection (with fans), it reached 17.6 percent at 12 p.m. These results applied to a day without dust. At 12

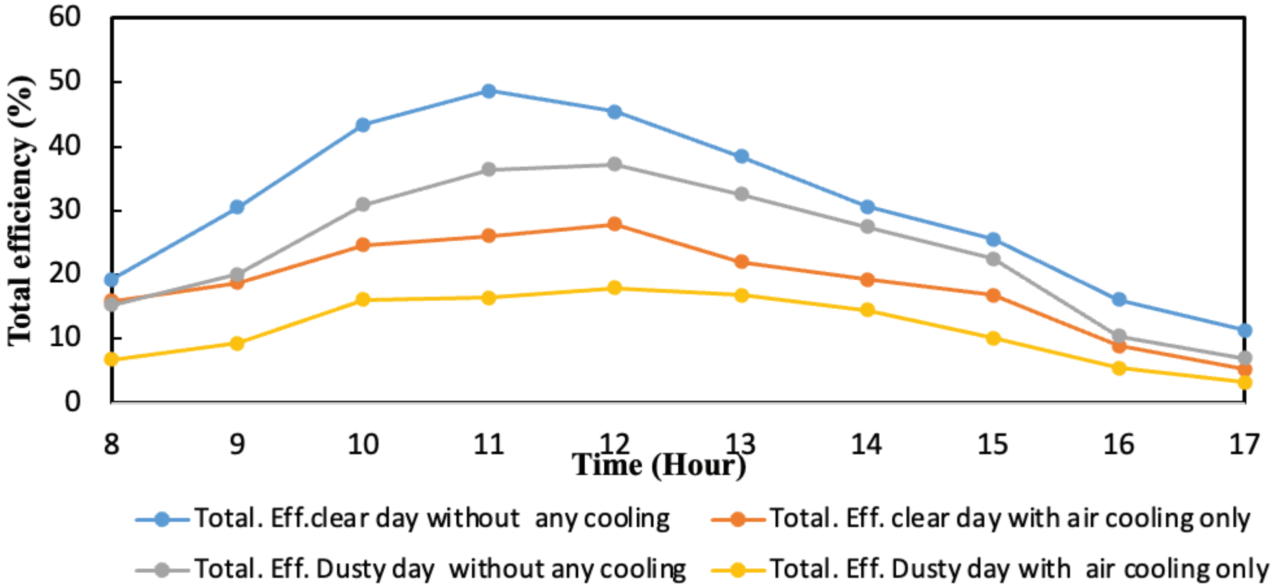


Figure 10. The aggregate competence of the system under different operating circumstances.

p.m., in the natural convection state, the maximum thermal competence of 34.1 percent was recorded in the presence of dust. At 12 p.m., the maximum thermal competency of 11.9 percent was observed in the forced convection status. The impact of operational conditions and climatic change is what causes this variation in thermal competency. This aligns with the earlier article [38].

Figure 10 illustrates the aggregate competence of PV/TWS. The total competence depends on the values of thermal and electrical competence, and the thermal competence is higher than the electrical efficiency. Consequently, the aggregate competence of the system is more significantly impacted by thermal efficiency. The highest overall system efficiency was obtained on a non-dusty day and when no DC fans were in use, reaching 48.6% at 11 a.m. While the overall system efficiency was highest on a dusty day when no DC fans were being used, reaching 36.4% at 11 a.m.

CONCLUSION

The current article examined how operational conditions and climatic variations affect the photovoltaic Trombe wall's performance. The primary findings of the experimental investigation were as follows:

1. Due to the effects of dusty weather, both the temperature inside the building and the temperature of the photovoltaic panels drop; the difference between the two recorded a 12 percent drop.
2. The PV Trombe wall system's electrical competence is reduced by dusty weather conditions; on a non-dusty day, the average daily in electrical competence was 2.4% higher than on a dusty day.
3. The highest electrical competency was attained on a day without dust; under forced load conditions (with fans), the competency was 10.2 percent, and under natural load conditions (without fans), it was 8.4 percent.
4. The system's maximum thermal competence of 17.6 percent was attained on a non-dusty day when the DC fans were operating. While the model without DC fans was, the efficiency was 40.1 percent.

NOMENCLATURES

A_{PV}	Photovoltaic panel area [m^2]
A_{duct}	Area of duct [m^2]
A_{out}	Top slot area [m^2]
A_{in}	Bottom slot area [m^2]
cp_{air}	The thermal capacity of air [J/kg.K]
C_{losout}	Loss modulus of the upper vent
C_{losin}	Loss modulus of the Bottom vent
C_d	Friction factor along the channel
D_H	Hydraulic diameter [m]
DC	Direct current [A]
H	Height [m]
I	Current [A]
V	Voltage [V]
SP	Solar panel
SR	Solar Radiation [W/m^2]
g	Gravitational [m/s^2]
$\dot{m}_{air}$	Air mass flow rate [kg/s]
$P_{electrical}$	net power [W]
$P_{consumed}$	Consumed energy [W]
PV	*Photovoltaic*
T_{outair}	The air temperature at the duct exit [K].
T_{inair}	The air temperature at the duct inlet [K].
TW	Trombe wall
I_{solar}	Solar radiation [W/m^2]
V_{air}	Air velocity [m/s]
Q_{air}	Gain of heat [W]
β	Coefficient of stretching [1/K]
ρ_{air}	The air's density [kg/m^3]
η_{total}	Total efficiency [%]
$\eta_{electrical}$	Electrical efficiency [%]
$\eta_{thermal}$	Thermal efficiency [%]

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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