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Case report

Experimental assessment of the performance of the PV/solar chimney under the cloudy weather

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ABSTRACT

One of the disadvantages of solar systems is their low efficiency due to weather conditions such as dust and clouds that reduce their performance. Therefore, this article examines the impact of cloudy weather on the performance of the PV/solar chimney to demonstrate the performance of these solar systems under overcast weather conditions. The PV/solar chimney system was designed and built, and two days in December were chosen for testing: 27 December with clear weather without clouds and 28 December with cloudy weather.

The results showed that cloudy weather has a clear effect on the performance of the PV/solar chimney where the intensity of solar radiation is low. Clouds act as a barrier preventing access to sunlight, as the electrical power generated on a clear weather day reached 341.92 W, while on a cloudy weather day, 187.88 Watts at noon. The kinetic energy on a clear weather day reached 17.212 mW, while on a cloudy weather day, it reached 9.47 mW at noon. The electrical efficiency on a clear weather day reached 15.96 %. In contrast, on a cloudy weather day, it reached 13.2 % when the test started at 9 a.m., after which the efficiency decreased with the increase in the intensity of solar radiation to become 13.574 % in clear weather while 12.12 % in cloudy weather at noon, and the thermal efficiency on a clear weather day reached 56.06 %. In contrast, on a cloudy weather day, 42 % at noon. The total efficiency in clear weather reached 69.65 %, while on a clear weather day cloudy by 54.12 % at noon.

Nomenclature

SC	Solar Chimney
PV	Photovoltaic
PVC	Polyvinyl Chloride
MPPT	Maximum Power Point Tracking
η_{elec}	Electrical efficiency
P_{elec}	Electrical power (W)
I_{solar}	Solar radiation (W/m^2)
I_{pv}	Photovoltaic- panel – current (A)
v_{pv}	Photovoltaic- panel- voltage (V)
Q_u	Heat gain power (W)
T_a	Ambient temperature (^{o}C)
C_p	Specific heat (J/kg.k)
h_w	Heat transfer coefficient (W/m^2.k)
$T_{o_{air}}$	Chimney outlet temperature (^{o}C)
$\dot{m}$	Mass flow rate (kg/s)
A_{ch}	Chimney tower area
$V_{ch,exp}$	Velocity of air exiting the solar chimney (m/s)
ρ	Air density (kg/m^3)
P_{kin}	kinetic power (mW)
η_{co}	Efficiency of the collector
α	Absorption
τ	Transmittance
T_{gl}	Glass temperature (^{o}C)
η_{tot}	Overall efficiency

1. Introduction

Nowadays, the world is witnessing a significant increase in the population and a greater need for energy resources, which leads to environmental pollution, which is likely to lead to the depletion of conventional fuel supplies (oil, gas, coal) and a significant increase in fuel prices globally [1]. Naturally, the urgent need for energy sources leads to the necessity of providing an alternative, non-polluting source of energy [2]. Given that conventional energy sources are used on a large scale and continuously, they are likely to run out in the next fifty years, as we see that the energy challenges in the world today are among the most pressing at the moment, which prompted scientists and

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engineers to search for new sources of energy that are inexhaustible and non-polluting to the environment [3,4]. These efforts led to the development of the concept of renewable energy, which includes sources such as solar energy, wind energy, hydroelectric dam energy, ocean and sea energy, geothermal energy, and others [5]. To reduce the amount of pollution and improve human and economic development, power generation from renewable energy sources, such as solar energy, is of paramount importance [6].

Many electrical energy systems currently rely on solar energy, such as PV panels, solar thermal plants, solar chimneys, etc [7]. The solar chimney, which was built to produce electric energy, had a great opportunity to use modern and clean environmental sources that do not pollute the environment [8]. One of the possible disadvantages of solar chimney systems is the low efficiency of the traditional solar chimney, so researchers have tried to look for new ways to improve the efficiency of the solar chimney by combining it with conventional energy systems or other renewable energy systems, which are called hybrid chimneys [9]. Based on the basic idea of heating the air and its ascent to the top by solar heating, the solar chimney system was proposed, as this technology is a modern and promising technology that converts solar energy into electricity [10]. Solar power plants using solar chimneys are promising future systems for producing and harnessing energy largely, producing clean, non-polluting energy for the environment [11,12]. The idea of the solar chimney system was first put forward in the world to produce energy in 1931, which appeared in the book written by Hans Gunter, where this idea was implemented and developed through the participation and assistance between the German government and one of the Spanish companies [13]. The first chimney designed and built in the world was the solar chimney designed by German engineer Schleich in 1981 to produce electricity in Manzanares in Spain [14]. The dimensions of the solar chimney designed by the German engineer in Manzanares were the height of the solar chimney m (180)and diameter (5.08 m), and the radius of the solar collector reached (122m) as shown in Fig (1), this model was operated from 1982 to 1989 and was capable of operating with an average of 150 kW of electricity [15].

The traditional solar chimney system consists of three main parts: the solar collector, the chimney tower, and (the generator and turbine), which are the energy conversion unit, which is a solar thermal power plant, is the part capable of converting the solar energy resulting from the solar rays falling on it into thermal energy is the solar collector [16, 17]. Through the fall of solar rays on the glass cover of the collector, the air is heated, a heat capacity is formed, and therefore its density will decrease. It begins to climb towards the chimney tower, after which the heat capacity turns into a kinetic capacity that lifts the air and pulls it inside the tower. Then, the kinetic capacity is converted into mechanical capacity through the presence of a wind turbine at the base of the tower; the air rotates the turbine mechanically, generating electrical energy, as shown in Fig (2) [18]. Solar chimney towers are defined as a technology for generating electric energy using solar energy and directing hot air through air turbine fans to convert it into electrical energy.solar chimney towers consist of a chimney (air duct)installed on a transparent and open surface with the surrounding medium, as this roof and the underlying floor together form a solar collector as shown in Fig. (2) [16]. One of the main disadvantages of solar chimneys is their low efficiency, so scientists and researchers have conducted many studies and research to improve their performance by combining or adding them with other technologies [10]. Hussein et al. [19] conducted a study to evaluate the performance of a new form of solar chimney, where the solar collector was integrated through a complete solar panel using a solar panel that is an alternative to the glass cover in traditional solar chimneys.

Chrobak et al. [20] studied many different effects of clouds and processes occurring in the atmosphere on the production of electrical energy using photovoltaic panels and concluded that the most negative effects on electricity production are clouds and cloud cover because they block the passage of sunlight, which reduces electricity production today, Fig. 3 shows the ten main types of clouds.

Numan et al. [21] conducted a theoretical and experimental study looking for the effect of clouds on the performance of a monocrystalline photovoltaic module. The study was conducted in Baghdad, where simulations were carried out using the MATLAB program to determine the effect, and the researcher concluded that clouds have a significant impact on the performance of photovoltaic modules, as they reduce the amount of solar radiation incident on photovoltaic panels, so they produce less energy on cloudy days.

Al-Kayiem et al [22].conducted an analytical study to find out the impact of the chimney height and the solar collector area on the performance of the solar chimney, where the mathematical model was simulated and converted to the MATLAB program and the analysis was done for the solar collector areas (15, 150 and 600 m^2) and chimney heights (5, 10 and 15m). The results showed that the performance of the system is affected by the intensity of solar energy at a collection area of 15 m^2 and a chimney height of (5 m). Hussein et al. [19] conducted a



Fig. 1. The solar chimney in Manzanares [15].

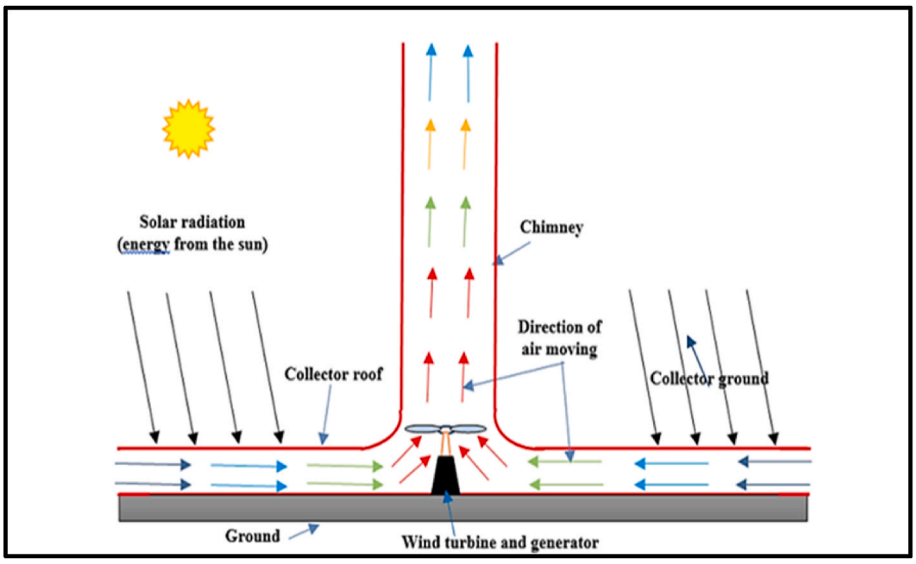


Fig. 2. The principle of operation of the solar tower [18].



Fig. 3. Main types of clouds [20].

study to evaluate the performance of a new design of a hybrid solar chimney through the use of a solar cell as a glass roof for the solar collector instead of a glass cover, and the results showed an increase in the temperature of photovoltaic panels with increased solar radiation. It turned out that the angle (45°) is the best angle to produce electricity, with the highest efficiency at the angle (30°,35°,40°), where the efficiency ranges from 8 % to 13 %. Al-Taaie et al. [23] studied the effect of the angles of the solar collector during the run, where the study was analyzed on the atmosphere of Baghdad-Iraq and at different test conditions and angles (0, 15°, and 30°), where the results showed there is a significant impact in changing the angle of inclination of the collector on the performance of the solar chimney, where we notice an increase in the air velocity inside the chimney as well as an increase in temperatures, where the maximum value reaches at an angle of (30°). Jamali

et al. [24] conducted a study to cool semi-transparent photovoltaic cells using a new solar chimney, where semi-transparent photovoltaic cells were used as the roof of the solar chimney and were cooled by the airflow generated by the chimney and found in the results that by cooling the power plant (STPV) in the solar chimney for radiation of (500 W) per square meter, an efficiency improvement of 29 % in energy generation is achieved. Hussam et al. [25] conducted a numerical and experimental study to evaluate the performance of the hybrid system by integrating photovoltaic panels with an inclined solar chimney, where the simulation was carried out using the ANSYS program and with various weather conditions; the results showed that the hybrid system produces energy with an efficiency ranging from 9 % to 11 %. Ayadi et al. [26] conducted a numerical study to evaluate the performance of the solar power plant for chimneys by changing the angle of the roof of the solar collector, where the dimensions of the system used in the study were the height of the collector (50 mm), the diameter of the solar chimney (160 mm) and the diameter of the solar collector(2750 mm) the study was conducted for four angles (−1.5°,-1°,0°,1°). The results showed that the roof of the negative collector positively increases the air velocity. Nia et al. [27] conducted an experimental study to identify and improve a solar chimney, where the simulation was performed under geometric variables with the tower height dimensions of (4 m) and the diameter of the collector of(5 m), the researcher concluded that the height of the radius of the collector and half of the diameter of the chimney increases the speed of air flowing in the collector; however, the height of the collector has negative effects as the highest air speed reached at the height of the collecter (5 m). Hussam et al. [28] conducted a study in which it was proposed to build a solar chimney integrated with photovoltaic cells to enhance the utilization of solar energy to increase the efficiency of the system. The results showed that the integration of the solar chimney with PV panels leads to an average decrease in the surface temperature of photovoltaic by (5.5 °C) and with higher efficiency than conventional. By reviewing published articles, it was noted that no study was concerned with the performance of the PV solar chimney system in cloudy skies. Therefore, the current article will analyze the system's performance in cloudy skies and compare it with the system's performance in clear skies.

2. Methodology

One of the problems that leads to a decrease in the efficiency of solar energy systems is cloudy weather, which affects the performance of solar systems due to the reduction of the intensity of radiation in cloudy weather. This research aims to study the performance of PV/solar chimneys to find out the extent of the impact of cloudy weather on their performance and efficiency. The article will be arranged as follows: The Partial shading conditions were explained in the third section **(**PSC) on photovoltaic arrays. The practical aspect was explained in the fourth section. The mathematical equations are described in the fifth section, the experimental side and the results are presented and discussed in the sixth section, and the conclusions are explained in the seventh section.

3. The Partial shading conditions (PSC) on photovoltaic arrays

There are significant effects caused by partial shading on photovoltaic modules. These effects include, firstly, the occurrence of some hot areas of photovoltaic modules, which cause damage to solar cells, leading to a decrease in the amount of energy generated by the system [29]; secondly, the amount of solar radiation incident on the surface of photovoltaic modules is uneven, i.e., some points receive a small amount of solar radiation due to shading, and the shading is caused by dust, cloudy weather, and also due to the shade of buildings or nearby trees, causing losses in the energy generated by the system [30]. The value of the current for solar cells that are not exposed to shading is much greater than the value of the current for solar cells exposed to shading, as it is assumed that the value of the current for the solar cell is the same in all branches of the photovoltaic unit, so hot spots are formed [31].

4. The practical side

The goal of this research is to analyze the performance of the photovoltaic chimney under cloudy conditions, so the solar chimney system was manufactured and built on the roof of the renewable energy research unit building at the Hawija Technical Institute, as shown in Fig. 4. The building was at an altitude of (8 m) and is located in the north of Iraq on the coordinate line (35.19 N^o. 43.46 E^o), where the readings were recorded for two days, one on the 27th with clear weather and the other on the 28th with cloudy weather in December 2023, where the reason for choosing the month of December was that the weather was overcast most of the time, so it was selected for the experiment.

The solar chimney system consists of the following parts:

- The base of the wooden system.
- The floor of the collector.
- PV panel.
- Glass cover.
- Solar chimney Tower.

Table 1 represents the engineering dimensions of the solar PV chimney parts.

4.1. The base of the system

To design the base of the system, we must take several factors into account, including the weight of the system; the base must withstand the weight of the system and withstand the wind speed, so the structure was designed from wood with a rectangular cross-section, its dimensions [length (2.42 m), width (2.32 m), thickness (0.1 m)] and a height (0.08 m) from the ground and the wooden frame was filled with white cork material because it is a thermal insulation material, lightweight and low cost, most importantly being available in the market and Figure (5-a) shows the wooden base filled with Cork.

4.2. The floor of the collector

The floor of the collector was made of aluminum material, where the base was coated with a layer with a rectangular section of aluminum dimensions [length (2.42 m), width (2.32 m), thickness (0.03)] placed on top of the Cork layer. The reason we chose aluminum is that it is considered an absorbent material, lightweight, has high thermal conductivity, and is somewhat cheap.

4.3. PV panel

Two PV panels were used to directly convert solar energy into electrical energy with a total capacity of two panels (1100W) with dimensions [2.28 m)) length, (1.13 m) width, (0.035 m) thickness [were installed on the surface of the compound floor as shown in Fig.(5-b), Table (2) shows the specifications of the voltage panels used in the experiment in detail.

4.4. Glass cover

Use a transparent glass cover for the solar collector with dimensions of [(2.42 m) length, (2.32 m) width, (0.004 m) thickness] where it allows solar radiation to penetrate the collector and was installed at an angle of inclination (5°) from the horizon and the height of the glass cover from the surface of the Photovoltaic plate to the outlet of the Collector (chimney entry) is (15 cm). The air entry distance is (0.03 m) above the Photovoltaic panels to prevent air leakage from and to the solar collector where place silicone is on the edges of the glass cover in contact with the chimney in the chimney entry area. Fig. (5-c) shows the



Fig (4). The PV/solar chimney used in the study.

Table 1
The main dimensions of the solar chimney.

NO.	Geometric parameter	Value
1	Length of solar collector (L_g)	2.42 m
2	Width of solar collector(W_g)	2.32m
3	Height chimney (H_{ch})	3.00 m
4	Chimney diameter (D_{ch})	0. 1m
5	Length of PV solar panel (L_{pv})	2.28 m
6	Width of PV solar panel (W_{pv})	1.13 m
7	Solar panel thickness(H_{pv})	3.5 cm

installation of the glass cover.

4.5. Solar chimney tower

It is a hollow cylindrical tube made of plastic (PVC) material with dimensions [(3 m) height, (0.1 m) diameter, (0.002 m) thickness]. It was installed in the center of the solar collector and worked as a pressure pipe where the sealant was placed on the edges of the chimney in contact with the solar collector to prevent the leakage of air coming out of the collector and inside to the chimney.

4.6. Accessories and tools used in the experiment

4.6.1. Temperature sensors

Thirteen thermal sensors were used in the experiment to measure the chimney temperature. The distribution of sensors across the chimney parts was as follows: two thermal sensors are installed under the solar panels, six sensors are installed on the upper surface of the PV panels, two of which are in the center of the PV panels, two in the first third of the PV panels, and two in the second third of the PV panels. Moreover, there are two sensors in the center of each side of the glass cover. There are three sensors in the chimney tower: the first at the base of the tower, the second in the middle of the tower, and the third at the top of the tower, where the sensors are distributed in different locations in order to get the closest and most accurate amount of the temperature rate correctly, Note that the accuracy of the thermal sensors is ($\pm$ 0.5) ^{o}C from -10 °C to 85 °C, Figure (6) shows the distribution of sensors in the solar chimney system.

4.6.2. Hot wire digital anemometer

The practical air velocity inside the solar collector and the chimney was measured using the AR866a digital hot wire anemometer, where two holes were made, one at the base of the chimney tower and the other in the middle of the chimney. The holes were made on the chimney tower in a circular shape and with a diameter of (0.02 mm). The holes were covered with silver insulating tape along the air duct in the chimney, as the distance between the holes is 1.5 m, where the air velocity is taken in different locations in order to find out which area of the chimney tower has the maximum air velocity, Note that the accuracy Digital Anemometer Air velocity(AR866A) Measuring Range(0.0~30m/s), Wind speed measurement error($\pm$3 % $\pm$ 0.1). The type of weather station (Davis vintage Pro2 Plus) is used to measure the intensity of solar radiation, ambient temperature, and wind speed.



(a)Filling the base with a layer of cork material



(b) PV/ panels installed on the base of the system



(c) The installation of the glass cover

Fig.(5). The main parts of the system.

Table 2
Detailed specifications of the photovoltaic panels used in the experiment.

Geometric parameter	Value
(Model Type)	MX -550M MONO CRYSALLINE 10BB PERS SOLAR PANEL
(Maximum power)	550 W
(Maximum power Voltage)	41.60 V
(Maximum power Current)	13.23 A
(Open Circuit Voltage)	49.80 V
(Short Circuit current)	13.99 A
(Dimensions)	(2.28*1.13*0.035) m
(Frame Material)	Aluminum
(Maximum System Voltage)	1500 V DC
(Maximum Seires Fuse)	25 A
(Weight)	29 kg
(Operating temperature in standard conditions)	25 °C
(Radiation in standard condition)	1000 W

4.6.3. Lamps (loads)

Six DC lamps with a capacity of one lamp(140W) were used. These lamps were connected to the battery and the Arduino controller to control the on and offload at a certain time so as not to exhaust the battery power. Figure (7) shows the circuit connection diagram of the designed model. The charge regulator type (ML2430/ML2440) regulates the voltage coming from the cells and prepares it before entering the battery. It also regulates the battery charge and the voltage coming out of it to electrical loads. The charge regulator protects the battery from continuous charging (overcharging), as the panels are disconnected from the battery when it is fully charged. Battery (FIERTE) was used to work with a voltage (12V) and current (100A). These batteries were used to store the electrical energy generated by solar cells during daylight hours to power the Arduino or used when the sun is absent to operate loads of electrical appliances.

5. Performance calculation

To calculate the useful capacity of the solar collector through the following equation [32]:

$$Q_u = \dot{m} c_p \ (T_{Out} - T_i) \tag{1}$$

where:

Q_u: The useful heat capacity, $\dot{m}$: mass flow rate of air, c_p: Specific density of air, *Tout*: The temperature of the air coming out of the solar collector, *Ti*: The temperature of the air entering the solar collector.

To calculate the mass flow rate, the following equation is used [33]:

$$\dot{m} = \rho A_{ch} V_{ch} \tag{2}$$

where:

ρ : The density of the air coming out of the solar collector, A_{ch} : area of solar chimney, V_{ch}: air velocity. The density can be calculated by the following equation [34];

$$\rho = 1.1614 - 0.00353[(T_{out} + 273) - 300] \tag{3}$$

The specific heat can be calculated by the following equation [32]:

$$c_p = [1.007 + 0.00004((T_{out} + 273) - 300)] \times 10^3 \tag{4}$$

The area of the solar chimney tower is calculated using the following equation [33];

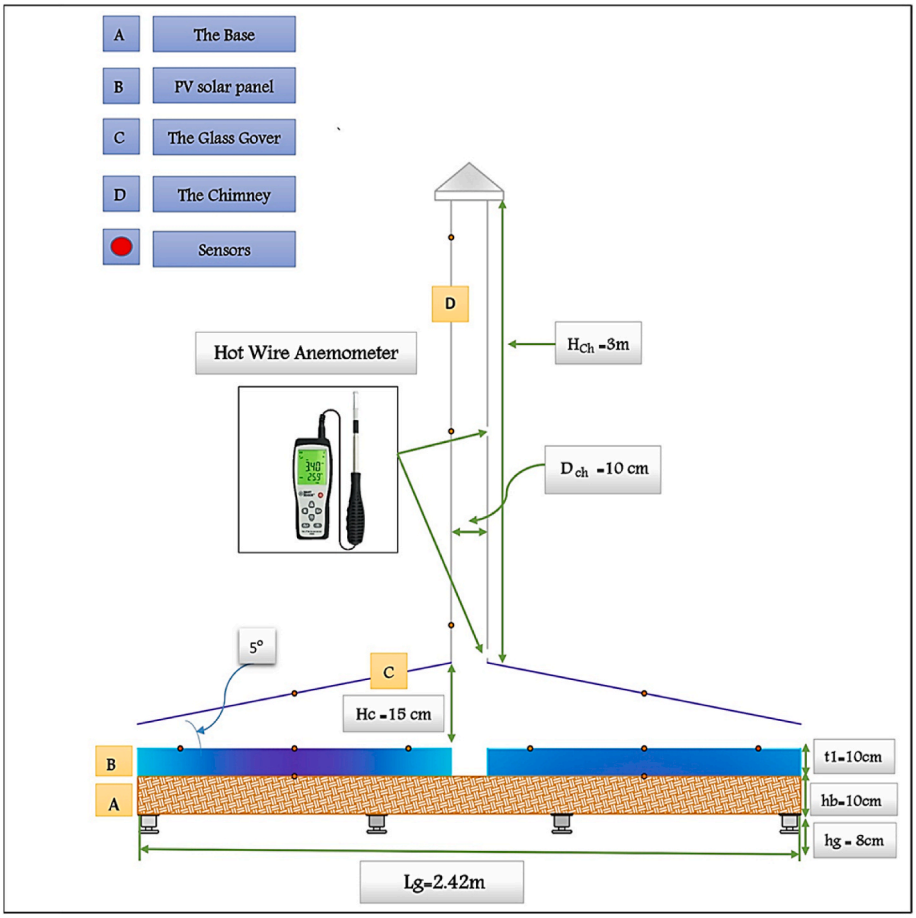


Fig. 6. Distribution of sensors in the solar chimney system.

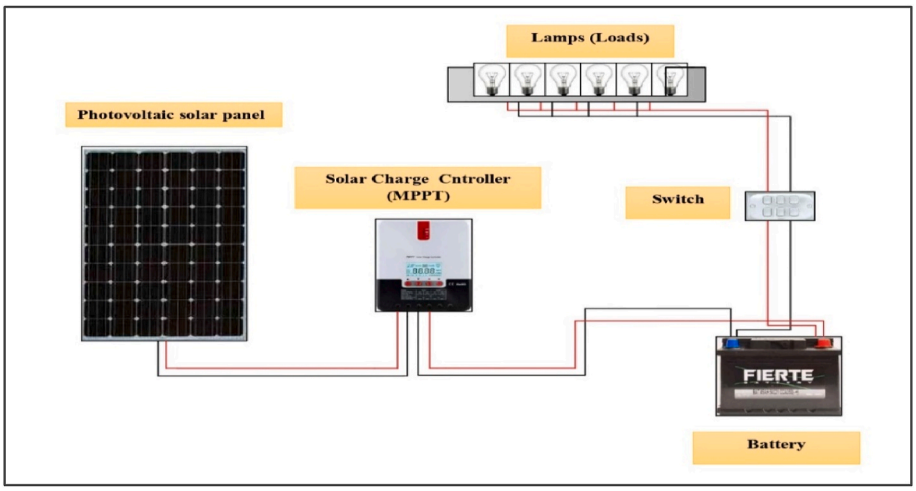


Fig. (7). The circuit connection diagram of the designed model.

$$A_{ch} = \frac{\pi}{4} D_h^{\,2} \tag{5}$$

where:

D_h: Diameter of solar chimney tower.

The solar energy absorbed in the collector can be calculated by the following equation [33]:

$$Q_{in=} A_{CO}\, I\, \alpha\tau \tag{6}$$

where:

Q_{in}: Absorbed solar energy, A_{co}: The area of the solar collector, I: The intensity of solar radiation, : The absorptivity of Photovoltaic panel, τ: Glass permeability.

In the following relations, we obtain the equation used to calculate the efficiency of the solar collector [22]:

$$Q_u = Q_{in} - Q_{loss} = A_{co} I\alpha\tau - h_w A_{co}\left(T_{gl} - T_{a)}\right) \tag{7}$$

$$Q_u = A_{co} I\alpha\tau - h_w A_{co}\left(T_{gl} - T_a\right) \tag{8}$$

The efficiency equation of the solar collector is obtained:

$$\eta_{Co} : \alpha\tau - \frac{h_w\left(T_{gl-}Ta\right)}{l} \tag{9}$$

where:

Tgl: the temperature of the glass cover, Ta: air temperature (ambient), h_w: the coefficient of heat transfer by both radiation and forced load is calculated by the following equation [35]:

$$h_w = 5.67 + 3.86 V_w \tag{10}$$

The electrical power generated by the voltage panels of the system is calculated theoretically by the following equation [36]:

$$p_{El\ theo=} \eta_{pv} I\, A_{PV} \tag{11}$$

Where: P_{elecpv} : The electrical power of solar panels, η_{PV} : Electrical efficiency of solar panels,

I_{solar} : The intensity of solar radiation, A_{PV} : The solar panel area

The equation practically calculates the electrical capacity of photovoltaic panels [36]:

$$p_{El\ ex=} i_{pv} v_{pv} \tag{12}$$

Where: v_{pv}: Voltages generated by PV panels, i_{pv} : current generated by solar panel

Due to the fact that the system is connected to the Arduino controller, the electric power reading is practically taken directly via the Arduino controller screen.

The efficiency of photovoltaic panels is calculated theoretically by the [37]:

$$\eta_{pv\ \ theo} = \eta_{ref}\left[1 - B_{ref}\left(T_{pv} - T_{ref}\right)\right] \tag{13}$$

Where: η_{ref} : is the efficiency of voltage panels under standard conditions, the value of which is (0.17), B_{ref} : temperature coefficient at standard conditions, the value of which is (0.04).

The efficiency of photovoltaic panels is calculated in practice by the following equation [38]:

$$\eta_{pv\ exp} = \frac{power}{Q_{av}} \tag{14}$$

$$\eta_{pv\ exp} = \frac{i_{pv} * v_{pv}}{I * A_{pv}} \tag{15}$$

The kinetic energy of air is calculated theoretically using the following equation [39]:

$$p_{kin\ theo} = \frac{1}{2}\rho A_{ch} V_{ch\ theo}^{\ 3} \tag{16}$$

The kinetic energy of air is calculated in practice using the following equation [39]:

$$p_{kin\ theo} = \frac{1}{2}\rho A_{ch} V_{ch\ exp}^{\ 3} \tag{17}$$

Air velocity is calculated theoretically by the following equation [39]:

$$V_{ch} = \sqrt{2gH_{ch}\frac{T_{CO.O} - T_a}{T_a}} \tag{18}$$

where: V_{ch} is air velocity at the base of the chimney, g:is ground acceleration, H_{ch}: is the height of the solar chimney tower. The air speed when entering the chimney is calculated practically using a Hot Wire Digital Anemometer. The equation used to calculate the overall efficiency of the system is derived from the following relationship [40]:

$$\eta_{total} = \frac{Q_u + p_{pv}}{I * A_{co}} \tag{19}$$

Also, the following relation can be used to calculate the overall efficiency:

$$\eta_{total} = \eta_{CO} + \eta_{PV} \tag{20}$$

- **The Uncertainty Analysis**

There is an error rate in the results due to the devices used in the study, where the error rate of the devices used is as shown in Table 3, and the following equation is used to find the error rate of the devices used in the experiment [41]:

$$\omega_R = \sqrt{\left(\frac{\partial \varnothing}{\partial x_1} \times \Omega_1\right)^2 + \left(\frac{\partial \varnothing}{\partial x_2} \times \Omega_2\right)^2 + \ldots\ldots\ldots \left(\frac{\partial \varnothing}{\partial x_n} \times \Omega_n\right)^2} \quad (21)$$

6. Results and discussion

The practical study was conducted in December 2023, where two days were chosen, one on 27 December with clear, cloudless weather and the other on the 28th with partly cloudy weather, in order to present the results. As shown in Fig. (8). It has been observed that the ambient air temperature in clear weather ranges from (6–17)degrees Celsius, and in cloudy weather, the ambient air temperature ranges from (8−15) degrees Celsius. The value of the radiation intensity reached its maximum on a day with clear weather. (485 W/m2).

6.1. The effect of clouds on the temperature of PV panels

Figure (9) shows the effect of cloudy weather on the temperature of solar panels for 27 December with clear weather and 28 December with cloudy weather, where it was observed that the temperature of photovoltaic panels for a clear weather day is (16.32 °C) while on a cloudy weather day (13.44 °C) at nine in the morning, after which the intensity of solar radiation increases and with it the temperature of solar panels rises, which on a clear weather day reaches (43.02 °C) while on a cloudy weather day to (37.40 °C) at noon, after that, the radiation intensity decreases and the temperature of the panels decreases with it, reaching on a day with clear weather to (22.223 °C) While on a day with cloudy weather to (23.778 °C) at the end of the Test at 4 p.m. It was noticed that the temperature of photovoltaic panels in cloudy weather is lower than that of panels in clear weather due to the fact that clouds act as a barrier to solar rays, reducing the temperature of the panels in cloudy weather they have reached (37 0.40 °C) at noon, the value of the radiation intensity is (301 W/m^2).

6.2. The influence of cloudy weather on velocity air

Figure (10) shows the effect of cloudy weather on the air velocity at the base of the solar chimney tower on 27 December with clear weather and 28 December with cloudy weather, where it is noted that the air velocity on a clear weather day (1.25 m/s) while on a cloudy weather day (0.84 m/s) at 9 a.m., the beginning of the experiment, and when the intensity of solar radiation increases, the air velocity increases to reach on a clear weather day (1.54 m/s)while on a cloudy weather day (1.26 m/s) at 12 noon, then the intensity of solar radiation begins to decrease and the air speed decreases with it to become on a day with clear weather (1.15 m/s) while on a day with cloudy weather (0.86 m/s) at the end of the experiment 4 p.m., it is noted from Figure (10) the reason is that in non-cloudy weather the solar panels are affected by the falling sunlight, which in turn affects the air molecules, as the air is heated, the energy of the molecules in it increases and then they begin to flow faster, which leads to an increase in speed inside the chimney, and, conversely, in cloudy weather, clouds act as a barrier blocking solar radiation.

Table 3
The uncertainty ratio of the devices used in the experiment.

Equipment	Measurement	Error
Hot Wire Digital Anemometer	Air Flow Velocity	±(3%)
Sensor DS18B20	Temperature	±(0.5%)

6.3. The impact of cloudy weather on electrical power

Through testing in clear weather on 27 December and cloudy weather on 28 December, the amount of electrical power produced by PV panels reached the power made for a day with clear weather (125.67 W) and the power with cloudy weather reached (67.659 W) at 9 a.m. Solar radiation begins to increase, and with it the electric power increases to reach noon with clear weather to (341.92 W) and up with cloudy weather to (187.88 W). The intensity of radiation decreases, and with it, the value of electrical energy decreases, reaching at the end of the test (111.2 W) in clear weather and (95.071 W) in cloudy weather, where we note that the electrical power generated during a day with clear weather is more than the energy produced on a day with overcast weather, the reason for this is that, as mentioned earlier, clouds act as a blocking barrier as shown Fig (11).

6.4. The effect of cloudy weather on kinetic power

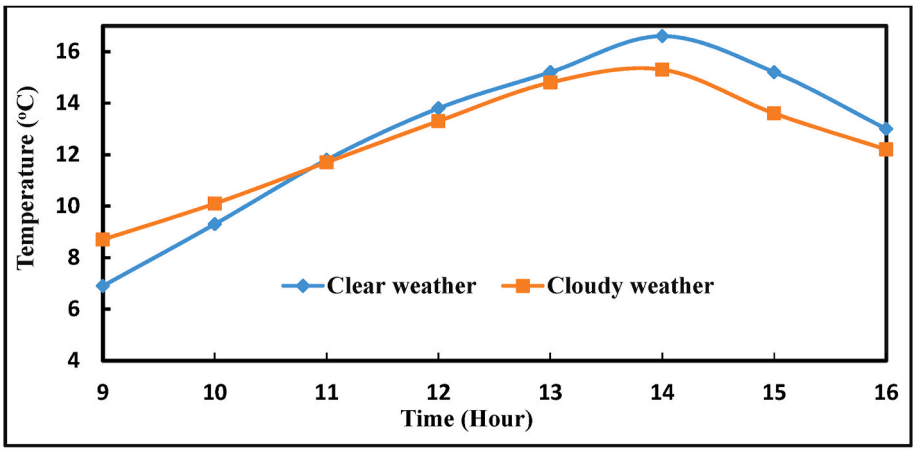
Figure (12) shows the kinetic power of the test days on 27 December and 28 December, where the kinetic energy of the solar chimney in clear weather was (5.525 mW) and in cloudy weather (2.911 mW) at 9 a.m. and with an increase in solar radiation, the kinetic power of the solar chimney begins to increase to reach a value of (17.212 mW) in clear weather and a value of (9.47 mW) in cloudy weather at noon, then the radiation intensity decreases. With it, the kinetic power decreases to reach (2.77 mW) with cloudless weather and up to (3.085 mW) with cloudy weather at the end of the test.

6.5. The effect of cloudy weather on the electrical efficiency of PV panels

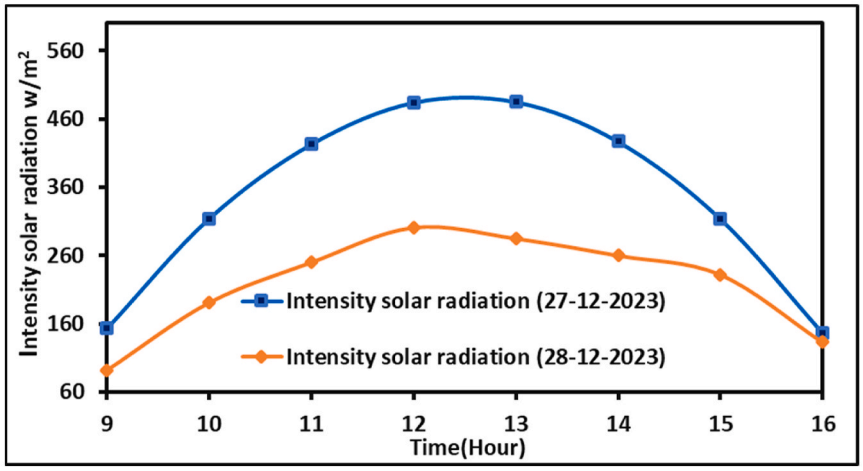
The electrical efficiency of the photovoltaic panels of the photovoltaic/solar chimney that was reached during the test conducted on 27 December in clear weather and on 28 December in cloudy weather, efficiency here means instantaneous efficiency, that is, every hour from the beginning of the Test at 9 a.m. to the end of the Test at 4 p.m., as Figure (13) shows that the amount of efficiency was (15.96 %) for a clear day, while (13.2 %) for a cloudy day at 9 a.m. at the beginning of the experiment, then the intensity of solar radiation begins to increase and the efficiency will increase by (13.574 %) in clear weather, while by (12.12 %) in cloudy weather at 12 noon, then intensity solar radiation will decrease The efficiency increases to (14.689 %) in clear weather, while (13.88 %) in cloudy weather at four o'clock in the afternoon at the end of the experiment, where the results showed that the electrical efficiency of panels in clear weather without clouds is higher than the electrical efficiency of panels in cloudy weather, and the reason is the low intensity of solar radiation in cloudy weather, which makes its efficiency lower than the efficiency of panels in clear weather without clouds and this is consistent with the results of previously published articles e.g., Refs. [42,43].

6.6. The effect of cloudy weather on total efficiency

The total efficiency of the PV/solar chimney for the test days reached on 27 December with clear weather and 28 December with cloudy weather, the total efficiency is meant here is the sum of the instantaneous electrical efficiency of the solar panels with the instantaneous thermal efficiency of the solar collector, and the thermal efficiency also has the greatest impact on the total efficiency of the hybrid solar chimney, as the total efficiency on a clear day reached (54.41 %) and reached on a cloudy day by (21.63 %) at 9 a.m. at the beginning of the test, then with increasing solar radiation intensity, the total efficiency begins to improve, and it reached (69.65 %) on a clear day and reached (54.12 %)on a cloudy day at noon, Then the radiation intensity decreases and the efficiency decreases with it, reaching an amount of (39.9 %) in clear weather and up to an amount of (31.48 %) on a cloudy day, as it is noted that the overall efficiency of the hybrid solar chimney with



(a)Ambient Temperature



(b) Intensity solar radiation

Fig. (8). a) The ambient temperature b) Intensity of solar radiation.

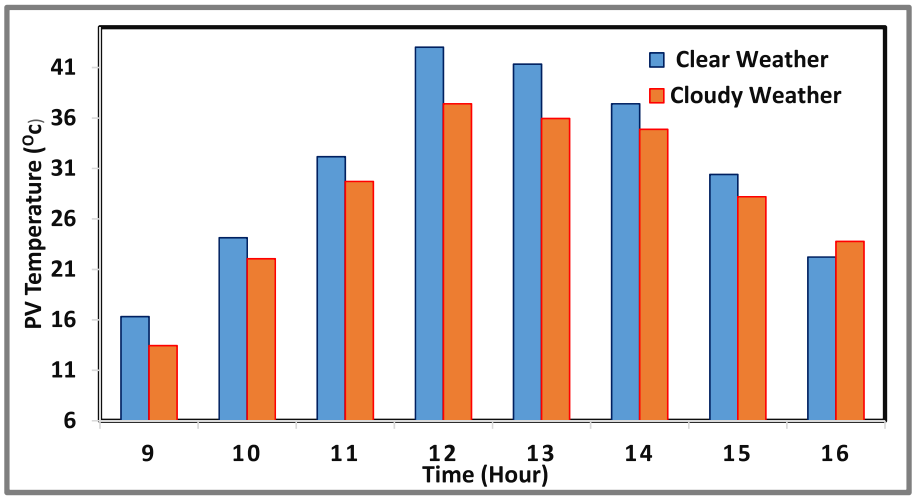


Fig (9). Temperature of PV panels for the clear weather and cloudy weather.

cloudy weather is less efficient than the hybrid solar chimney with clear weather due to the lower intensity of solar radiation as in Figure (14).

6.7. The effect of cloudy weather on thermal efficiency

The thermal efficiency of the PV/solar chimney for the test days is 27 December with clear weather and 28 December with cloudy weather, as it depends on the amount of heat absorbed and stored by the solar

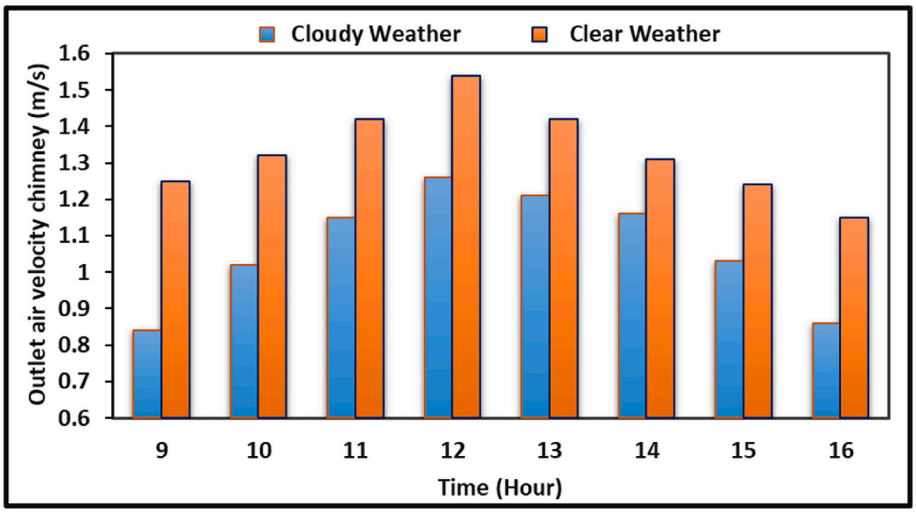


Fig (10). The velocity of the air coming out of the Solar Collector in clear and cloudy weather.

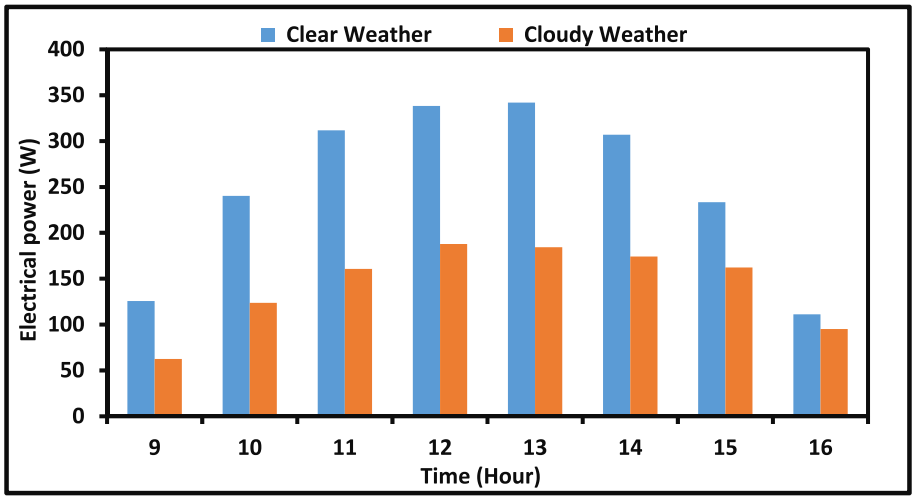


Fig (11). Electric power was produced on the 27th day with clear weather and on the 28th day with cloudy weather.

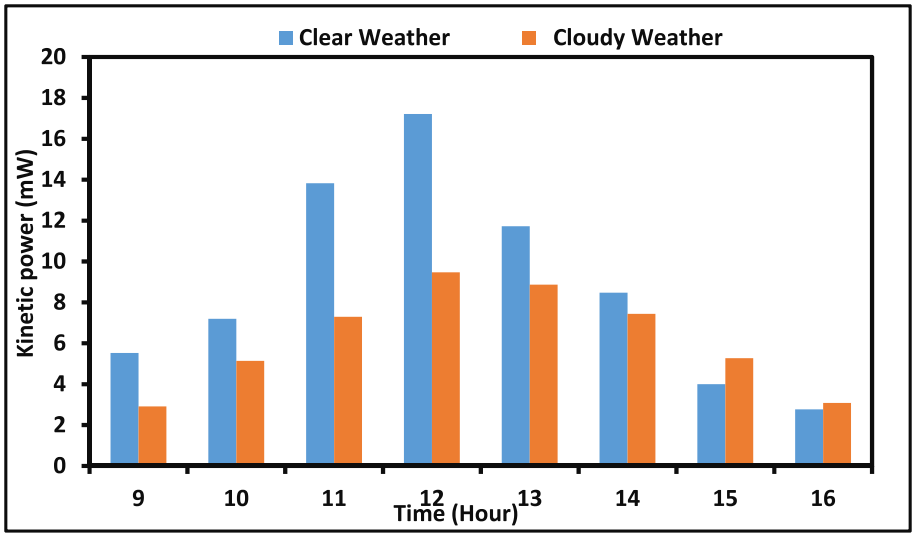


Fig (12). Kinetic power produced for the 27th day with clear weather and for the 28th day with cloudy weather.

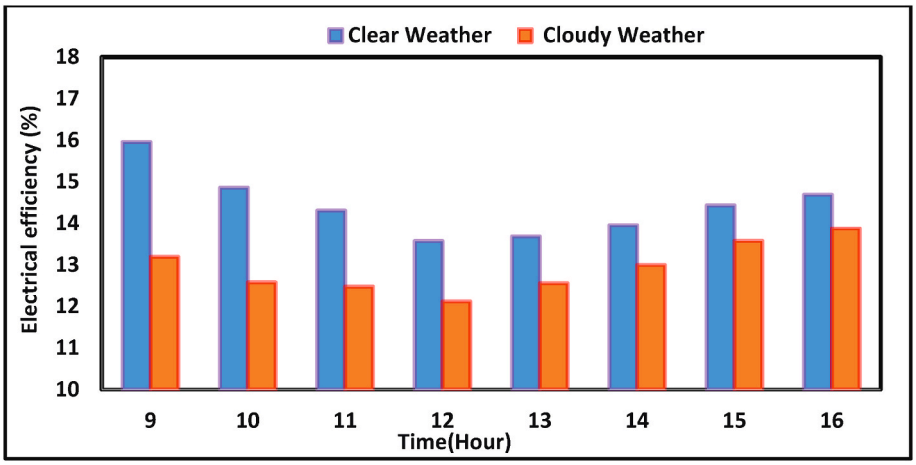


Fig (13). Electric efficiency in clear and cloudy weather.

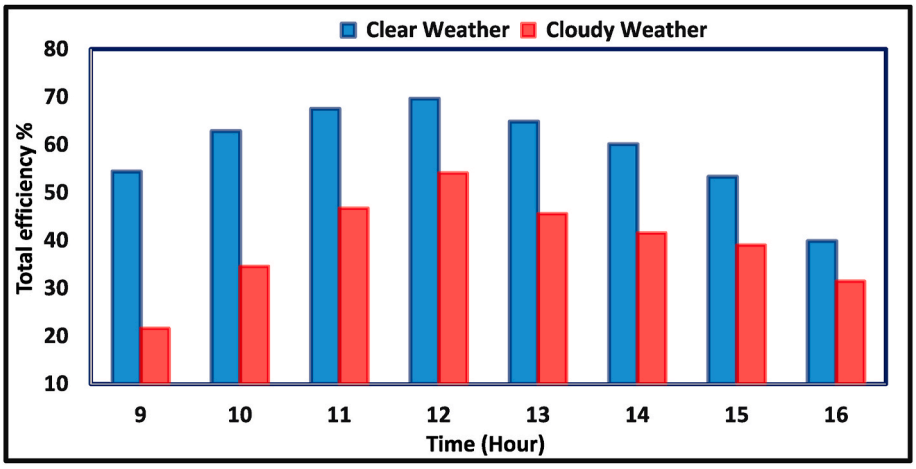


Fig (14). Total efficiency in clear and cloudy weather.

collector, where the thermal efficiency of a clear day reached an amount of (38.45 %) and a cloudy day reached an amount of(8.43)% at 9 a.m. at the beginning of the test, then the intensity of solar radiation begins to increase, the thermal efficiency increases to reach in clear weather by (56.08 %), and in cloudy weather, it reached (42 %) at noon, and then the radiation intensity decreases solar efficiency decreases with it to reach on a clear day (25.22 %) and a cloudy day reached (17.60 %) at 4 p.m. It was noticed that the thermal efficiency of a clear day is more than that of a cloudy day. This is due to the fact that the solar collector stores heat in a larger amount in clear weather, which leads to an increase in thermal efficiency. On the contrary, on a cloudy day, the solar collector absorbs less heat due to the lack of sunlight, which reduces thermal

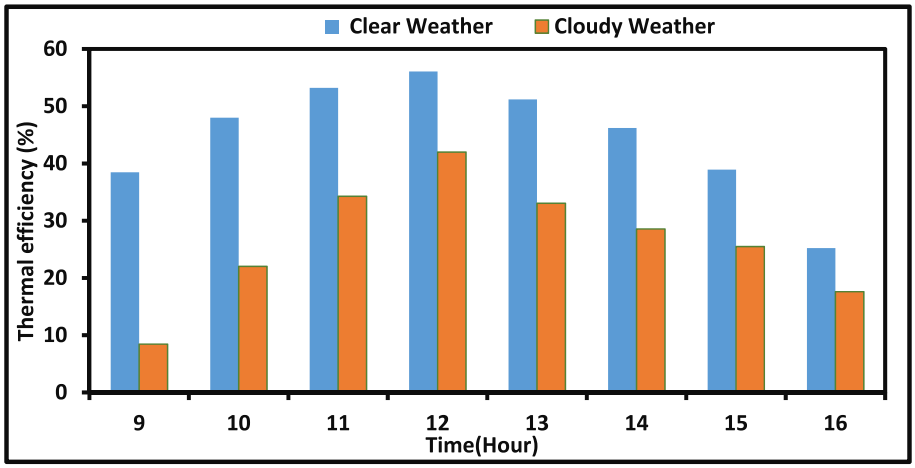


Fig (15). Thermal efficiency in clear and cloudy weather.

efficiency, as shown in Figure (15).

7. Conclusion

From the results obtained, it has concluded the following:

1 -The temperature of the PV panels in clear weather is higher than the temperature of the panels on a cloudy day due to the absence of solar radiation, which means the intensity of radiation is low in cloudy weather, where the highest temperature of the panels in cloudy weather reached (37.40 °C).
2 -the speed of the air coming out of the solar collector on a clear weather day is higher than on a cloudy weather day, where the air speed reaches for the 27th day with clear weather (1.54 m/s). In contrast, on 28 December, in cloudy weather (1.26 m/s) at noon because the radiation intensity is low in overcast weather, which makes the temperature of the solar panels low. So, the air inside the solar collector heats a little, which makes its speed low.
3 -The electrical energy generated on a clear day is higher than the electrical energy on a cloudy day, as the electrical energy reached the highest value for 27 December with non-cloudy weather by 341.92 W while on 28 December with cloudy weather (187.88)Watts, as well as the kinetic power of 27 December with clear weather higher than the kinetic power of 28 December with a cloudy weather as it reached (17.212 mW) with clear weather while with cloudy weather it reached (9.47 mW) at noon
4 -The results showed that the resulting electrical efficiency on 27 December with cloudless weather was higher than on 28 December with cloudy weather, where the value reached (15.96 %) with clear weather and (13.2 %) with cloudy weather at the test began at nine in the morning and reached (13.574 %) with clear weather and (12.12 %) with cloudy weather at noon.
5 -The thermal efficiency on a sunny and clear day is higher than the thermal efficiency on a cloudy day, where the highest value of the thermal efficiency on a clear day reached (56.08 %). In comparison, the efficiency value reached (42 %)on a cloudy day, as well as the overall efficiency of the hybrid solar chimney with sunny weather without clouds is higher than the efficiency on an overcast day, where the efficiency reached on 27 December with clear weather (69.65 %) and reached on 28 December with cloudy weather (54.12 %) at noon in the middle of the day.

CRediT authorship contribution statement

Firas Hussein Merie: Writing – original draft. **Omer K. Ahmed:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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