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INVESTIGATION OF THE ENERGY OUTPUT OF PARABOLIC TROUGH RACKS BASED ON USING DIFFERENT RHOMBOID LAYOUT

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ABSTRACT

Energy problems are the most prominent problems in the world these days. Hence, the process of continuous improvement of energy production technology and its development has become the goal of all countries in the world, including Jordan. This study is based on verifying the energy production quantities of concentrated solar energy systems - parabolic trough racks using different arrangement patterns of the solar receiver fields. Where it was found through this study that the arrangement patterns of the fields have an impact on the quantities of energy produced from the concentrated solar power plants - parabolic trough racks.

Keywords: energy, concentrated solar energy systems, solar receiver fields.

1. INTRODUCTION

Energy is of the greatest importance these days in achieving internal stability for all countries, as life today depends on the energy in its various forms and sources of production. From here begins talking about energy security in all forms in terms of research on various traditional and renewable energy sources, and the availability of resources is considered the basis for stability in the general life system. Parallel to the search for sources of energy production of various kinds, the processes of continuous development and improvement of the available systems also emerge with the aim of maximizing the energy product from them [1-5]. The development and improvement mechanisms are different, including design and preliminary studies, as well as the best ways to integrate systems with each other, and it also includes continuous development by keeping pace with the latest technologies in order to improve and increase production processes. The development patterns in energy production varied in two directions. The first is to replace traditional sources with renewable sources and the second is to replace old technology with advanced modern technology [6-37].

In the division of the processes of improvement in energy production the research and transformation to renewable sources instead of traditional sources, to achieve stability through the sustainability of production stemming from the sustainability of the sources [38]. Here, various types of renewable energy emerge, which include solar energy, wind energy, nuclear energy, geothermal energy, wave energy, tidal energy, and many more [39-41]. The second way in the processes of improving energy production includes the development and improvement of old systems with the help of modern technology, which includes the use of combined cycles instead of simple cycles in the production of energy from traditional power plants, the development of engineering designs and an attempt to create the best operating environment in order to maximize the energy product. In the search for renewable resources and the development of old systems, many methods of research and development have emerged and have become one of the most important aspects of life these days [42-45].

In the search for renewable energy sources, we find that solar energy is the most likely to be used as a basic and main alternative to achieve sustainable energy production and stability for the countries of the world. The availability of solar energy in abundance at most parts of the world is the main reason for considering solar energy as a primary source of alternative sources of traditional energy, as there are many countries around the world that enjoy a high rate of sunshine hours as well as a high rate of solar radiation intensity [22, 46-49]. Jordan is one of the countries in the world fortunate with this type of renewable energy sources, as Jordan enjoys an average of sunshine hours that are not less than 6 to 7 hours during the worst days of the year with a high rate of solar radiation strength which is considered one of the highest among the countries of the world. Recently, Jordan has been heading as all countries in the world to secure the energy needs through the use of renewable energy [7, 8, 10-12, 15, 18, 22, 31, 46-50].

Many projects for energy production with renewable energy sources such as solar and wind energy have emerged, as Jordan tends towards these sources with great strength, as the percentage of dependence on these sources is from Jordan's total need for energy is about 20% these days [8, 10-12, 15, 17, 18, 42, 51-53]. Jordan intends to expand it through vital projects that help with that, such as the Arab electrical grid line project between Jordan, Egypt, Syria, and Iraq, with the aim of achieving grid stability and increasing reliance on renewable energy. Also, there are many legislations that help increase reliance on renewable energy by imposing some engineering codes that are relatively dependent on renewable energy in various applications [42, 54].

Many ways have emerged to take advantage of solar energy in energy production, as it has become possible to produce energy directly from solar energy by using photovoltaic cells that convert solar energy into electrical energy directly. Concentrated solar energy systems have also emerged, which are one of the most important solar applications in energy production, as they have the ability to produce very high temperatures by concentrating solar rays. Many of the concentrated solar energy systems have recently started to appear as a solution and a basic alternative to using solar energy, including solar towers, dish systems, Fresnel systems, and parabolic trough systems, which are the main points of this study [10, 15, 18, 31, 46-49].

The parabolic trough system is considered one of the concentrated solar systems and is widely used because of its distinctive characteristics in the production of energy as it works to focus the solar rays on a line as a target for this concentration and its temperature reaches relatively high degrees' comparison with the other concentrated solar systems. The thermal product is used to rotate a steam turbine to produce energy in the result. From here emerges the need to study the components of this system and try to develop and improve as much as possible with the aim of maximizing production from it [55, 56]. One of the ways used to develop these systems is to develop solar tracking systems so that they become corresponding to the solar rays for the longest time possible and at the best angles aiming to obtain the greatest benefit from these systems as well as developing the materials that it is fabricated from it and developing integration between the components of the concentrated station completely and also study the development of parabolic trough system arrangement mechanisms in solar fields to study the effect of different arrangements on energy production from these systems[57-61].

Many researchers have studied the improvement of the energy production from concentrated solar energy systems, including Alrwashdeh, where he studied the effect of the blocking solar panels on each other and linking them to energy production [18]. He also studied the effect of the different orientations in the Fresnel systems and their effect on energy production [16].

In this study, the effect of the different rhomboid layouts in concentrated solar energy systems - parabolic trough and the effect of these rhomboid layouts on the energy production from it will be highlighted.

2. METEOROLOGICAL CONDITIONS AND GEOGRAPHICAL IN MA'AN-JORDAN

The Jordanian governorate of Ma'an is the largest governorate in Jordan, located in the far south about 200 km from Amman the capital of Jordan within the longitude 35° east and latitude 30 north. Ma'an Governorate is characterized by very high sunshine hours, which exceeds 3000 hours annually, and a rate of solar radiation strength is the highest in Jordan and among the highest in the world. Figure-1 shows the sunshine hours in Ma'an - Jordan.

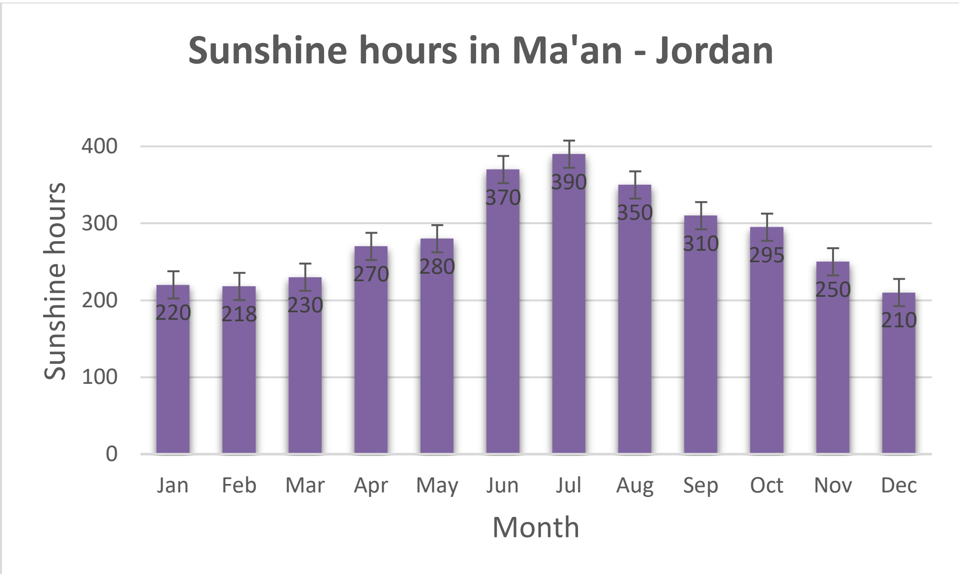

Figure-1. Sunshine hours in Ma'an - Jordan around the year.

The large area of Ma'an governorate, in addition to the number of sunshine hours and strength, is one of the most important factors that make this governorate the right place to invest in it by using different solar energy systems. The area of Ma'an Governorate is about 32,832 km2. as is clear from the Figure-2A. The temperature distribution over the year in the Ma'an governorate is illustrated in the Figure-2B. Ma'an Governorate is considered one of the provinces with a desert character and expansive lands that are easy to exploit for the purposes of exploiting solar energy. Among the problems that are considered an obstacle to the use of different solar energy systems in Ma'an governorate is the dense dust that crosses the governorate at different times of the year, which leads to blocking the sun's rays from the solar energy systems and dispersing those rays.

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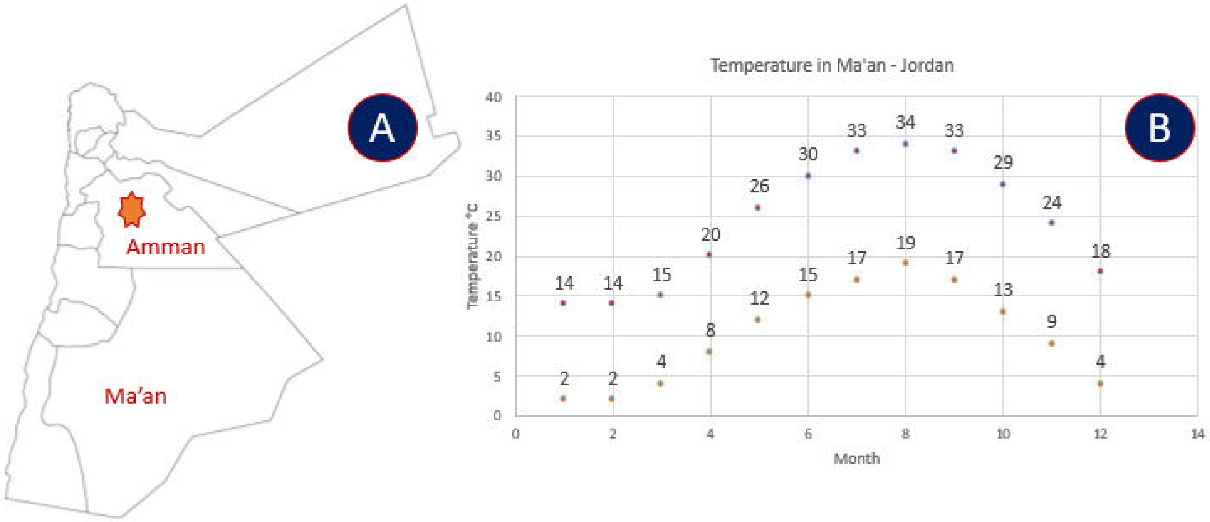

Figure-2. Jordan map with Ma'an governorate highlighted (A), Temperature distribution in Ma'an governorate around the year (B).

3. CONCENTRATED SOLAR POWER CSP CALCULATIONS

Parabolic trough systems are used in the processes of focusing direct solar rays on a receiving tube to raise the temperature of the material inside it, then collect the material with the thermal energy to be used to drive a steam turbine and produce the necessary energy. The parabolic trough system consists of many parts such as the ray reflectors in what is known as the mirrors, the receiver tube, the storage tank, the tracking systems, the cooling systems, the steam turbine, and finally the electric generator.

Practically the calculations of concentrated solar energy systems begin from the calculations of solar radiation, which is one of the most difficult engineering calculations due to the multiplicity of factors that affect it. Here, some calculations of solar radiation will be started, followed by calculations for concentrated solar power systems - Parabolic trough systems [31, 48].

The process of determining the exact position of the sun is the basis of solar calculations. Hence, solar declination is defined as the angular position of the sun at noon, relative to the equator, and is given by the unit of degrees. The calculation is done according to the equation below.

$$\delta = 23.45 \sin\left(2\pi \frac{284+n}{365}\right) \tag{1}$$

Where, n is a day of year (i.e. n =1 for Jan 1, n = 32 for Feb 1, etc.).

The solar hour angle is the displacement angularly of the sun east or west of the local meridian; morning negative, afternoon positive. The solar hour angle is equal to zero at solar noon and varies by 15 degrees per hour from solar noon. The sunset hour angle is the solar hour angle corresponding to the sunset. It can be calculated from the equation below.

$$\cos \omega_s = -\tan\phi \tan\delta \tag{2}$$

Where, δ is the declination, and ϕ is the site latitude.

The solar constant is the solar radiation power per unit area at the outer border of the Earth´s atmosphere with an amount of 1367 W/m^2. Regarding the amount of solar radiation outside the earth's atmosphere, it can be calculated through the equation below.

$$H_0 = \frac{24\times 3600 G_{sc}}{\pi}\left(1+0.033\cos\frac{360n}{365}\right)\times\left(\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right) \tag{3}$$

The calculations of concentrated solar energy systems are based on direct rays of sunlight, so that these systems have the ability to focus this type of rays only. Concentrated solar energy systems rely on solar tracking systems to make CSP systems face the longest possible period to the sun, and this tracking can be calculated through the equation below.

$$\tan s = \tan\theta_z |\cot(\gamma - \gamma_s| \tag{4}$$

Where, s is the zenith angle which is the angle between the line to the zenith and the optical plane. γ is the azimuth angle which is the mirroraperture orientation in relation to the horizon. γs is the solar azimuth angle which means that the mirror aperture is oriented to the east in the morning and to the west in the afternoon.

Concentrated solar energy systems - Parabolic troughs are exposed to many factors of energy loss, the most important of which are energy loss through optical, thermal loss, loss from support systems, and others. The energy loss from the optical losses is around 25 % of the direct irradiance, while the thermal energy losses

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constitute 15 %and the power block losses are 42%, parasitic energy consumption around 2%. Finally, the net electric output is around 16%.

The efficiency of concentrated solar systems - Parabolic trough is made up of the average efficiency of the subsystems that make it up. The Parabolic trough system is economical and, thermal efficiency ranges from 60-80%. The overall efficiency from collector to grid, i.e. (Electrical Output Power)/ (Total Impinging Solar Power) is about 15%.

4. RESULTS AND DISCUSSIONS

Solar radiation carries energy with it and is utilized through various solar energy applications in its various forms as well, such as a direct benefit by converting solar energy into electrical energy through photovoltaic systems or indirectly using concentrated solar energy systems. In this study, the focus of concentrated solar energy systems - Parabolic trough will be highlighted, and as is clear from the Figure-3, different rhomboid layouts have been used, and these layouts have an impact on energy production. Studying the different rhomboid layouts of the solar field helps to choose the best layouts for building a concentrated solar system and thus maximizing the energy production from it.

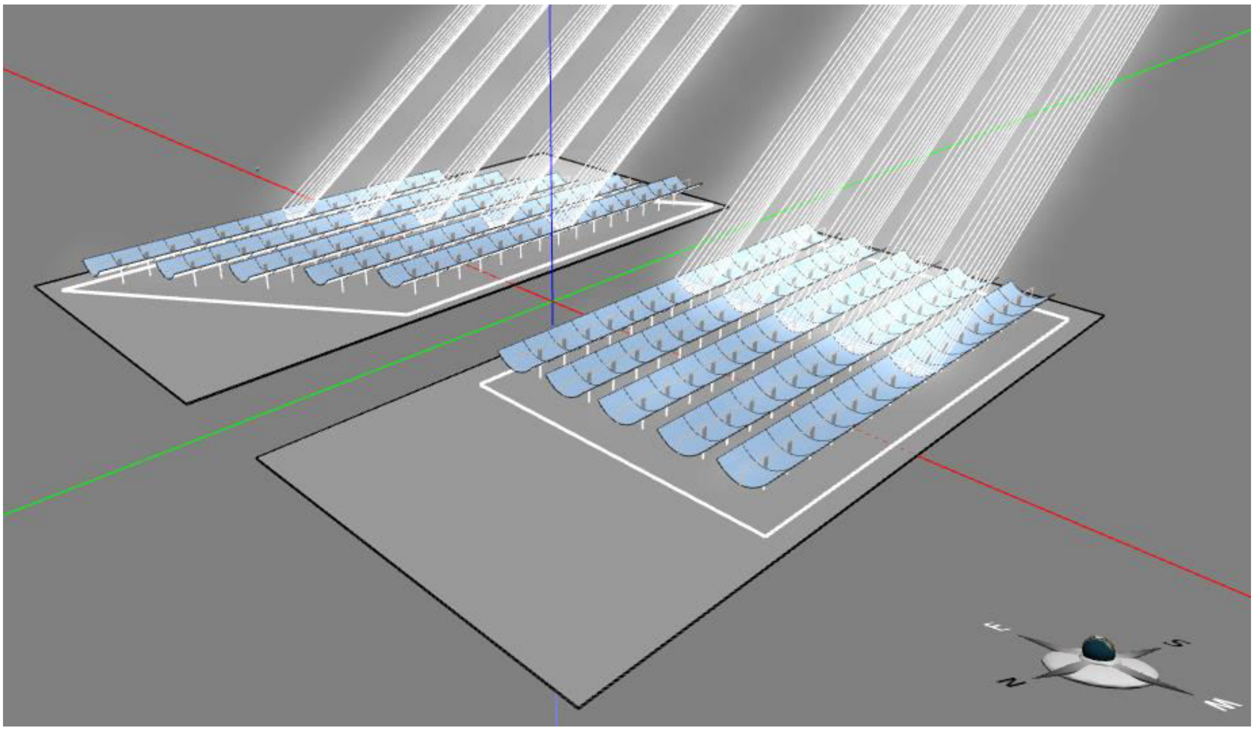

Figure-3. Concentrated solar energy systems - Parabolic trough field with different rhomboid layouts.

The design of solar energy systems is based on studying energy production during the worst days of the year in order to provide the energy requirement in the worst conditions. Figure-4A shows the rhomboid layout used in the concentrated solar energy system - Parabolic trough, which is the regular layout between the parts used, and the Figure-4B shows the rate of energy production from the regularly arranged rhomboid layout on the tenth of December, which is the worst day in solar radiation in the city of Ma'an - Jordan. The total energy production from the system is 664 kWh during the 10th of December based on the regularly arranged rhomboid layout.

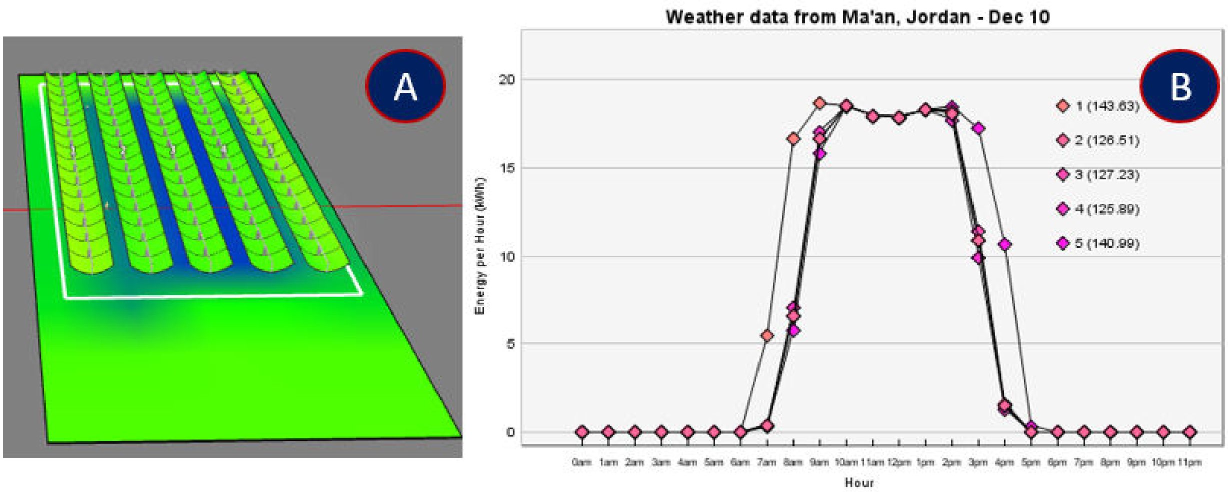

Figure-4. CSP- Parabolic trough with regular rhomboid layout (A), Energy production during 10th of Dec based on the regular rhomboid layout (B).

To develop and improve the energy production of concentrated solar systems - Parabolic trough, many layouts of the fields are being used. Figure-5A shows the second arrangement used, which is an irregular rhomboid layout of the parabolic trough field, and the Figure-5B shows the rate of energy production from the parabolic trough with the irregular layout during the worst solar radiation day of the year, which is the tenth of December. The power output from the irregular rhomboid layout is about 714 kWh.

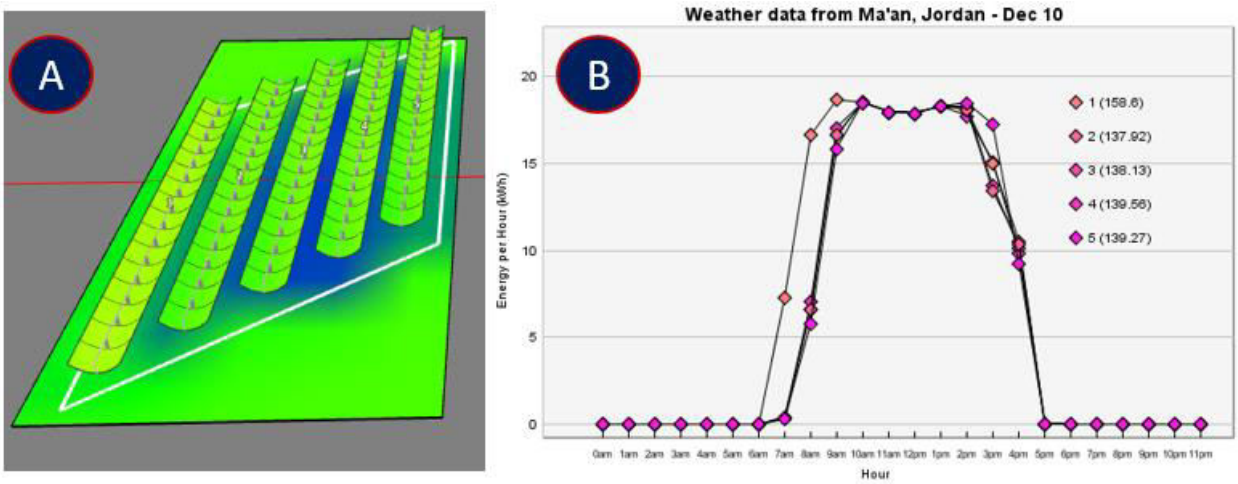

Figure-5. CSP- Parabolic trough with irregular rhomboid layout (A), Energy production during 10th of Dec based on the irregular rhomboid layout (B).

To measure the efficiency of using the different rhomboid layouts fields in the concentrated solar energy systems - Parabolic trough, the average annual energy production from these layouts is calculated and compared to each other, and then judged on the best rhomboid layouts that should be used to maximize the energy production of concentrated solar systems - Parabolic trough. It was found that the Parabolic trough system with the irregular rhomboid layout is the best in energy production at a rate of 504683 kWh/year compared to the parabolic systems with the regular rhomboid layout, in which the energy production reached 470546 kWh/year which means that the irregular layout is better in the energy production by 8%. The reason that irregularly rhomboid layout systems are the best in energy production is due to the reduction of the energy waste due to shade and blocking that occurs to the mirrors from each other, as part of the mirrors is a canopy and the rate of blocking outside the other mirrors which are not affected by this and here the energy production from the fields is maximized in the irregularly rhomboid layout. Figure-6A shows the energy production during the year from the regular rhomboid layout (A) and from irregular rhomboid layout (B).

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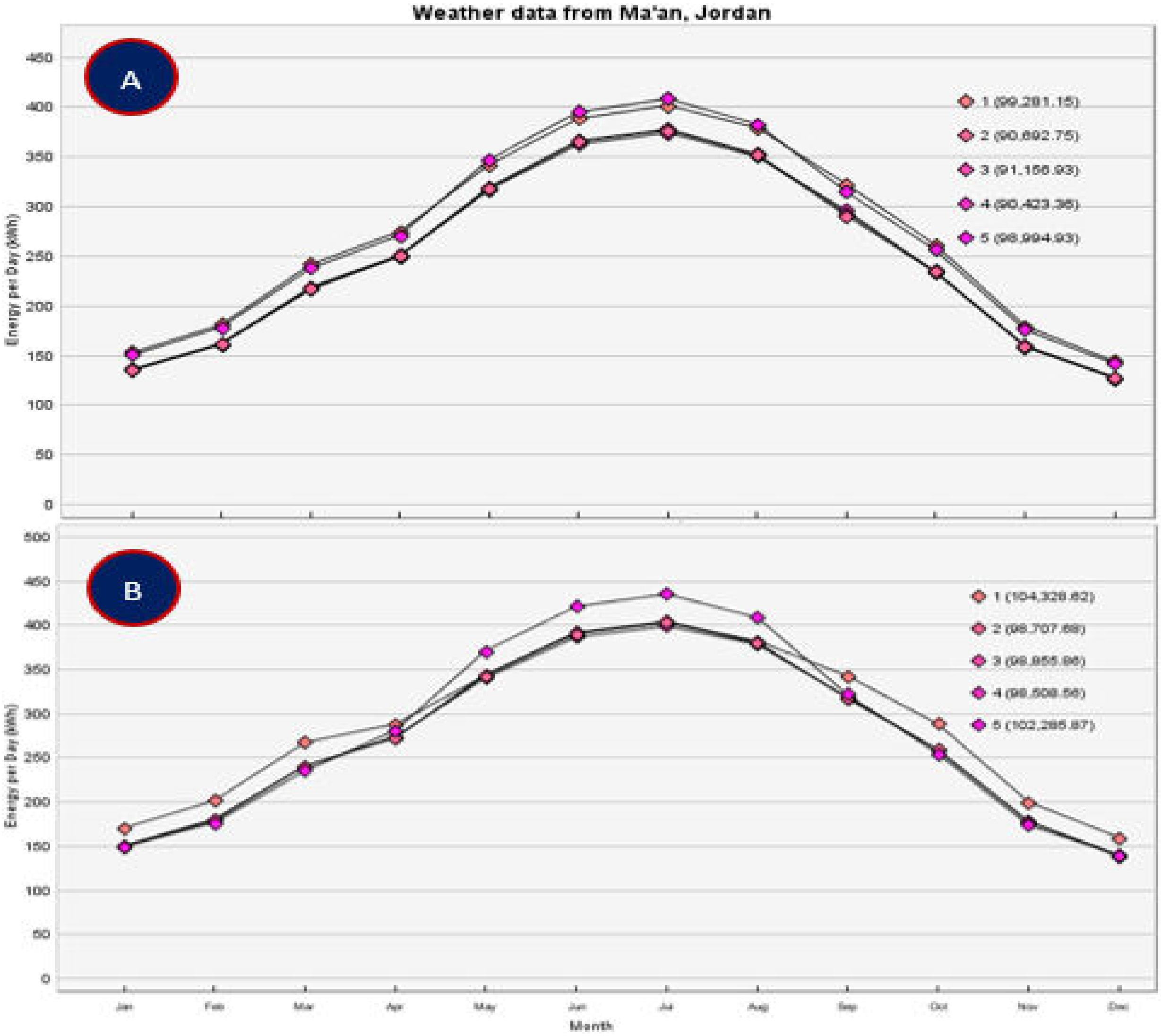

Figure-6. CSP- Parabolic trough energy production during the year from regular rhomboid layout (A), irregular rhomboid layout (B).

5. CONCLUSIONS

In this work, the energy productivity of concentrated solar systems - Parabolic trough was studied in a different rhomboid layout that included the regular and irregular rhomboid layout, and it was found that the energy production from the irregular rhomboid layout was greater than the regular rhomboid layout by a percentage of 8% throughout the year. The reason for the increase in energy production from the irregular layout compared to the regular layout is the reduction in the energy losses due to the shadow and the blocking between the mirrors and thus leads to the increase in productivity.

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