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RESEARCH ARTICLE

## ENERGY AND EXERGY ANALYSIS OF A SOLAR PHOTOVOLTAIC PERFORMANCE IN BAGHDAD

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### ABSTRACT

Photovoltaic modules usually generate electricity from a specific range of light frequencies and cannot cover the whole solar range of infrared, ultraviolet and diffused light. Hence, much of the striking sunlight energy is wasted by the solar modules. Thus, energy and exergy analysis were conducted to determine the performance of a solar photovoltaic module in Baghdad, Iraq. An engineering equation solver (EES) software has been using to develop the mathematical model. The environmental parameter of solar radiation, ambient temperature, and wind speed were obtained using Meteonom software. The operating parameters of a PV module includes normal operation cell temperature, open-circuit voltage, and short-circuit current were obtain from manufacturer data sheet. The results showed that, the exergy efficiency ranged from 10.8% to 15.8 %, while the energy efficiency varies between 15.71% to 15.74 % and the exergy destruction varied from 182.8 to 352.3 W/m<sup>2</sup> throughout the year. It has been found that, the first law efficiency was greater than second law efficiency. The differences between the two efficiencies from January to December are (25.6%, 31.1%, 25.1%, 25.6%, 17.8%, 9.6%, 9.6%, 1.2%, 0.5%, 0.45%, 2.5%, and 14.6%) respectively. While the exergy destruction through the same 12- months are (195.4, 233.5, 304.3, 352.3, 333.8, 292.9, 309.3, 274.6, 249.8, 215.9, 187.4, and 182.8) W/m<sup>2</sup>.

### KEYWORDS

Solar photovoltaic, Exergy analysis, Exergetic efficiency, Solar energy.

## 1. INTRODUCTION

Renewable energy, also known as clean energy, comes from natural sources or processes that are continually replenished. It is the main alternative to fossil fuels nowadays for their low air pollution and CO<sub>2</sub> emissions. A solar photovoltaic is a standout amongst the hugest and quickly developing technology that converts the solar radiation into direct current electricity by using semiconductors. Photovoltaic solar panel performance depends on solar cell temperature, output voltage, current, module area, ambient temperature and solar radiation intensity [1]. Among different renewable energy technologies, the photovoltaic (PV) is the best technology known and widely used for generating electricity. The use of photovoltaic for generating electricity developed from 400 to 600 billion kilowatt-hours from 2010 to 2017 [2]. A group of researchers evaluated the energy and exergy performance of a photovoltaic/thermal (PV/T) collector integrated with a greenhouse in India [3]. The results showed that yearly exergy thermal has been obtained to be 12.8 kWh, yearly exergy input to the greenhouse was calculated to be 21291 kWh and the total exergy output during 2006–2007 was 728.8 kWh. The exergy efficiency for the PV/T system was 4%. From the analysis, it was found that maximum monthly electrical generation occurs in March while the minimum occurs in August. A researcher analyzed a (PV/T) collector with and without glass cover by using energy and exergy model [4]. It is clear that the energetic efficiency of the glazed collector was found always better than the unglazed collector. To maintain high exergy efficiency, unglazed PV/T system would be favorable when the packing factor, ratio of water mass to collector area, and wind velocity increased. In other hand, the increase of on-site radiation or ambient temperature led to choose a

glazed PV/T system. The energy and exergy analysis for four different Indian cities of a hybrid micro-channel photovoltaic thermal (MCPVT) module and a single channel photovoltaic thermal (SCPVT) module were investigated by a previous scholar [5]. The results showed that the thermal gain of MCPVT increased over SCPVT by (70.62% - 74.05%).

The overall annual exergy gains of MCPVT ranged from (60.19% - 63.47%) higher than SCPVT module. The exergy efficiency of MCPVT was higher than SCPVT by (57.61% - 63.19). A researcher investigated the performance of the photovoltaic system under full and no-load conditions for a DC refrigerator. For no load condition, the average photovoltaic energy and exergy efficiencies in May were found to be 8.4 and 11.4% respectively. In the case of a full load condition, the average photovoltaic efficiencies of energy and exergy were 8.2 and 11.2% respectively in the same month [6]. A previous researcher theoretically analyzed the exergy life cycle and compared the performance of three unique setups, nanofluids-based PV/T, a standard PV and PV/T [7]. They announced that the nanofluids-based PV/T demonstrated the best execution contrasted with the standard PV and PV/T. At the ideal estimation of solar radiation, nanofluid-based PV/T created 1.3 MW h/m<sup>2</sup> of high-grade exergy every year while PV and PV/T were 0.36, 0.79 MW h/m<sup>2</sup>, respectively. The lowest exergy payback time of 2 years was due to the nanofluid-based PV/T. A recent scholar investigated two grid-connected photovoltaic systems monocrystalline silicon (c-Si) and copper-indium-diselenide (CIS) that located in Malaysia [8]. Results have demonstrated that the CIS system had a higher efficiency than the c-Si system by 23. The minimum

efficiency occurred in September for c-Si with 9.3 % and in August for CIS with 11.3 %. The maximum efficiency occurred in February for c-Si with 12.3 % and 14.4 % for CIS. This work aims to evaluate the performance of a photovoltaic solar for the whole year in Baghdad according to energy and exergy analysis.

## 2. CASE STUDY

The study was conducted in Iraq, Baghdad (33.3 N latitude, 44.2 E longitude). The analysis has been developed by using (EES) software. The environmental parameter of solar radiation, ambient temperature, and wind speed were obtained using Meteorom software. The operating parameters of (infinity KD - P260) PV module were obtained from manufacturer data sheet as listed in Table 1.

**Table 1:** Manufacturer data sheet for (infinity KD - P260) PV module.

Current at maximum power ( $I_m$ )	Amp.	8.5
Voltage at maximum power ( $V_m$ )	volt	30.62
Short circuit current ( $I_{sc}$ )	Amp.	9.04
Open circuit voltage ( $V_{oc}$ )	volt	37.98
Normal operation cell temperature (NOCT)	°C	46-50
Weight	kg	18.5
Dimension	mm	1650*992*35

## 3. ENERGY AND EXERGY ANALYSIS

Electrical efficiency is quantifying as the ability of a solar panel to convert the sunlight into electricity. This is done when sunlight interacts with silicon cells inside a solar panel to generate the electrical current. The electrical efficiency of a solar panel can be calculated as the electrical power that has been converted by the panel to the maximum power that comes from the solar radiation if it was all converted to electricity [9,10].

$$\eta = \frac{\text{power}}{G_t * A} \quad (1)$$

Where  $G_t$  is the solar radiation,  $A$  is the panel's area and power can be calculated by:

$$\text{power} = I * V * FF \quad (2)$$

The current and voltage of the PV module can be expressed as:

$$I = I_{sc} * G_t (kW) \quad (3)$$

$$V = V_{oc} - 0.0023 * \text{no. of cell} * (T_c - 25) \quad (4)$$

Where  $I_{sc}$  is the short circuit current while  $V_{oc}$  is the open circuit voltage. The solar panel temperature  $T_c$  can be expressed by:

Temperature of PV module ( $T_c$ ) can be estimated as [10]

$$T_c = T_a + \frac{NOCT-20}{0.8} * G_t (kW) \quad (5)$$

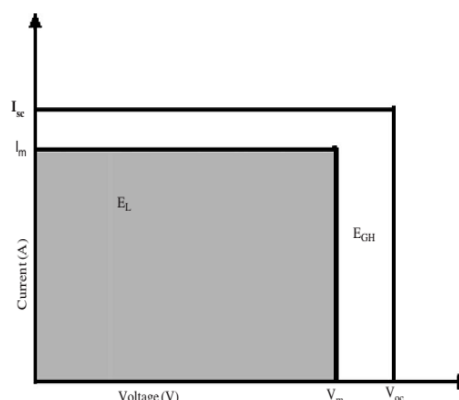
The Nominal Operating Cell Temperature (NOCT) is defined as the temperature of the panel reached when it is open circuit assuming 800W/m<sup>2</sup> irradiance, 20°C ambient temperature and wind speed of 1m/s with an open PV back side.

The fill factor represents the most extreme power transformation effectiveness of the PV modules and it can be calculated using the below equation [11].

$$FF = \frac{I_m * V_m}{I_{sc} * V_{oc}} \quad (6)$$

Where  $V_m$  and  $I_m$  are the voltage and the current of the PV module at maximum power.

On the other hand, the second law of the thermodynamics was basically deals with the Exergy, is characterized as maximum helpful work that is extracted from a system. The electrical power of the PV modules is the result of the current and the voltage output from the device. This transformation productivity is anything but a steady. In any case, there is a most power, where the voltage is  $V_m$ , which is not as much as the open-circuit voltage,  $V_{oc}$  yet near it, and the current is  $I_m$ , which is less the cut off,  $I_{sc}$  however near it too (Fig. 1)



**Figure 1:** I-V curve

Exergy investigation procedure use for energy and mass conservations standards with the 2<sup>nd</sup> law for the investigation outline and change of energy and different system. Exergy is characterized as the greatest measure of useful work that can be delivered by a device as it comes to equilibrium with a reference condition [12]. The general type of exergy for a control volume for the Pv modules as

$$Ex_{out} = Ex_{el} - Ex_{th} \quad (7)$$

Where  $Ex_{out}$ ,  $Ex_{el}$ , and  $Ex_{th}$  are the exergy of output, electrical, and thermal respectively.

$$Ex_{el} = \text{Power} \quad (8)$$

$$Ex_{th} = Q * \left[ 1 - \left( \frac{T_c}{T_a} \right) \right] \quad (9)$$

Where  $Q$  represents heat losses from the PV cell, can be estimation by

$$Q = U * A * (T_c - T_a) \quad (10)$$

The overall heat transfer coefficient of PV module ( $U$ ) includes convection heat transfer coefficient ( $h_{conv}$ ) and radiation heat transfer coefficient ( $h_{rad}$ )

$$U = h_{conv} + h_{rad} \quad (11)$$

Convective coefficient

$$h_{conv} = 2.8 + 3 * V_w \quad (12)$$

Where  $V_w$  is the wind speed.

And radiation heat transfer coefficient between PV module and atmosphere

$$h_{rad} = \epsilon * \sigma * (T_{sky} + T_c) * (T_{sky}^2 + T_c^2) \quad (13)$$

$\epsilon$  Emissivity of the panel (0.9)

$\sigma$  Stefan Boltzmann's Constant ( $5.67 * 10^{-8}$ ) (W/m<sup>2</sup>-K<sup>4</sup>)

$T_{sky}$  is the sky's temperature evaluated using Daguette's formula

$$T_{sky} = [T_a^4 * (1 - 0.261 * \exp(-0.000777 * (T_a - 273)^2))]^{0.25} \quad (14)$$

The exergy input for a PV module is given by the petela theorem it [13]

$$Ex_{in} = G_t * A * \left[ 1 - \frac{4}{3} * \left( \frac{T_a}{T_{sun}} \right) + \frac{1}{3} * \left( \frac{T_a}{T_{sun}} \right)^4 \right] \quad (15)$$

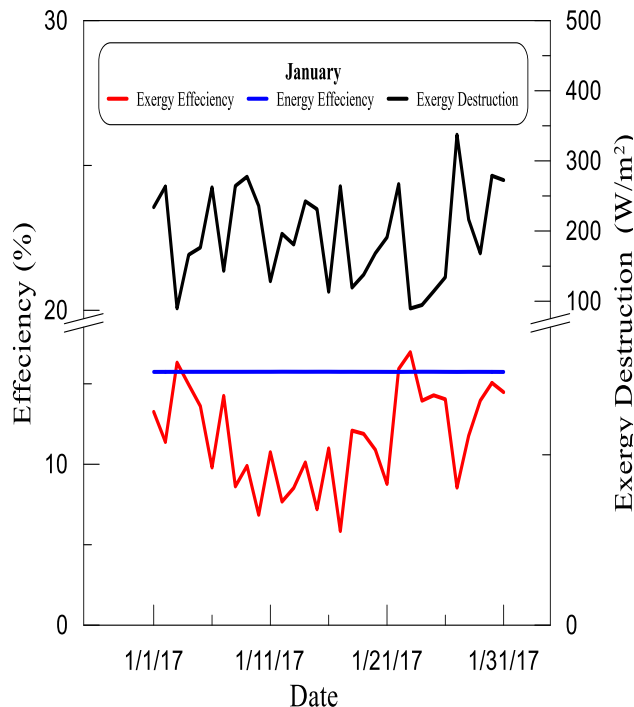
Sun temperature ( $T_{sun} = 6000 K$ )

As detailed in the exergy efficiency is given as [14,15]:

$$\eta_{ex} = \frac{Ex_{out}}{Ex_{in}} \quad (16)$$

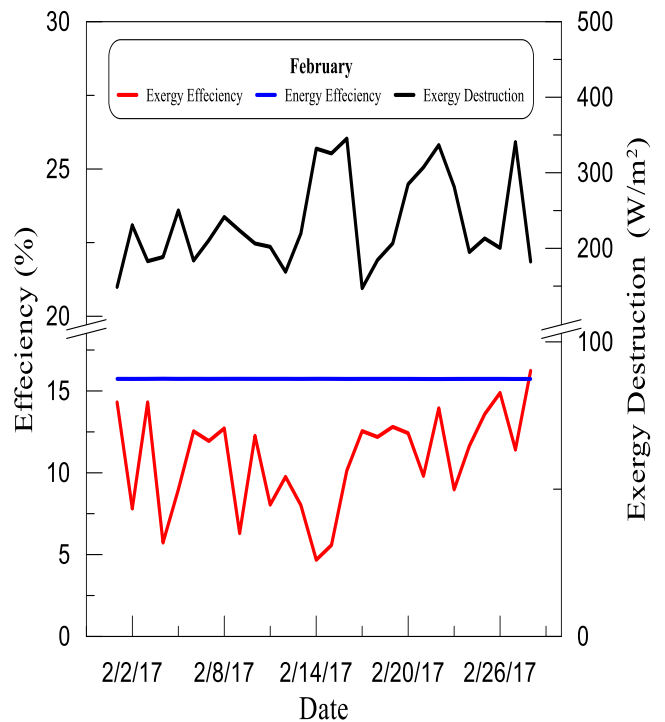
#### 4. RESULT AND DISCUSSION

The PV module was analysis by applied energy and exergy models. Exergy efficiency is most convenient, reliability, effective, and more efficient tool than the energy efficiency for estimation the efficiency of the PV module. All figures from 2 to 13 show the destruction of solar PV exergy, energy and exergy efficiencies for the PV module through the year, for all figured constant value of energy efficiency even though the solar intensity was changed through the year. The augmentation in the quantity of photons attracting solar PV module prompts increment the current. The solar PV module performance is adversely influenced by the module temperature. As increase in the temperature of module, the short circuit current was increase while rapidly decreasing happing in open-circuit voltage. This is on the grounds that the expansion in temperature prompts the decrease in the band hole of the characteristic semiconductor. The energy efficiency was almost constant due to the fact that the power increases with the increase of the solar radiation. The exergy efficiency is inversely proportional to the exergy destruction. The exergy destruction represents the thermal losses of the system due to the increase of ambient and cell temperatures. Also the clouds, dust and gases that contained in air effect on its. The variation of the destruction of solar PV exergy, energy and exergy efficiencies ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ ) - January was show in figure 2, It can be seen that the maximum values of ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ ) were 337.3  $W/m^2$ , 15.74%, 16.9 % respectively, while the minimum values were 89.5  $W/m^2$ , 15.73%, 5.8% respectively.

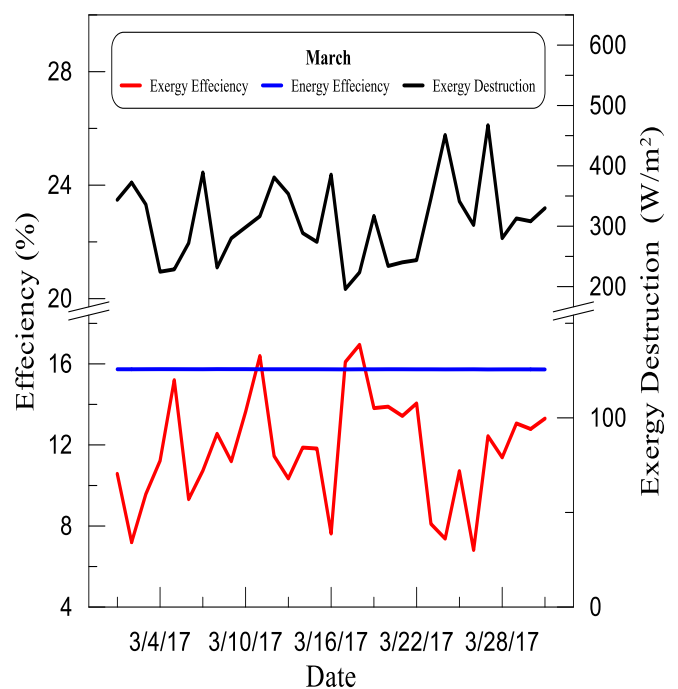


**Figure 2:** Destruction of solar PV exergy, energy and exergy efficiencies - January

It can be display from Figure 3 that the maximum values of ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ ) - February were 345.2  $W/m^2$ , 15.74%, 16.3 % respectively, while the minimum values were 147.1  $W/m^2$ , 15.73%, 4.6% respectively. Figure 4 shows that the maximum values of ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ ) - March were 467.3  $W/m^2$ , 15.73%, 16.9 %, respectively, while the minimum values were 165.6  $W/m^2$ , 15.72%, 6.8% respectively.



**Figure 3:** Destruction of solar PV exergy, energy and exergy efficiencies - February



**Figure 4:** destruction of solar PV exergy, energy and exergy efficiencies - March

The maximum and minimum variation of ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ ) - April was show in figure 5, the results indicated that the maximum values were 479.8  $W/m^2$ , 15.73%, 16.7 % respectively, while the minimum values were 205.9  $W/m^2$ , 15.71%, 7.3%, respectively. The maximum and minimum variation of ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ ) - May was show in figure 6, the results indicated that maximum values were 431  $W/m^2$ , 15.72%, 17.7 % respectively, while the minimum values were 145.8  $W/m^2$ , 15.71%, 7.5%, respectively. It can be display from Figure 7 that the maximum values of ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ ) - June were 342.4  $W/m^2$ , 15.72%, 17.8 % respectively, while minimum values were 239.8  $W/m^2$ , 15.71%, 7.8%, respectively.

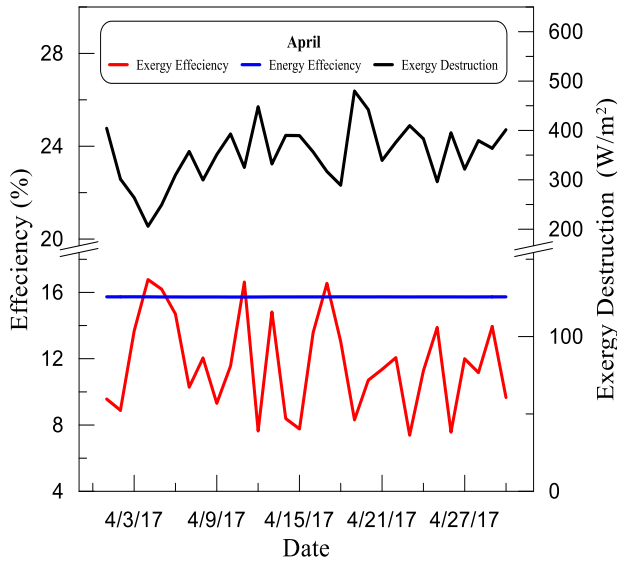


Figure 5: Destruction of solar PV exergy, energy and exergy efficiencies - April

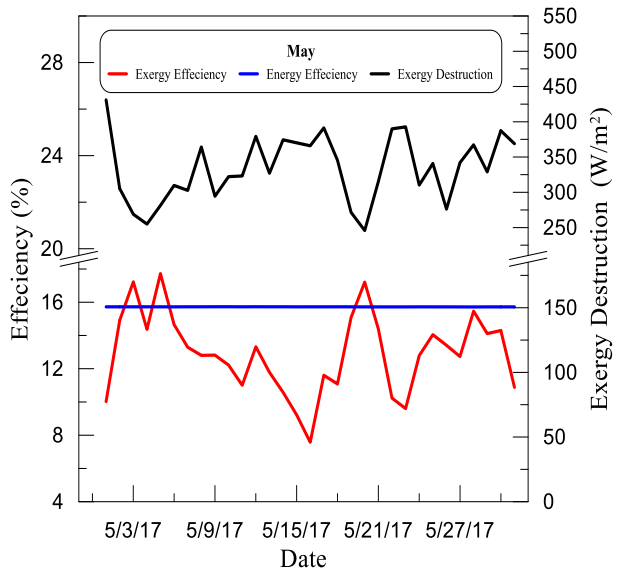


Figure 6: Destruction of solar PV exergy, energy and exergy efficiencies - May

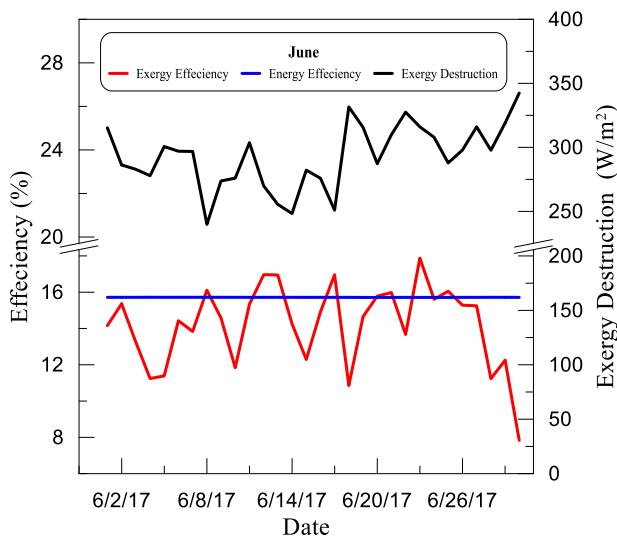


Figure 7: Destruction of solar PV exergy, energy and exergy efficiencies - June

The maximum and minimum variation of  $(Ex_{des}, \eta, \eta_{ex})$  - July was show in figure 8, the results indicated that the maximum values were 354.1 W/m<sup>2</sup>, 15.71%, 17.6 %respectively, while the minimum values were 218.2 W/m<sup>2</sup>, 15.7 %, 10.2 %respectively.

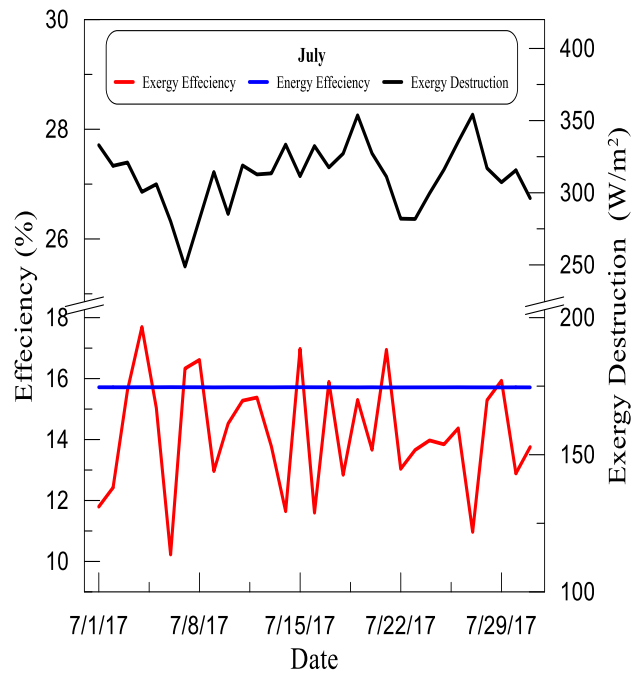


Figure 8: Destruction of solar PV exergy, energy and exergy efficiencies - July

It can be display from Figure 9 that the maximum values of  $(Ex_{des}, \eta, \eta_{ex})$  - August were 322 W/m<sup>2</sup>, 15.72%, 18.4 % respectively, while minimum values were 228.9 W/m<sup>2</sup>, 15.71%, 10.7 % respectively.

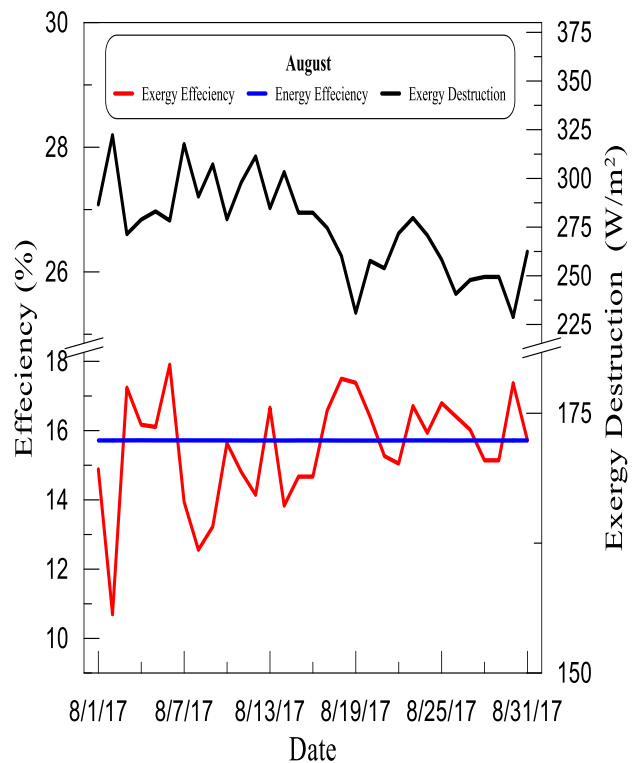
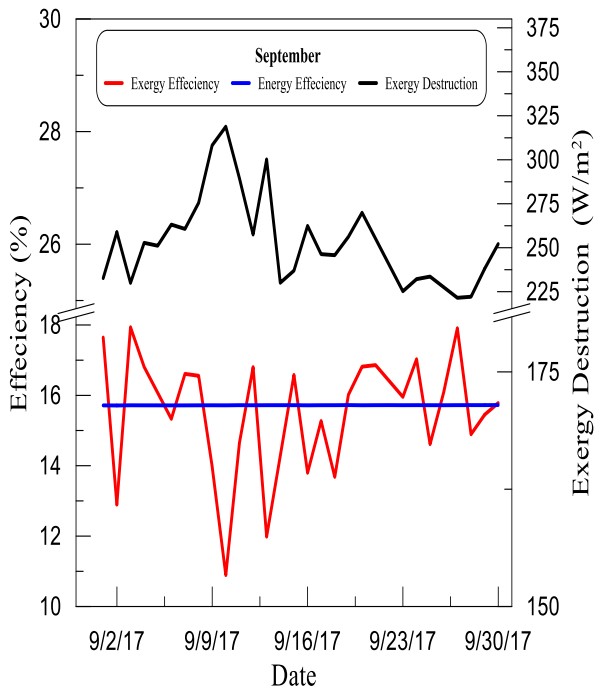


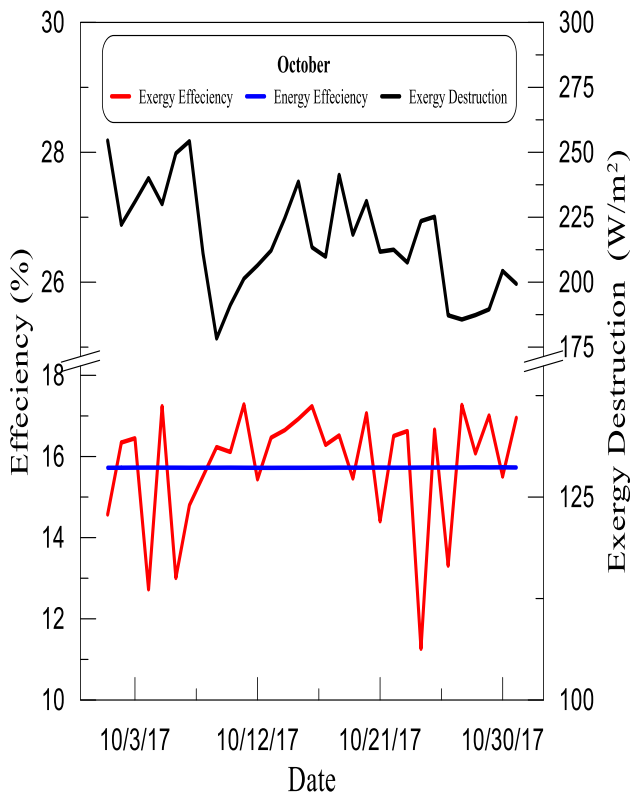
Figure 9: Destruction of solar PV exergy, energy and exergy efficiencies - August.

Figure 10 shows that the maximum values of  $(Ex_{des}, \eta, \eta_{ex})$ - September were 318.8 W/m<sup>2</sup>, 15.72%, 18.6 % respectively, while the minimum values were 190.8 W/m<sup>2</sup>, 15.71%, 10.8% respectively.



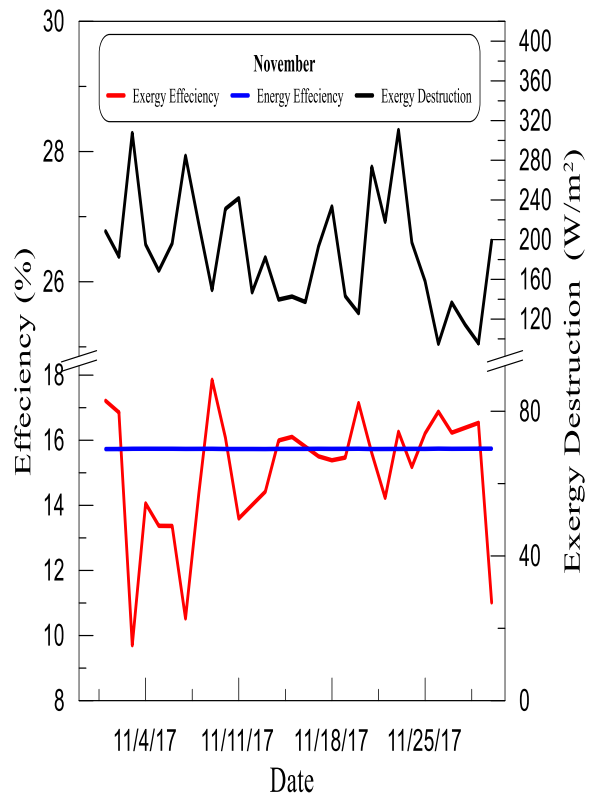
**Figure 10:** Destruction of solar PV exergy, energy and exergy efficiencies – September

It can be notice from Figure 11 that the maximum values of ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ ) - October were 254.5 W/m<sup>2</sup>, 15.73%, 17.2 %, respectively, while minimum values were 178.3 W/m<sup>2</sup>, 15.72%, 11.2% respectively.

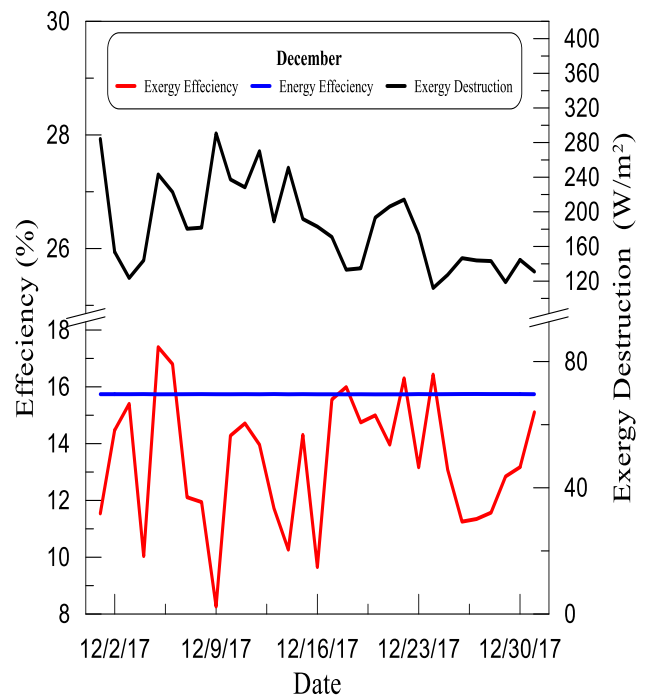


**Figure 11:** Destruction of solar PV exergy, energy and exergy efficiencies – October.

It can be seen from Figure 12 that the maximum values of ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ ) - November were 310.4 W/m<sup>2</sup>, 15.74%, 18.3 % respectively, while minimum values were 190.8 W/m<sup>2</sup>, 15.72%, 9.7% respectively. Figure 13 shows that the maximum values of ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ )- December were 290.6 W/m<sup>2</sup>, 15.74%, 17.3 % respectively, while the minimum values were 111.9 W/m<sup>2</sup>, 15.73%, 8.2% respectively.



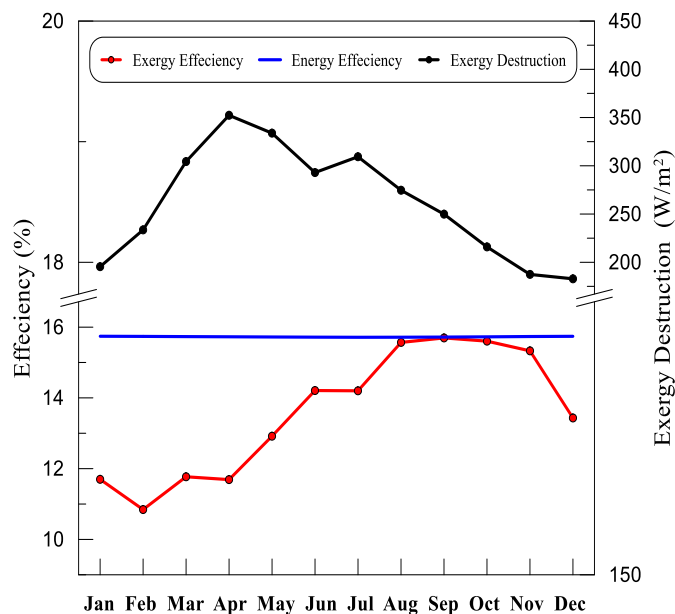
**Figure 12:** Destruction of solar PV exergy, energy and exergy efficiencies - November



**Figure 13:** Destruction of solar PV exergy, energy and exergy efficiencies – December

The variation of the destruction of solar PV exergy, energy and exergy efficiencies ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ ) - throughout the year was show in figure 14, the results indicated that the ( $Ex_{des}$ ) throughout the whole year from January to December are are (195.4, 233.5, 304.3, 352.3, 333.8, 292.9, 309.3, 274.6, 249.8, 215.9, 187.4, and 182.8) W/m<sup>2</sup>. Also its can be notice that the energy efficiency through the same 12- months (15.74%, 15.73%, 15.72%, 15.72%, 15.71%, 15.71%, 15.71%, 15.71%, 15.72%, 15.73%, 15.74%) respectively, while the exergy efficiency throughout the whole year are (11.6%, 10.8%, 11.7%, 11.6%, 12.9%, 14.2%, 14.2%, 15.5%, 15.63%, 15.66%, 15.3%, 13.4%) respectively.

Also, it can be indicated from the figure that the energy performance was greater than that of exergy throughout the year, where the efficiency differences between them throughout the whole year from January to December are (25.6%, 31.1%, 25.1%, 25.6%, 17.8%, 9.6%, 9.6%, 1.2%, 0.5%, 0.45%, 2.5%, and 14.6%) respectively.



**Figure 14:** The variation of destruction of solar PV exergy, energy and exergy efficiencies ( $Ex_{des}$ ,  $\eta$ ,  $\eta_{ex}$ ) - throughout the year

## 5. CONCLUSION

In this paper, the energy and exergy analysis of the Solar Photovoltaic (infinity KD – P260) at Baghdad (latitude = 33.3 N and longitude = 44.2 E). The conclusions are:

1. The exergy efficiency ranges from 10.8% to 15.8 %, while the energy efficiency varies between 15.71% to 15.74 % and the exergy destruction varied from 182.8 to 352.3 W/m<sup>2</sup> throughout the year.
2. The efficiency of energy was greater than efficiency of exergy throughout the year,
3. The exergy destruction through the same 12- months are (195.4, 233.5, 304.3, 352.3, 333.8, 292.9, 309.3, 274.6, 249.8, 215.9, 187.4, and 182.8) W/m<sup>2</sup>.
4. The energy efficiency throughout the whole year from January to December are (15.74%, 15.73%, 15.73%, 15.72%, 15.72%, 15.71%, 15.71%, 15.71%, 15.72%, 15.73%, 15.74%) respectively.
5. The exergy efficiency throughout the whole year from January to December are (11.6%, 10.8%, 11.7%, 11.6%, 12.9%, 14.2%, 14.2%, 15.5%, 15.63%, 15.66%, 15.3%, 13.4%) respectively
6. The efficiency differences between energy and exerg analsis throughout the whole year from January to December are (25.6%, 31.1%, 25.1%, 25.6%, 17.8%, 9.6%, 9.6%, 1.2%, 0.5%, 0.45%, 2.5%, and 14.6%) respectively.

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