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Technical Assessment of Rooftop PV Configurations in Baghdad Using PVsyst and SketchUp

Walla Kareem Musa [1*], **Alaa Hussien Shneishil** [2]

[1,2] Physics department, College of education, Mustansiriyah University. Baghdad, Iraq.

E-*mail:* [1] wallakareem88@uomustansiriyah.edu.iq

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ABSTRACT

Solar photovoltaic (PV) systems are one of the best options to solve the electricity shortage in Iraq because the country has high solar radiation almost all the year. In this paper, many different rooftop PV systems were designed for a college building in Baghdad and tested by using SketchUp and PVsyst programs. The SketchUp software was used to make a 3D model of the building and to study the shading effect from nearby objects, while PVsyst was used to simulate the system performance and electrical output. The work included two types of solar panels (Monocrystalline and HJT), with both fixed and seasonal tilt angles, and two installation directions (portrait and landscape).

The effect of the distance between the rows of panels was also studied. To make the results closer to the real case, losses like dust, aging of the panels, and system shutdown time were added in the simulation.

The results showed that HJT panels gave higher energy production and better performance ratio compared with the monocrystalline ones. Also, using seasonal tilt increased the yearly energy by around 5%. Increasing the distance between panel rows helped to reduce shading and improve system efficiency, but it also reduced the total number of panels on the roof. In general, this work proved that the correct design of tilt angle, orientation, and spacing can improve the technical performance of rooftop PV systems under Baghdad climate, and using 3D modeling helps to get more realistic results.

التقييم الفني لتكوينات منظومات الطاقة الشمسية الكهروضوئية على الأسطح في بغداد باستخدام برنامجي PVSYST و SketchUp

ولاء كريم موسى، علاء حسين شنيشل

*Corresponding author.

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ملخص: أنظمة الخلايا الشمسية الكهروضوئية تعد من أفضل الحلول لمشكلة نقص الكهرباء في العراق، لأن البلاد تمتاز بإشعاع شمسي قوي خلال معظم أيام السنة. في هذا البحث، تم تصميم عدد من الأنظمة الشمسية على أسطح المباني لأحد مباني الكلية في بغداد، وتم اختبارها باستخدام برنامجي SketchUp و PVsyst . تم استخدام برنامج SketchUp لبناء نموذج ثلاثي الأبعاد للمبنى ودراسة تأثير الظلال الناتجة عن الأجسام القريبة، بينما استُخدم برنامج PVsyst لمحاكاة أداء النظام وحساب الطاقة الكهربائية المنتجة. تضمن العمل نوعين من الألواح الشمسية (أحادية البلورة Monocrystalline وتقنية HJT)) ، مع زاويتين للميول (ثابتة وموسمية)، وباتجاهين للتركيب (عمودي وأفقي). كما تمت دراسة تأثير المسافة بين صفوف الألواح. ولجعل النتائج أقرب إلى الواقع، أُضيفت في المحاكاة بعض الخسائر الحقيقية مثل تراكم الغبار، تقادم الألواح، وفترات توقف النظام عن العمل. أظهرت النتائج أن ألواح HJT أعطت إنتاجًا أعلى للطاقة وأداء أفضل مقارنة بالألواح الأحادية البلورة. كما أن استخدام الميل الموسمي زاد من الطاقة السنوية بنحو 5%. أما زيادة المسافة بين صفوف الألواح فقد ساعدت في تقليل الظلال وتحسين الكفاءة، لكنها في المقابل قللت عدد الألواح الممكن تركيبها على السطح. بشكل عام، أثبتت هذه الدراسة أن التصميم الجيد لزاوية الميل، واتجاه التركيب، والمسافات بين الصفوف يمكن أن يحسن الأداء التقني للأنظمة الشمسية فوق الأسطح في مناخ بغداد، وأن استخدام النمذجة ثلاثية الأبعاد يساعد في الحصول على نتائج أكثر واقعيةالعربية.

الكلمات المفتاحية: منظومة كهروضوئية، PVsyst، SketchUp، التظليل، ألواح HJT، نسبة الأداء الدراسة.

1. INTRODUCTION

Energy is an important part of the global economy, but still many developing countries continue to face difficulties in accessing reliable electricity infrastructure [1]. Nearly 40% of the electricity in a country is actually consumed by the residential building [2-3]. During the last decades, energy consumption has raised a lot because of new technologies and the increasing use of energy on different levels, which also bring with it more environmental problems [4]. To respond to these issues, the European Council in 2014 created a framework that targeted 27% of energy to be from renewable sources by 2030 [5]. Later, in 2015, more than 30 countries met in Paris Climate Conference, where they tried to keep the global temperature rise under 2°C, and also discussed the effects of climate change in 2020 [6]. Based on this, renewable energy resources appeared as a good alternative to solve energy problems which traditional centralized power plants cannot fix [7]. Especially in the residential sector, there is a need to move toward clean energy such as solar photovoltaic (PV) systems. Solar power is now one of the most effective answers for the fast-growing electricity demand and environmental challenges [8]. With the decrease of fossil fuels, solar PV is more and more seen as a practical way for generating electricity [9]. This technology is already accepted in the market, does not need much labour to operate [10] , and in many countries, it is considered one of the cheapest electricity sources. In fact, in high-radiation regions, solar PV systems might be even cheaper than all other sources by 2050 [11]. At the moment, 99% of installed solar capacity around the world is grid-connected PV systems, while standalone ones with batteries are less common [12]. In recent years, energy demand grew rapidly due to population growth and the expansion of construction projects [13]. Together with problems like climate change, depletion of fossil fuels, and the rise and fall in oil prices, these issues strongly affect both the economy and renewable energy developments. Because of that, researchers are more encouraged to explore alternative sources like solar and wind power [14]. In the Middle East, especially Iraq, solar energy is more available and accessible than other renewable options such as geothermal, biofuel or tidal energy [15]. Iraq is in a good geographical position to take advantage of solar power, as it has some of the highest solar radiation levels in the world. For example, Baghdad records between 2160 and 7000 MJ/m² annually [16], and the western desert has the highest solar power potential in the region with an average of 170 W/m². The country, located between longitudes 38°45'–48°45' east and latitudes 29°5'–37°22' north, covers an area of 435,052 km² [17]. Because of its geography—with mountains in the north and flat lands in the south and center—the climate is mostly sunny all year, but the north has a bit less clear atmosphere. Iraq's weather is very hot in summer, with midday temperatures reaching 43–50°C, while in winter the temperatures can be from 1°C to 8°C [18]. These natural conditions make solar energy very promising in Iraq. With the urgent need to diversify energy resources, solar has gained more attention in the last years. Thanks to new technologies and lower installation costs, it is becoming very competitive. PV cells are especially useful because they convert sunlight directly into electricity, without any fuel, noise, or pollution, and with little maintenance [19]. To make sure solar projects work efficiently, simulation models are used to choose the best PV module types, configurations, and capacity based on the specific irradiance, weather, and temperature of the location. Such models are also important to estimate energy yield in different conditions, to detect problems, and to improve system performance [20]. Calculating both annual and monthly energy yield is important for financial analysis, planning, and feasibility studies [21]. Also, probabilistic assessments help in risk analysis and deciding whether a project is viable [22]. Moreover, PV output simulations are critical for grid integration studies, because they show how PV systems interact with the grid, voltage profiles, and overall power generation [23-24].

2. RELATED WORKS

Several studies have examined the performance of photovoltaic (PV) systems under various technical and environmental circumstances, especially in areas with significant solar potential like Iraq. These investigations offer crucial information about how solar systems behave and react to site-specific elements, including temperature, dust, and shade.

Mahmood [16] presented a standalone photovoltaic system to power three labs chosen for the case study; these labs are part of the faculty of electronic and communications engineering at Al-Nahrain University in Baghdad. In this work, simulation is done using the Pvsyst6 software package. Using data from NASA-SEE databases, Satellite observations for Baghdad, the calculations of the suggested PV system were contrasted with the simulated outcomes produced by the PVsyst6 simulation tool. A relatively high degree of agreement between the simulated and calculated values indicates that the model can be used to offer these labs.

The performance evaluation of a 5kWp CIGS grid-connected PV solar system was shown by Naseer [25]. The CIGS system was set up at the Al-Mansour Company in Baghdad, Iraq. The performance analysis of the CIGS system (actual system) and a comparison with the PVsyst simulation program are presented in the paper to determine how closely the CIGS system resembles the PVsyst perfect system in the Baghdad climate. For real and PVsyst systems, the capacity factor and performance ratio averaged 20.4% and 80.2% annually, respectively, and 22% and 83%, respectively. These Figure.s show that the CIGS PV solar system installed in Baghdad is doing quite well.

Hazim [26] determined the performance of a grid-tied PV solar system, the ideal tilt and orientation angles are five kWp CIGS PV. Installed in Bagdad, Iraq (Latitude 33.3 º N, Longitude). By shifting the orientation (Azimuth Angle) toward the east, west, and south, the

PVsyst simulation program calculates the quantity of electrical energy produced, solar irradiation, and performance ratio. When using the monthly adjustment, the ideal tilt angles and PR are 45º to 55º and 87.5% for January, February, November, and December, and 30º to 33º and 84.5% for March, April, September, and October, and 0º to 15º and 80.8% for May, June, July, and August. When using the seasonal adjustment, the ideal tilt angles are 45 degrees in the winter and 15 degrees in the summer. When considering the ideal fixed tilt angle for the entire year, 30 degrees is the perfect fixed angle.

Ebhota [27] used PVsyst software, and optimized the tilt angle and orientation of a standalone c-Si monocrystalline solar photovoltaic (PV) system. The proposed solar photovoltaic system was located at 9 Mountain Rise, Berea, Durban, South Africa. The tilt, azimuth, and battery operating temperature parameters that allow the best possible performance from solar PV systems were reported in this work. For a fixed PV panel mounting, the tilt and azimuth angles that are taken into consideration are 0° to 90° and -100° to 100°, respectively. According to the data from PVsyst design and simulation software, tilt 40° and azimuth 0° had the maximum available energy, specific energy, used energy, solar fraction, and the lowest loss.

Al-Ghezi [28] examined the effects of solar radiation and operating temperature on the output power and efficiency of polycrystalline PV panels in Baghdad, Iraq, both experimentally and numerically. Numerous measuring tools have been employed to carry out field tests in outdoor settings in order to confirm the accuracy of the simulated results with experimental ones. It was employed to ascertain the properties and functionality of a 120W polycrystalline photovoltaic panel across a range of solar radiation and operating temperature conditions. Because weather variations highly influence the PV panel's characteristics in terms of temperature and solar radiation, the testing results showed that they perform differently under real operating settings than they do under standard test conditions (STC).

Abed [29] focuses on the evaluation of a five kWp On-Grid Mon-crystalline silicon photovoltaic (PV) solar system. This photovoltaic system is situated in Baghdad. Performance ratio and capacity factor have annual daily averages of 74.7% and 17.75%, respectively. In Baghdad, Iraq, monocrystalline silicon (Mono-Si) appears to function well. The findings of this investigation were as follows: Winter performance ratios for the mono-Si system are found to be good, but summer performance ratios are bad. It has been discovered that in hotter regions like Iraq and the Arabian Gulf, first-generation technology, or silicon technology, is significantly damaged and subsequently degenerates.

Shneishil [30] analyse of a 1 MWp grid-connected solar PV power plant for the Baghdad/Iraq location, MATLAB was used to model the installed system from January 2020 to December 2020. The findings indicate that August has the highest monthly slanted solar irradiation value, while November has the lowest. A higher intensity of solar radiation does not always translate into more electricity being produced by a solar panel, and temperature influences cause the efficiency of the solar cell to decrease. Despite Iraq's high temperatures, particularly during the summer, a cooling system can extend the lifespan of solar panels and boost power output, which is necessary to maximize their usefulness.

The coordinates of every solar photovoltaic technology examined in Hussein [31] study are in the city of Baghdad. These technologies include 15 kWp HJT, five kWp CIGS, 107 kWp poly-Si, and five kWp mono-Si. Mono, poly, and HJT Si are the first generation, whereas CIGS is the second. Because weather conditions have less impact on HJT and CIGS technologies than other technologies, their efficiency is declining less than that of Mono and Poly-Si. Because CIGS and HJT have a lower temperature coefficient than Mono and Poly-Si (silicon), they perform better in PR. In other words, compared to Mono-Si and Poly-Si, CIGS and HJT are less impacted by ambient temperature.

Mahdi [19] investigated monthly grid performance of a fictitious 100 MWp solar project connected to the Al-Khwarizmi College of Engineering system. The simulation, which is conducted using PVsyst 7.2 and HelioScope software, makes use of Meteonorm 8.0 data. The simulation is run at a fixed tilt angle all year long with the aim of producing the most energy possible. The optimal angles, or an east-west angle that is fixed at 10 degrees to the south azimuth, are determined by the building's latitude. Analysis of shading and panel orientation impacts, as well as the selection of highly effective design solutions, are made possible by HelioScope's 3D display, which facilitates a natural and perceptive design process.

Recent studies from North Africa and the Mediterranean provide useful benchmarks for rooftop PV performance and highlight the importance of tilt selection and soiling losses in climates comparable to Iraq. Attari et al. [32] evaluated a 5 kWp grid-connected rooftop PV system in Tangier (Morocco) using one-year monitored data and reported IEC-style performance indicators, showing seasonal variations in PR and yield. A Casablanca rooftop case study [33] compared different PV technologies (mc-Si, pc-Si, and a-Si) and presented benchmark PR and final-yield values for a Mediterranean urban environment. In Algeria, Bouacha et al. [34] analyzed a 9.5 kWp grid-connected rooftop PV system monitored over three years and reported PR/yield behavior under North African operating conditions. In Egypt, Hassan et al. [35] assessed a 30.26 kW rooftop grid-connected PV plant in Cairo (hot-desert climate) and provided annual PR and yield metrics suitable for comparison with MENA cities. Concerning soiling, Elamim et al. [36] experimentally studied dust accumulation effects on rooftop PV systems in Mohammedia (Morocco) and quantified noticeable reductions in PV output without regular cleaning. The IEA PVPS Task 13 report [37] provides a widely accepted reference for soiling losses and their impact on PV plant performance. For tilt optimization in Tunisia, Slouma et al. [38] used PVsyst and PVGIS to estimate optimum tilt ranges in Borj Cedria, while Ben Othman et al. [39] validated tilted-surface radiation models and assessed gained energy for different tilt settings in Tunisia.

However, most regional works focus on either field performance benchmarking (PR/yield) or tilt/soiling analysis separately, while fewer studies combine detailed 3D rooftop shading, systematic multi-variant PVsyst simulations, and a direct comparison of high-efficiency technologies (e.g., HJT) in an urban rooftop context such as Baghdad. This motivates the present work.

In this work, the performance of a grid-connected rooftop PV system is studied under the weather conditions of Baghdad. First, SketchUp program was used to make a 3D model for the College of Education building in Mustansiriyah University, and with Skelion plugin the shading effect was also calculated. After that, the model was imported into PVsyst software where different system designs (variants) have been tested. The designs included different PV module types (Mono and HJT), different tilts (fixed and seasonal), and also variations in the panel orientation (portrait/landscape) and spacing between rows. In the simulations, the common losses like soiling, shading, degradation and system unavailability were also considered. The results will help to find the most suitable PV configuration for Baghdad that gives good energy yield, as well as environmental advantages.

3. SIMULATION SOFTWARE

To create an efficient PV system for the college building, two simulation software programs are used. They are SketchUp software and PVsyst software, respectively.

For 3D modelling and shadow analysis of a distant building, Sketch Up is used. Landscape architecture is one of the many drawing and design applications that make use of SketchUp capabilities. Other applications include industrial, product, interior, and architectural design. Use Sketch Up for this project because it allows for more accurate shadow analysis. For shadow analysis, the SketchUp file is first exported and then imported into the PVsyst program [40].

PV systems are designed using PVsyst software. A commercially available program for modelling solar PV plants is called PVsyst. The PVsyst software library includes the most widely used solar modules, inverters, and all other components needed for a photovoltaic system project. Additionally, it captures losses from partial shadowing, mismatched PV modules, cable losses, inverter losses, and the effect of temperature variations on its calculations of electrical output power. Because of this feature, it is a trustworthy tool for figuring out how much electrical energy a system is designed to produce [41].

4. METHODOLOGY

To PVsyst software and Sketch Up layout tools are used to design this PV on a grid system. The suggested method's flow chart is displayed in Figure. 1. Here the steps of the proposed method:

1. Open Sketch Up software and choosing a place. A building of education college in Mustansiriyah university has been selected for this purpose.
2. Get rooftop photos of a building in from Sketch Up software.
3. Design the 3D building to match with photo with adding objects in rooftop to make the simulation near to the real state. The college has two identical separating buildings as shown in Figure. 2. According to the design specifications, the building in this area was chosen for the grid-connected solar PV system. The roof's actual useable area is of each building is 11 m x 44 m is total area 968 m2 for the PV array installation. However, the entire area is unusable because to specific losses including shading and soiling losses, in addition to PV panel arrangement guidelines like row spacing, slope, orientation (azimuth), and the reason for installing the PV array. The total load of college approximately 500 KW, but the free area of PV system is covering 100 KW approximately as shown in system design.
4. Skelion tool in Sketch Up software is used to add solar panels with more options on building ‘s rooftop such number of modules, Space between panels, pitch distance and other distances. In this step four possible solar panel configuration (Portrait vs Landscape, pitch distance 0 m vs 0.5 m) The 3D constructed of the building with solar panels are shown in Figure. 3.
5. Open PVSYST software and create new object (On Grid) then select the Baghdad site. The

local latitude and longitude for Baghdad, Iraq (latitude 33.3° N, longitude 44.4 ° E) The measured monthly average was about 5.20 kWhr/m2 in Baghdad [42]. The annual global horizontal solar irradiation (GHI) received in Baghdad of 1986.4kWh/m2[25]. This model will import by PVSYST software to apply shading.

6. In variant field different solar system configurations will be created. At first the 3D model which exported in step 4 will be import to PVSYST through Near shading in optional field. Figure. .4 show the 3d model appearance in PVSYST. Now, PVSYST consider the shading effect in its calculations.
7. In main parameters select the orientation field (tilt and azimuth angles) with two options (fixed tilted plan and seasonal tilt adjustment). Figure. 5 and 6 show these options.

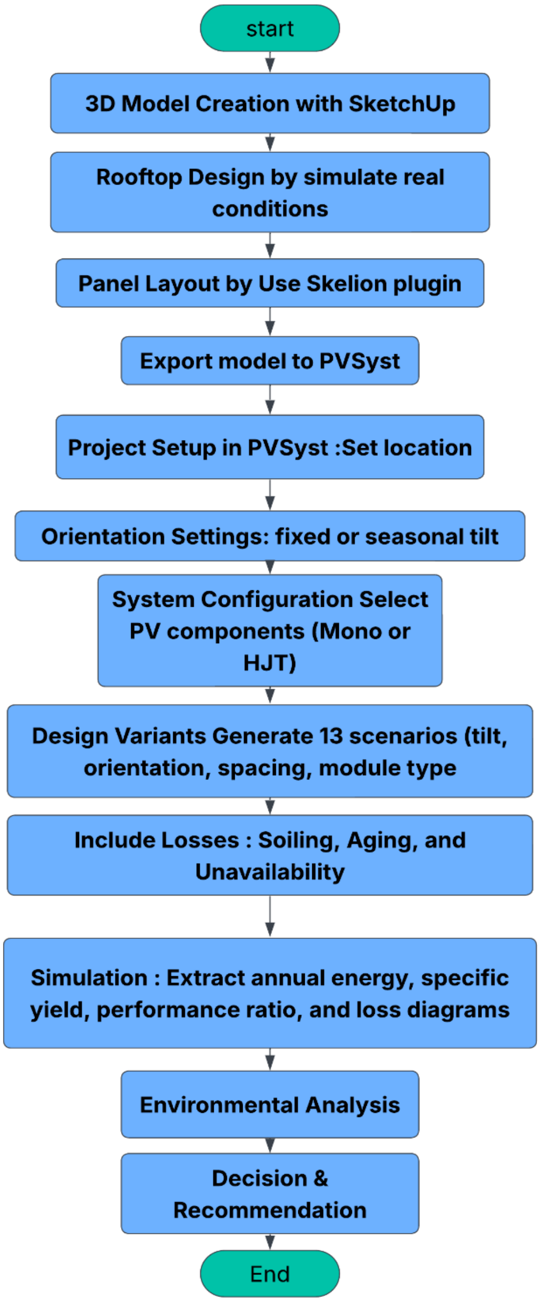

Figure 1. Flow chart of the prosed method

8. In system field the PV system components is selected according database stored in PVSYST such type of module, inverter with their manufacture. In these step two choices of module type (Monocrystalline, HJT).

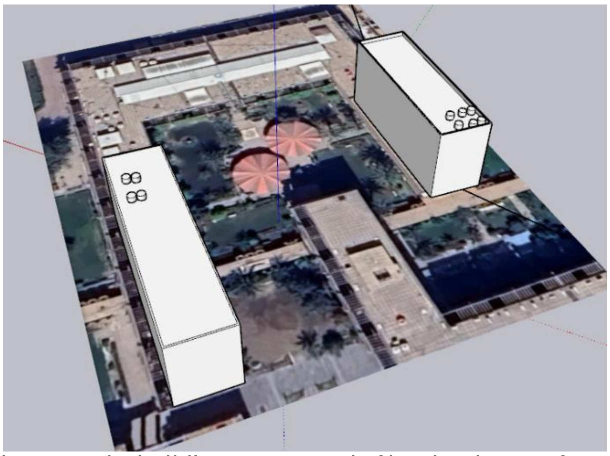

Figure 2. The building constructed of by Sketch Up software

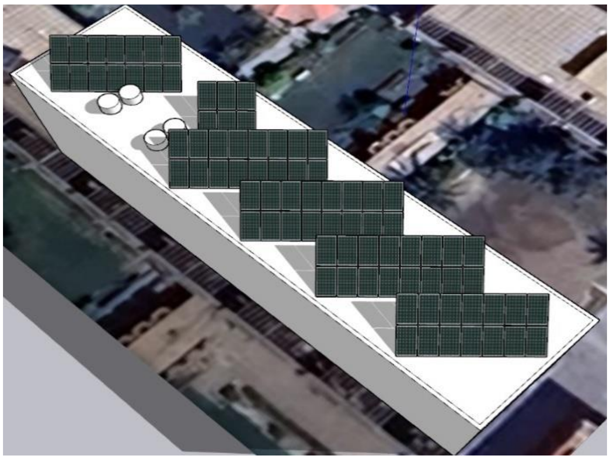

Figure 3. The building with Portrait sorting

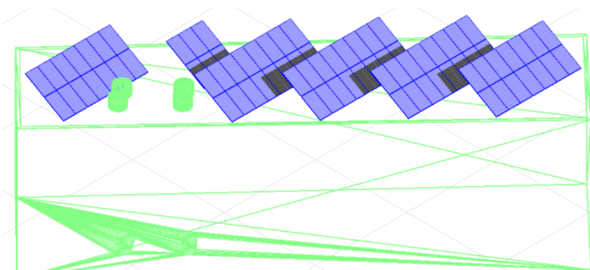

Figure 4. The shading scene construction in PVSYST.

There are numerous manufacturers worldwide. The PV modules RCM-680-8DBNM (monocrystalline) and RCM-680-8DBHM (HJT) were selected for this work based on their features. Table.1 and 2 show the characteristic of both types. From the tables, it noted the Temperature Characteristic of HJT panel is better than monocrystalline and this will be confirmed at the result.

The number of modules depended on sorting type of panels. Portrait configuration has 192 modules, Landscape configuration has 162 modules, Portrait configuration with pitch distance

0.5 m has 154 modules finally Landscape configuration with pitch distance 0.5 m has 148 modules.

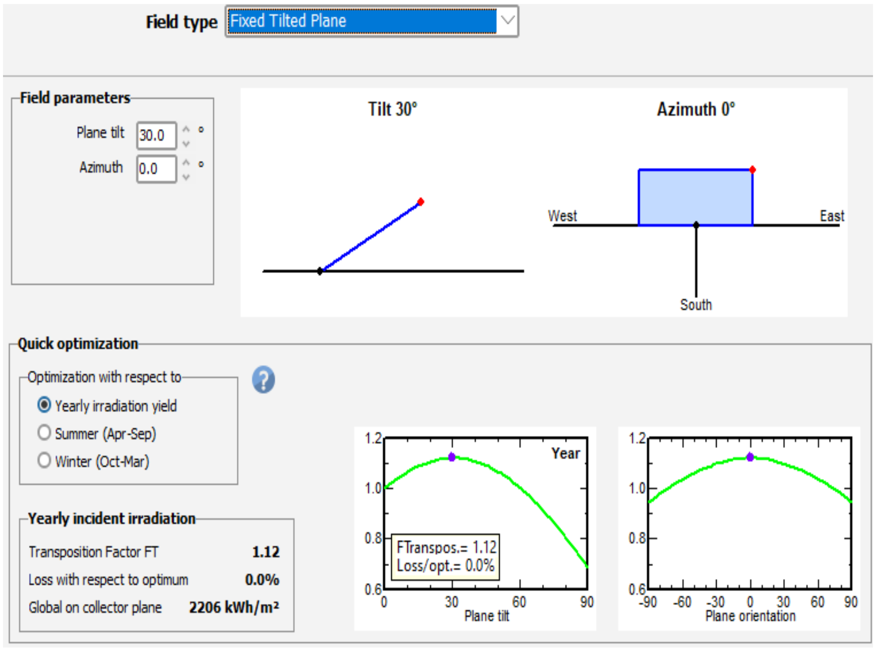

Figure 5. Parameters of the PV module arrangement system orientation with fixed tilted plan

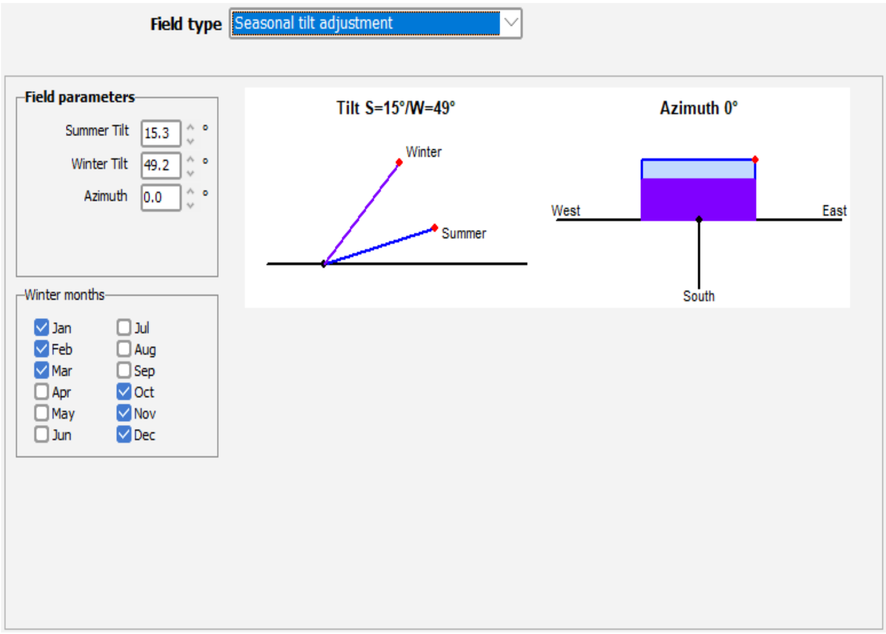

Figure 6. Parameters of the PV module arrangement system orientation with seasonal tilted plan

Portrait configuration has a greater number of module so it expected to produce more energy

9. Select the inverter type of SMA with suitable size according to PV array power. Figure. 7 show the single line diagram of the system.
10. To make the system nearest to the particle case, different losses are added such soiling losses with 3%, Aging (use degration in simulation by simulate the module at year no. 10) and Unavailability (with 2% approximately 7.3 days).

Table 1 .Characteristic of RCM-680-8DBNM solar panel

Cell Type	N-Type
Maximum Power	680
Maximum Power Voltage	39.7
Maximum Power Current	17.13
Open Circuit Voltage	47.5
Short Circuit Current	18.11
Pmax Temperature Coefficient	-0.30% / °C
Voc Temperature Coefficient	-0.25% / °C
Isc Temperature Coefficient	+0.046% / °C
Operating Temperature	-40 ~ +85 °C
Nominal Operating Module Temperature (NMOT)	43 ± 2 °C
Dimension (mm)	2384 x1303 x35

Table 2. Temperature Characteristic of RCM-680-8DBHM solar panel

Cell Type	HJT
Maximum Power	680
Maximum Power Voltage	42.08
Maximum Power Current	16.16
Open Circuit Voltage	49.2
Short Circuit Current	17.18
Pmax Temperature Coefficient	-0.24% / °C
Voc Temperature Coefficient	-0.22% / °C
Isc Temperature Coefficient	+0.047% / °C
Operating Temperature	-40 ~ +85 °C
Nominal Operating Module Temperature (NMOT)	42 ± 2 °C
Dimension(mm)	2384 x1303 x35

The distance between PV panels was determined using the following algorithm with Figure. 7:

$$P = (2.L + S).\cos(\varphi) \quad (1)$$

Where P is the minimum distance between PV panels, L is the high of PV module if the solar panel configuration is portrait and equal to width of PV module if the solar panel configuration is landscape, S is the space between PV module, φ is tilt angle, X is chosen to 0.5 meter.

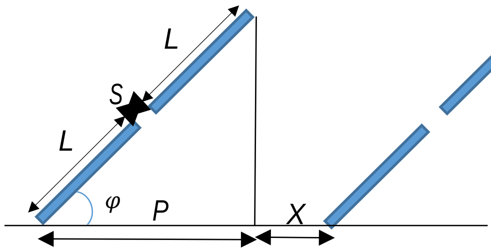

Figure 7. Distance Between PV Panels

Table 3 PV Solar Panel Configuration

1	Monocrystalline _Fixed
2	HJT _Fixed
3	Monocrystalline _Seasonal
4	HJT _Seasonal
5	HJT _ Portrait
6	HJT_Landscape
7	HJT _ Portrait _with extra distance 0.5
8	HJT_Landscape _with extra distance 0.5
9	Monocrystalline _Landscape
10	HJT _ Landscape_ Soiling
11	HJT _ Landscape_ Soiling_ Aging
12	HJT _ Landscape_ Soiling_ Aging_ Unavailbilty
13	Monocrystalline _Landscape_ Soiling_ Aging_ Unavailbilty

According to above configuration there 13 variants as shown in table 3. So, there are 13 variant that employ possible PV panels configuration which help us to choose most suitable and nearest to particle case.

5. SYSTEM PERFORMANCE PARAMETER

It is possible to compare photovoltaic systems with different configurations at different locations by analysing their normalized system performance indices, which include yields, losses, and efficiencies. System efficiencies are standardized to array size, energy yields are amounts adjusted to rated array power, and losses are the variations between the reference and actual daily yields [43].

5.1. Produced Energy

As shown in equations 2 through 4 [25], energy produced is the quantity of alternating current energy that leaves the photovoltaic system while it is operating. It can be computed hourly, daily, or monthly.

$$E_{AC},H = \sum_{t=1}^{60} E_{AC},t \quad (2)$$
$$E_{AC},D = \sum_{H=1}^{24} E_{AC},H \quad (3)$$
$$E_{AC},M = \sum_{D=1}^{N} E_{AC},D \quad (4)$$

Where E_{AC},t : Alternating current (AC) energy output per minute
E_{AC},D: Alternating current (AC) energy output per hour.
E_{AC}, M: Alternating current (AC) energy output per day
E_{AC},M : Number of days in the month.

5.2. Specific production

The following formula represents the final yield, which is the ratio of energy delivered to the system during a specific time period (days, months, or years) to the installed power [44].

$$Y_f = \left(\frac{E_{AC}}{P_{DC}}\right) \quad (5)$$

where E_AC is the total PV system's net energy output (in AC kWh); P_DC is the installed PV array's rated kW (in DC kWp)

5.3. Performance Ratio

The solar photovoltaic system's overall losses are displayed by the Performance Ratio (PR). The performance ratio shows how optimal performance (100%) is achieved throughout working hours [45].

The European Standard that outlines the general guidelines for PV system performance monitoring and analysis [26], for both grid-tethered and independent systems, is IEC 61724. Therefore, the standard defines a performance ratio (PR) as the quotient of the system's final yield (Yf) to its reference yield (Yr) in order to provide information on the energy efficiency and reliability of a PV installation. This PR shows the overall effect of losses on the system output due to array temperature as well as system component inefficiencies or failures, including balance of system components.

$$PR = Y_f / \left(\frac{H_i}{G_{i,ref}}\right) \quad (6)$$

where Y_f is the final yield; H_i is the total in-plane irradiation (in kWh~m); and, lastly, G_(i,ref) is the array irradiance reference plane (1 kW~m), which is the irradiance at which P0 is calculated. The monthly performance ratio, also known as PR monthly or just PR from here on, is the performance ratio that is assessed for a reporting period of one month because the available data had a monthly resolution [46].

6. SIMULATION RESULT

Three primary parameters were evaluated in the main simulation findings. First, the Produced Energy (KWh) will be calculated for 13 variants which is consider most important measurement. All losses such shading and soil of last variant are shown in Figure. 8, also the specific production of 12 months are shown in Figure.9, Figure. 10 show the Energy Grid through year with different solar panel type, it be noted that, both fixed and seasonal tilts, the comparison of Mono and HJT technologies demonstrates that seasonal adjustment leads to a better energy yield, particularly during the summer. HJT Seasonal panels outperformed all other configurations in terms of annual output, highlighting the importance of tilt strategy and panel technology in optimizing PV performance.

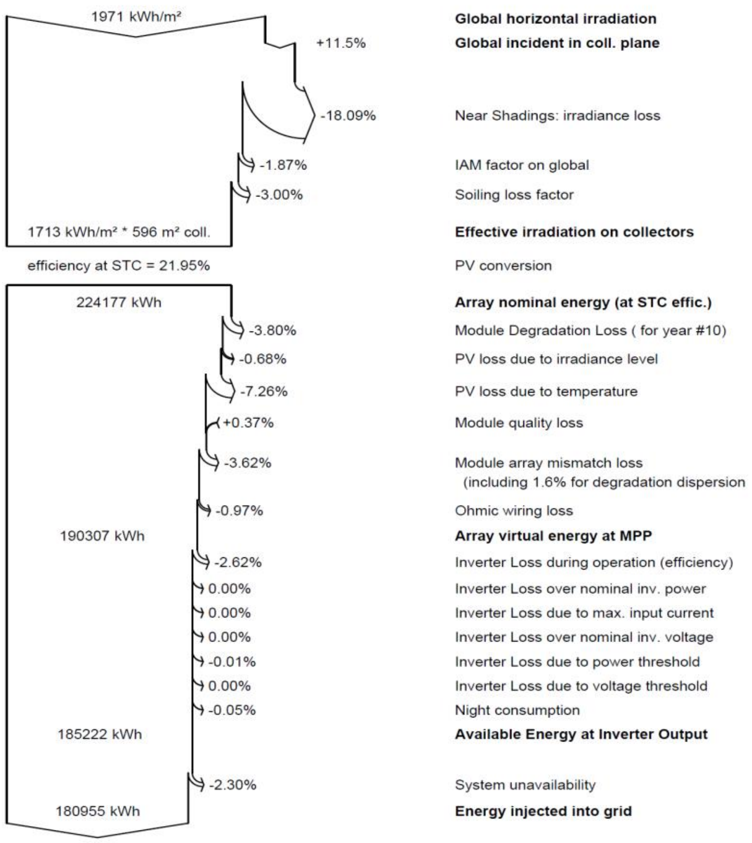

Figure 8. Loss Diagram

Figure. 11 Energy Grid through year with different solar panel configuration, Performance is strongly impacted by row spacing (0.5 m) and orientation (Portrait vs. Landscape). Although it takes up more installation space, the Landscape arrangement continuously performed better than the Portrait. Spacing also helps to reduce shading losses.

Figure. 12 Energy Grid through year with different losses, the almost optimal state is shown by the red curve (HJT Landscape). The energy output gradually drops as other loss factors like soiling, aging, and unavailability are taken into account. The importance of operational and environmental losses is highlighted by the fact that this effect is more noticeable in the summer, when energy yield is at its highest.

Table 4 will be discussed according to six metrics.

1) The highest annual energy production was achieved by the HJT system with seasonal tilt, reaching about 253,304 kWh/year. This was slightly higher than the Mono seasonal tilt system (248,081 kWh/year), while the HJT fixed-tilt and Mono fixed-tilt options produced 244,305 and 239,329 kWh/year, respectively.

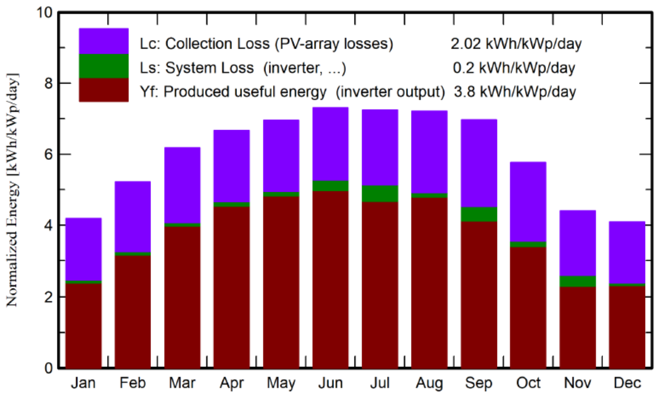

Figure 9. Normalized productions (per installed kWp)

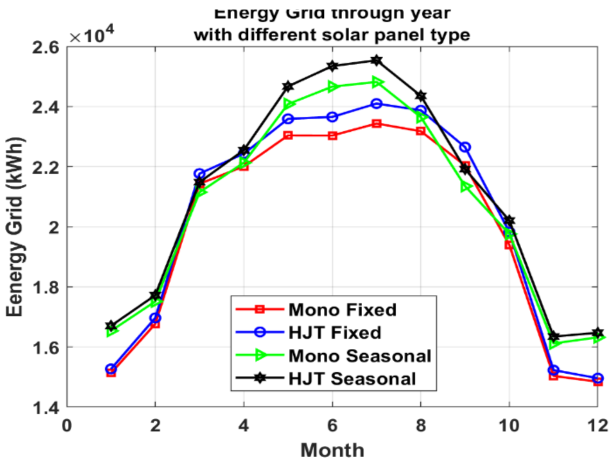

Figure 10. Energy Grid through year with different panel type

After accounting for typical operational losses such as soiling, module aging, and system unavailability, the net output dropped to around 180–196 MWh/year. This indicates that the advantage of seasonal tilt can be significantly reduced if maintenance practices are not adequately implemented.

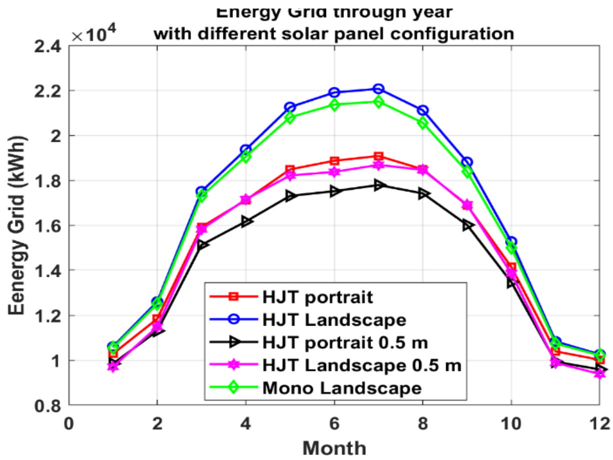

Figure 11. Energy Grid through year with different

As expected, the total generated energy scales with both the installed capacity and roof coverage. In the fixed-tilt configuration, increasing the row spacing to +0.5 m helped improve the performance ratio (PR) by minimizing row-to-row shading. However, this adjustment reduced the number of installed modules and, consequently, the system capacity, which lowered the absolute annual output to about 171–178 MWh/year.

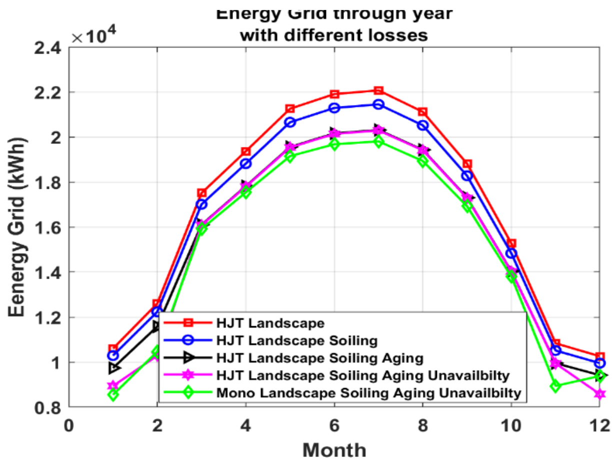

Figure 12. Energy Grid through year with different losses solar panel configuration

2) The normalized annual energy yield, expressed as kWh per kWp installed, shows that the HJT system with seasonal tilt in landscape orientation achieved the highest performance, producing around 1,900–1,940 kWh/kWp/year. The HJT landscape fixed-tilt configuration followed with about 1,871 kWh/kWp/year.

When more realistic operating conditions typical of urban rooftops are considered—such as dust accumulation, module aging, and system downtime—the effective yield decreases noticeably, dropping to approximately 1,386–1,544 kWh/kWp/year.

3) The Performance Ratio (PR), which represents the ratio of actual energy output to the theoretical yield and serves as an efficiency indicator independent of solar irradiation, reached its highest levels with the HJT fixed and seasonal tilt systems, averaging around 83–85%.

However, when real-world factors such as shading, soiling, and module aging are taken into account, the PR drops significantly to about 62–70%. In some fixed-tilt configurations, increasing the row spacing by 0.5 m reduced row-to-row shading and improved performance;

for example, the HJT landscape fixed with +0.5 m spacing achieved a PR of roughly 77.35%. These results highlight the importance of proper tilt and spacing design, along with effective soiling management and shade control, in order to sustain a high system performance ratio.

Table 4 Performance of 13 PV System Variants

Variant	No. of PV modules	PV Array total power (KWP)	Total power of inverter (KWP)	Produced Energy (kWh/year)	Specific production (kWh/kWp/year)	Perf. Ratio (100%)
Monocrystalline _Fixed	192	131	120	239,329	1,833	83.45
HJT _Fixed	192	131	120	244,305	1,871	85.19
Monocrystalline _Seasonal	192	131	120	248,081	1,900	83.46
HJT _Seasonal	192	131	120	253,304	1,940	85.22
HJT _ Portrait	162	110	100	181,510	1,648	75.01
HJT_Landscape	192	131	120	201,576	1,544	70.29
HJT _ Portrait _with extra distance 0.5	147	100	99.9	171,465	1,715	78.09
HJT_Landscape _with extra distance 0.5	154	105	100	177,922	1,699	77.35
Monocrystalline _Landscape	192	131	120	197,975	1,516	69.03
HJT _ Landscape_ Soiling	192	131	120	195,809	1,500	68.28
HJT _ Landscape_ Soiling_ Aging	192	131	120	185,493	1,421	64.68
HJT _ Landscape_ Soiling_ Aging_ Unavailbilty	192	131	120	180,955	1,386	63.1
Monocrystalline _Landscape_ Soiling_ Aging_ Unavailbilty	192	131	120	178,163	1,365	62.12

In practice, the HJT landscape fixed model with soiling, aging, and unavailability losses is often applied as a realistic baseline. By explicitly considering degradation and downtime. Out of the 13 simulations, the HJT modules in fixed landscape orientation, while including real losses like dust, panel aging and downtime, come out as the most balanced solution between cost of investment and long-term benefit.

Table 5 provides a comparative overview of PV system studies. Based on the unified comparison matrix, the present work stands out as the most comprehensive and decision-oriented. It consistently reports produced energy, normalized yield, and performance ratio across thirteen design variants, including fixed and seasonal tilt, portrait and landscape orientations, different row spacing's, and two module technologies (Mono and HJT). The integration of PVsyst simulations with 3D shading modelling in Sketch Up ensures high accuracy. Unlike most previous studies, which focus only on limited subsets or aggregated data, this work applies a detailed loss modelling approach that incorporates not only thermal, ohmic, and mismatch effects but also soiling, module aging, unavailability, and shadowing. In summary, this work prove that rooftop PV in Baghdad is technically possible the performance of system can be improved by adding modern techniques such optimization with MPPT [50].

Table 5. PV Systems Comparative

ID	Tools	Loss Modeling (Soiling/Aging/Outages/Shading)	Design Diversity (#Variants, Tilt/Orientation/Spacing/Tech)	Notes
proposal	PVsyst + SketchUp	Soiling / Aging / Outages/ Shading (+ thermal, wiring, mismatch)	13 variants; Fixed & Seasonal tilt; Portrait/Landscape; Spacing (0–0.5 m); Mono & HJT	Most comprehensive: detailed losses , best suited for practical design.
[45]	PVsyst + SAM + field measurements	Irradiance / Temperature / Collection/Ohmic (partial); no explicit soiling/aging	Single system; fixed tilt; as-installed orientation	Strong validation; limited design diversity
[26]	PVsyst	Irradiance/Temp via PVsyst; no soiling/aging/outages	Fixed vs Seasonal tilt; azimuth sweeps; single tech	Actionable tilt/azimuth; full loss set.
[31]	Analytical aggregation + short field window	PR-based only; no explicit soiling/aging/outages	Cross-tech snapshot (Mono/Poly/HJT/CIGS); fixed tilt	Direct cross-tech comparison; short timeframe
[47]	SketchUp-based tool + SAM validation	Soiling / Thermal / Inverter / DC / Mismatch ; 3D shading	Generic multi-array support; adjustable tilt/orientation	Rich loss modeling & 3D; strong validation.
[48]	Load survey + PV sizing workflow	Not core (focus on load policy)	Illustrative design only; not Baghdad-focused	Context paper for load/peak policy; low relevance to Baghdad KPIs.
[19]	PVsyst + HelioScope	Partial loss modeling; 3D shading via HelioScope	Design-level comparison; fixed/optimized tilt; several variants	Good local comparison; lacks field validation .
[49]	PVsyst	Irradiance / Temp / Battery Aging / System losses (PR, SF, excess energy, missing energy)	Single system , Fixed tilt	practical for standalone design

7. COMPARTIVE CONTEXT (MENA / North Africa)

To add regional context beyond Baghdad, we compared our results with rooftop PV studies from North Africa and Egypt. In Tangier, Morocco, Attari et al. [32] monitored a 5 kWp rooftop system and reported about 6411 kWh/year delivered to the grid, with the performance ratio (PR) varying widely (about 58% to 98%) depending on operating conditions. In Casablanca, Morocco, a rooftop study that compared different PV technologies [33] showed that the best subsystem (mono-crystalline) achieved around PR ≈ 76.7% and an average final yield ≈ 4.53 kWh/kWp/day (roughly 1650 kWh/kWp/year). In Algeria, Bouacha et al. [34] evaluated a 9.5 kWp rooftop grid-connected installation and reported a final yield ≈ 3.37 kWh/kWp/day (about 1230 kWh/kWp/year) with PR around 70%, noting that near shading and inverter-related issues reduced the overall performance. In Cairo, Egypt, Hassan et al. [35] assessed a 30.26 kW rooftop plant and found a strong annual performance with PR ≈ 83% and final yield ≈ 4.479 kWh/kWp/day (around 1635 kWh/kWp/year). Compared with these regional benchmarks, our best Baghdad configuration HJT_Landscape achieved PR = 70.29% and specific yield = 1544 kWh/kWp/year (annual energy 201,576 kWh), which is within the range reported for similar rooftop PV systems in North Africa and Egypt, especially when realistic losses and urban shading effects are considered. Table 6 summarizes the above comparison.

Table 6. Comparison with other countries

Location (City)	Capacity (kWp)	Technology / Variant	Tools / Data	Annual energy (kWh/year)	Specific yield (kWh/kWp/year)	PR (%)	Notes (losses / context)
Baghdad Iraq	131.00	HJT_Landscape	PVsyst + SketchUp (3D shading)	201,576.0	1,544	70.29	Includes shading; best-performing landscape configuration in the realistic set
Tangier Morocco [32]	5.00	Poly-Si (20×250 Wp)	Monitoring (2015)	6,411.3	1,282	58–98	Annual energy to grid: 6411.3 kWh (2015); Yf range 1.96–6.42 kWh/kWp/day; CF 14.84%
Casablanca Morocco [33]	5.94	mc-Si (best of 3 techs)	Production data (2015–2016) + PVGIS	Not reported	1,653	76.70	Paper compares a-Si / pc-Si / mc-Si; mc-Si has highest PR (76.7%) and Yf (4.53 h/day).
Algiers (CDER) Algeria [34]	9.50	PV system (3×3.2 kWp sub-systems)	Monitoring (2016–2018), IEC 61724 indicators	Not reported	1,230	70.00	Paper reports PR ≈70% and Yf=3.37 h/day; low PR attributed to near shading and inverter type.
Cairo Egypt [35]	30.26	Mono-Si	Monitoring (1 year)	49,508.0	1,635	83.03	Paper reports annual PR ≈83.03% (also shown as 83.08% in annual-average discussion); CF ≈18.72%.
Borj Cedria Tunisia [38]	Not reported	Tilt optimization study (PV system)	PVsyst + PVGIS	Not reported	Not reported	Not reported	Provides North Africa context for optimum tilt selection; complements Tunisia tilted-radiation validation work [39].

8. CONCULSION

Using PVsyst and SketchUp software, thirteen rooftop solar designs were assessed in the

Baghdad climate for this work. The findings demonstrate that while seasonal tilt and HJT modules can theoretically produce more energy, dust collection, panel aging, and downtime have a significant impact on actual performance. This demonstrates that designers should take into account realistic loss effects in addition to ideal simulation. Because it strikes a balance between energy output and PR, the HJT landscape fixed with losses incorporated seems to be the most practical option out of all the examples that were studied. Furthermore, the work suggests that Baghdad's rooftop PV design should prioritize dependability, ease of maintenance, and cost-effective operation in urban settings in addition to maximum annual yield. Three key suggestions for engineers and decision-makers can be made based on the findings:

- ☐ In order to prevent issues and lower long-term costs, fixed or low-maintenance designs are preferable.
- ☐ It is necessary to plan for dust and soiling management, such as by utilizing self-cleaning solutions or cleaning schedules.
- ☐ To verify simulation assumptions and increase the credibility of the results, further field measurements and pilot projects are required.

In general, this paper integrates technical and environmental factors and offers practical advice for Baghdad's sustainable rooftop photovoltaic expansion. Other dry communities that want to embrace renewable energy with fewer hazards can also use the results as a guide.

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