AI based Microgrids Performance Optimization using Integrated Solar techniques

Phlip Y. Najeeb[1], Ashraf Aboshosha[2], and Ayman Haggag[3]

***Abstract*—Many countries are working to install small solar power plants on residential and local buildings' roofs. In Egypt, numerous public buildings, such as schools, have empty and unutilized roofs that are mostly free from shadows or obstacles. The research suggests the installation of small-scale solar stations on the building's rooftops. These stations would make use of large portions of the roofs to produce clean electricity, powering the institutions and connecting them to the public electrical grid. The research explores ways to enhance the efficiency of these small-scale independent solar stations by examining various factors such as building dimensions, site coordinates, panel size, roof area available for installation, Sun angles each day, and roof heights. Key factors that affect photovoltaic panels include regional climatic conditions, panel inclination angles, distances between panel rows, solar radiation, and panel temperature. To analyze these variables, the research utilized numerous programs involving artificial intelligence, including PVSYST, Skelion, and Google Earth. These tools helped determine optimal distances between rows and optimal inclination angles for solar panel installation. They also enabled the assessment of climatic factors' impact on panel performance, calculations of the produced electrical energy, and estimations of annual energy production losses. The findings indicated that the optimal inclination angle for solar module ranges from 18 to 22º to minimize shadows' effects on energy production. Furthermore, the results emphasized the significance of solar radiation, demonstrating a direct relationship between the average monthly sun radiation and the power produced by the panels.**

***Keywords*—PV simulation, PV mathematical model, PV temperature effect, PV radiation effect, SketchUp software, PVSYST software, Inclination angle, Skelion software.**

I. INTRODUCTION

THE public buildings rooftops in many countries worldwide are considered a public good but aren't utilized to their full potential. These rooftops are empty and free from obstructions or shadows. Egypt has numerous public buildings, particularly public schools, with 38,052 schools as of 2022/2023 [1]. However, the rooftops of the public schools in Egypt are currently unused.

Burning fossil fuels produces greenhouse gases, contributing to the two-degree increase in the earth's temperature annually. Many countries around the world are increasing their utilization of renewable resources to generate electrical electricity, particularly using photovoltaic units. This involves setting up big solar power plants on expanses of land outside of urban areas as well as smaller photovoltaic stations within many cities. Given the lack of available land within cities, it is more practical to utilize the public buildings' unused rooftops to produce clean electricity to power these buildings and contribute to the nation's overall electrical network. Therefore, this research recommends using smaller stations on public buildings' roofs. The successful installation of small independent solar stations depends on various factors. These include the solar panels' dimensions, the site's coordinates, the available surface area for the station, the sun's heights and angles in that region, dust levels, the modules' inclination degrees and the separations between module arrays. In addition to these factors, other variables such as soiling, fill factor, parasitic resistances, solar irradiation, module temperature, material deterioration, and shading.

This study utilizes various artificial intelligence software, including Skelion software, Google Earth, and PVSYST software, to determine the largest solar panels which can fit in the space that is provided, the module orientation, number of possible rows for building's area, the ideal spacing between rows, the optimal angles for establishing panels, climate's impact on solar panels and the amount of electricity they generate, The monthly percentage of losses in the station's production, the regular sun angle during year, the site's geographic locations, size, and surrounding obstructions are all taken into account.

Michelon [2] examined BIM (Building Information Modeling) for daylight dynamic modeling in Brazil, emphasizing the implications for future urban climate and building design. They stated the following phases in the process: The case study's representative Brazilian building was chosen based on its dimensions, location, and style of construction. Using industry-standard tools, a comprehensive BIM model that included geometric data, material characteristics, and spatial linkages was created. The BIM model was integrated with sunlight dynamic simulation software to analyze how daylight is distributed throughout the

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1. Phlip Y. Najeeb is with the Electronics Technology Department, Faculty of Technology and Education, Helwan University, Cairo, Egypt (e-mail: flip.mashreqipost21@techedu.helwan.edu.eg).
2. Ashraf Aboshosha is with Rad. Eng. Dept., National Center for Radiation Research and Technology, Egyptian Atomic Energy Authority, Cairo, Egypt (e-mail: ashraf.aboshosha@eaea.sci.eg).
3. Ayman Haggag is with the Electronics Technology Department, Faculty of Technology and Education, Helwan University, Cairo, Egypt (e-mail: haggag@techedu.helwan.edu.eg).

building over the course of the year. This analysis considered various factors, including the effect of the heat island, energy usage, and comfort of sight, to assess the effect of sunlight performance on the building's urban environment. In Brazil, BIM-based daylight dynamic modeling serves as a useful instrument for enhancing urban climate and building design. By offering information about energy efficiency, daylight distribution, and comfort of sight, BIM contributes to the creation of more resilient and sustainable cities.

Karimi [3] identified the primary determinants of photovoltaic system efficiency and offered a thorough manual for building and refining a roof-top PV power plant that is linked to the grid. They spoke about the variables that determine electricity output, including efficiency, grid connection, temperature inverter, and sun irradiation. Power generation is directly impacted by the quantity of solar energy that reaches the panels. Geographical position, orientation, panel inclination, and shade from nearby structures are some of the variables that affect irradiance. Solar cells may become less efficient at higher temperatures. Appropriate ventilation or cooling solutions can lessen this impact. To connect to the grid, the inverter converts the solar panels' DC electricity into AC power. The overall performance of the system may be greatly enhanced by high-efficiency inverters. The system's power production and economic feasibility may be impacted by the grid connection's quality and related restrictions. Site evaluation, solar radiation measurement, rooftop structural evaluation, shading evaluation, system design, inverter sizing, panel selection, and routine maintenance were among the other construction and optimization factors they covered.

Takialddin [4] underlined the significance of clever management techniques for optimizing the output and efficiency of PV systems. More accurate and flexible energy management solutions are now possible thanks to artificial intelligence (AI), which has shown itself to be a potent instrument. System degradation, weather forecasting, grid integration, and partial shading are just a few of the numerous AI applications in photovoltaic energy management. AI models can estimate solar irradiance with high accuracy by utilizing real-time updates, historical meteorological data, and present circumstances. AI systems can track Photovoltaic system performance and identify indications of deterioration, allowing for prompt maintenance and extending system life. AI can ensure effective electricity generation by reducing the detrimental effects of partial shade on PV systems. AI can reduce peak load and provide grid stability services by coordinating energy storage with system demands. Reduced expenses are another advantage of AI-driven PV power management. By streamlining system maintenance and operation, AI can lower the total cost of solar energy.

Honglu [5] suggested a brand-new soft sensing strategy to evaluate these variables by applying clever modeling approaches. Data collection, feature engineering, choosing a model and training, validation of models, and real-time estimation were all included in the suggested approach. Additionally, the suggested method's benefits included flexibility, scalability, cost-effectiveness, and reliability. This approach was used for defect detection, power prediction, and system optimization. An innovative technique had numerous uses, including precise temperature and sun irradiance estimations for power output prediction, which improved connection to the grid and energy management. Through the adjustment of parameters like energy storage plans and inverter settings, it was utilized to maximize system performance. Potential flaws or irregularities in the photovoltaic system were revealed by differences between the measured and predicted values. Using indirect data and mathematical models, the soft sensing methodology was a viable substitute to traditional methods, which frequently rely on costly and complicated sensors that can be prone to breakdowns and maintenance requirements. Thus, while cutting expenses and enhancing system efficiency overall, this approach produced precise and trustworthy estimations.

Chen [6] discussed finding photovoltaic (PV) systems' ideal angles to optimize solar energy collecting. He highlighted the significance of determining the right angle, considering elements like the system's location and the presence of shadows. Chen also presented a novel formula based on the system's exposure to direct sunshine, which can assist in figuring out the perfect angle for any given place. Through testing on 8 different sites, the author found the equation to be approximately 5% accurate. This formula has the potential to enhance the efficiency and affordability of solar energy. Additionally, it can contribute to cost reduction by determining the minimum system size required to produce a certain quantity of energy. Moreover, the equation can be utilized to optimize the effectiveness of current solar energy systems by identifying the optimal angle for improved efficiency.

In Saudi Arabia, Garni [7] researched the optimal angles for maximizing solar PV energy yield. The author determined the ideal orientation angles in various Saudi Arabian locales using a simulation tool, considering elements such as solar radiation data, latitude, and longitude. The study revealed that the best orientation angles differ depending on the place but generally fall within a couple of degrees to the south. For instance, in Riyadh the best orientation angle is 25º south, while in Jeddah, it is 22º south. Additionally, the study found that the best orientation angles vary slightly for various seasons. For example, in Riyadh the best orientation angle in winter is 28º south, while in the summer, it is 22º south. The researcher concluded that Saudi Arabia's ideal solar PV orientation angles differ somewhat from the conventional advice of due south. To optimize energy, the author advises Saudi Arabian solar photovoltaic installers to determine the precise ideal orientation angles for their site.

Raptis [8] conducted a study on the best inclination angle for photovoltaic panels to maximize energy capture. The author used a combination of measurements and model simulations to demonstrate that the optimal inclination angle varies depending on the time of year and the location of solar panels. In general, an inclination angle of 30 degrees is optimal for most locations. However, in some locations, the optimal inclination angle can be as high as 40 degrees in winter months. The author also highlighted the importance of considering the local climate when choosing an inclination angle to solar panels. For instance, in areas with frequent snow cover, it may be better to choose an inclination angle that is less than 30 degrees to prevent snow from accumulating on the panels. Overall, this article provides a comprehensive overview of the factors that affect the optimal inclination angle for photovoltaic panels and highlights the importance of considering the local climate when making this choice.

K. Lau [9] conducted a study on the impact of ambient temperature, inclination angle, and orientation on hybrid photovoltaic (PV) and diesel systems in equatorial climates. The study utilized a tool for simulation to assess the performance of these systems under various conditions. The findings revealed that ambient temperature significantly affects the efficiency of hybrid PV/diesel systems, with higher temperatures leading to decreased PV panel efficiency due to reduced electricity production. Additionally, the study indicated that the inclination angle and orientation of PV panels play crucial roles in their performance. While the optimal inclination angle in equatorial climates typically corresponds to the location's latitude, it may vary based on factors like panel shading and seasonal solar radiation changes. Similarly, the optimal orientation for PV panels in equatorial climates is generally south facing, but it can also be influenced by panel shading and seasonal solar radiation variations.

Based on previous studies, several factors impact the energy production of photovoltaic modules. The inclination angle of these panels has an especially important and noticeable impact on the efficiency of production. Therefore, this study proposes a method to determine the optimal inclination angle for installing photovoltaic modules.

II. Definitions

A. Sunlight Radiation and Sunlight Angles

The sun position in the sky relative to a point on the Earth's surface can be described using two angles: the azimuth angle (β) - and the solar altitude angle (α). In Fig. 1, angle (α) represents the angle generated by the sun's location and the horizontal plane of the earth's surface, while angle (β) describes the angle formed by a vertical plane containing solar disc, and a line pointing directly north. At noon on the sun, angle (α) is at maximum value, angle (β) is at 180º, the sun is halfway across sky. Two components of the total (global) solar irradiance, G_h (W/m^2), that strikes the earth's horizontal surface are l. the beam (direct) horizontal radiation, (I_{bh}), which originates in the solar disc itself, 2. the horizontal sky radiation spread (I_{dh}), that is first scattered by molecules and particles, including clouds. Equation (1) [10]: expresses this:

$$G_h = I_{bh} + I_{dh} \quad (1)$$

Additionally, the surface reflects some of the radiation, this isn't taken into account in this case because it won't be as important for horizontal surfaces as it is for inclined surfaces. Researchers calculate the beam normal irradiation I_{bn}, which includes the roughly parallel rays from the diameter solar disc,

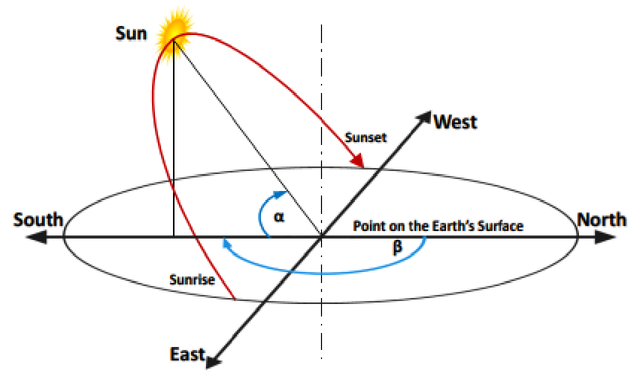


Fig. 1. Sun Angles, the height (α) and azimuth (β)

by using a pyrheliometer with a small field of view (5.8º to 5º) [11], fixed to a tracking device and pointed in the direction of the sun. The relationship between (I_{bh}), (I_{bn}) is the following "(2),":

$$I_{bh} = I_{bn} \times \cos(\theta) \quad (2)$$

The solar zenith angle, indicated as (θ), is the angle that a horizontal surface and the solar disc form, θ = 90º - α. A cosine response of a flat-surfaced solar (light) sensor to incoming radiation is what this is known as. An azimuth angle (β) is unnecessary for determining the angle of incidence of a direct sun ray for a horizontally oriented surface for a surface, (θ) is equal to the complement of the solar altitude angle (90º - α). The response to a direct sunshine beam for a horizontally oriented solar module would equal (I_{bn} x cos (90º - α)), and (α) is solar height. The inclination angle of a solar collector (sensor, array, or module) concerning the horizontal surface of earth is equal to (θ), or the solar zenith angle when the collector is pointed directly at the sun. The expression follows when the global horizontal sun irradiance is represented by equations (l) and (2):

$$G_h = I_{bn} \times \cos(\theta) + I_{dh} \quad (3)$$

Since it keeps the (θ) between solar modules and the direct sunbeams at (0º), where cos (θ) = 1, a 2-axis tracking system is most successful in improving the solar energy harvest for beam radiation (with no clouds). On cloudless days, the visible portion of the radiation makes up 85–90% of the energy from the sun, whereas the remaining 10%–15% is diffuse radiation from sky, mostly scattered by air particles[12]. On cloudy days, around 80% of the sun's energy is dispersed. Since the sun's diffuse radiation isn't parallel to its beam radiation, tracking the sun dramatically lowers the quantity of solar energy generated by a photovoltaic (PV) system on cloudy days [13] and also demonstrates the difference in the relative size of the components of G_h on the sunny and cloudy day. Based on the statistics previously discussed, insolation can be defined as the total quantity of sunlight integrated throughout a given time period. The earth's surface receives about 1000 W/m^2 of solar radiation on a cloudless summer day. The term "one sun" is occasionally used to describe the "standard" 1000 W/m^2 beam of energy and is used in tests to evaluate the output of solar modules.

B. Studies on Improving Basic Inclination Angles

To find out the ideal inclination angle for a solar collector, Elsayed [14] carried out a study that considered the effects the amount of glass coverings, the latitude angle, the clearness index, and ground reflectivity. Concerning latitude, meteorological information, and the nature of the energy demand, Kern [15] determined the ideal inclination of the solar collector. Yadav [16] offered several methods for figuring out an optimal inclination angle to solar panels. Chang [17] used nonlinear time-varying particle swarm optimization to determine the best solar collector inclination angles for seven Taiwanese towns to increase the output electrical power of the modules. A theoretical approach was devised by Soulayman [18] to determine the optimal inclination angle of a solar collector in a free orientation at any time of the year for a surface facing the equator in northern hemisphere. Based on the average horizontal radiation of 152 locations across China, Tang [19] calculated the ideal inclination angles for solar arrays and created a contour map showing the ideal inclination angle for south-facing collectors.

C. The Variations of Inclination Angles for Different Climatic Zones

Kacira [20] looked into the optimal inclination angles for solar collectors in Sanliurfa, Turkey, and discovered that a monthly and seasonal gains in solar radiation over fixed inclination angles were 1.1% and 3.9%, respectively. Monthly optimal inclination angles ranged from 13º to 61º in June and December. Jafarkazemi [21] researched the best inclination angles for PV modules in Abu Dhabi, Emirates, also suggested that an inclination angle be changed twice/year. According to examination, the monthly optimal inclination angles for south-facing surfaces shift from -9º in June to 52º in December. The optimal angle of inclination and orientation for solar collectors at any location in Malaysia's territory was determined by Bari [22], who also discovered that seasonal modifications of the solar collectors might capture up to 40% more of the sun's energy than a fixed slope for the entire year. In the Plataforma Solar de Almeria in Spain, Navntoft [23] analyzed 4 years' worth of solar UV rays measurements on horizontal and tiled surfaces. Kaddoura [24] looked into the optimal inclination angles to solar panels in many cities in Saudi Arabian and found that by doing this 6 times a year, 99.5% of solar power that might be harvested with daily solar panel adjustment could be captured. Le Roux [25] studied the optimal azimuth and inclination angles in South Africa and found that annual insolation for optimally fixed solar panels receives 10% more sunshine than horizontal solar panels and 45% more direct sunlight than horizontal solar collectors. In Saudi Arabia, Benghanem [26] conducted the optimal inclination position for the solar panels also found that, in comparison to selecting an angle of inclination for the month, selecting a fixed angle for the results in an energy collecting loss of about 8%. Elminir [27] looked into the ideal inclination angle for PV modules in Helwan, Egypt, and found that the maximum daily insolation on a south-facing collector was incident close to the horizontal surface during summer and received with an inclination angle of around 43.33º in the winter. A study by Lave [28] found that in United States, solar panels with a specific inclination angle produce 10% to 25% more energy as latitude increases. In Pakistan, Abasi [29] computed the diffuse and global solar radiation. Ulgen [30] determined the optimal inclination angles for installing solar energy collectors in Turkey and found that they vary from 0º to 61º from June through December. Moghadam [31] looked into the optimal inclination angles for PV modules in Zahedan and Bandar-Abbas, 2 Iranian cities, and found that just two inclination angle adjustments resulted 8% increase in total amount of energy collected in a year. In Cyprus, Ibrahim [32] studied the ideal inclination angle and found that it is 48 degrees in winter and 14 degrees in the summer. Using statistics of sunlight hours, Ahmed [33] looked on the efficiency of solar energy use in Pakistan. He found that April has the lowest diffuse radiation and July the highest. He determined that solar energy could be used successfully throughout the year, except during the monsoon season. During fixed-inclination photovoltaic systems in Nigeria, Ekpenyong [34] created a polynomial model to determine the best inclination angle during winter. He found that the perfect winter inclination angle is 24.73º. In New Delhi- India, the best inclination angle for solar module, Ahmad [35] discovered that the best inclination angle varies between 0º and 58º for summer and winter. To maximize performance, Saraf [36] determined the ideal inclination angle for solar panels in Iraq. The results indicated that when the inclination angle of solar panel is modified eight times a year rather than daily, the same amount of energy is gathered. In Bangladesh, Gosh [37] calculated the ideal inclination position of solar collectors and found that it is 10º for March through September also 40º for October through February. Bakirci [38] optimized inclination angles in Turkey and found that the ideal inclination angle fluctuated between 0º and 65º during a year. Using a mathematical model, Yakup [39] evaluated the best inclination angles for Brunei Darussalam and discovered that adjusting the inclination angle 12 times a year results in 5% increase in solar radiation annually compared to the case of a solar array fixed to a level surface. According to Aja [40], the ideal inclination angle in Malaysia vary according to the season, ranging from 0º to 27º. Skeiker [41] conducted a similar investigation in Syria and discovered that by altering the inclination angle of the solar module 12 times, the highest amount of sunlight output throughout the year is possible.

D. Influencing Factors

Several factors are considered when determining the spacing between two rows of PV modules. Whether the PV modules are arranged singly or in pairs, the first consideration is their size. Additionally, the designer's chosen inclination angle is important. The size and the production of station are also influenced by the dimensions and available space for its installation.

E. Skelion program

Skelion is the simulation program that serves as a plugin for SketchUp. It assists in calculating the workings and operations of PV systems. This software enables the design of system configurations and helps determine the amount of energy generated. The output is based on a simulation of the system's size, which depends on the location of PV system's site. The results can include numerous simulation variables shown as hourly, daily, or monthly values. The "loss diagram" helps anticipate system design flaws. The steps listed below are used to run simulations in Skelion program: -

1. *The Defined Project*

Numerous websites and meteorological files are already available in the Skelion databases. On the other hand, people can design projects according to the location of site and the meteorological information they plan to utilize.

2. *Creation of System Variants*

User must create the calculation version of the project created in step 1. They must define the module orientation, system configuration, and loss parameters.

3. *Executing the Simulation*

The simulation produces various reports for the photovoltaic system. Users can store the results for additional examinations, export them to different programs, or analyze them within the program. The research aims are as follows:

- Evaluate the site's potential for solar energy.
- Consider the available space when designing the photovoltaic system and its layout.
- Use Skelion software simulation to evaluate performance ratios and losses.
- Determine the optimal angle for installing PV panels to maximize electrical energy production and minimize shadow effects on the panels.

III. Work Suggestions

When comparing small and large solar power stations, Losses are shown to rise in proportion to the station's size. This research examines the losses of standalone photovoltaic system and its performance. Various factors contributing to losses are analyzed, and the plant's performance is measured using its performance ratio. The Skelion simulation was used to assess losses across different fields, and the performance ratio was calculated using simulated performance. Operating the station includes assessing energy, solar assets, losses, and the overall effect of performance ratios.

IV. Methodology

A. Building the standalone photovoltaic system

Rooftop standalone systems aren't connected to any grid and can have capacities ranging from a few watts to several kilowatts. The primary components of these systems are solar modules, a controller, and an inverter. These systems run on batteries. Solar panels are installed over a mounting framework and generate DC electricity. The battery is charged using the charge controller, which has 2 tasks: charge batteries and guard against overcharging. It prevents any nighttime reverse current flow from batteries back into solar panels. The stored energy is converted by the inverter into AC to operate AC equipment. Additionally, there is a requirement for additional accessories, such as UV-safe cables suitable for outdoor applications. It's important to keep control of losses and voltage drops inside the cable to an absolute minimum.

B. The project's Geographical Location

This research was conducted in a public school. There are public buildings with large, clear roofs in different locations within Egyptian cities. The building is often located in the middle of a large area, so its roof isn't affected by shadows from other structures.

Fig.2.shown, the public school has three buildings with obstacle-free roofs, covering an area of 1478 m^2. By utilizing Google Earth, the dimensions and location of the school buildings were determined. The master building has two sections: one measuring 48 x 9m and the other 28 x 10m, with an area of 808 m^2. The southern building measures 48 x 9m, covering 423 m^2, and the rear building measures 10 x 25m, with an area 247 m^2. These dimensions make the buildings suitable for constructing a medium-sized photovoltaic power station. The results from the Skelion program and Google Earth show convergence in the school site's coordinates and the three buildings' dimensions, indicating the reliability of the expected search experiment results. According to the database of Skelion software, El Manyal- El Nile Secondary School is at longitude 31.2270ºE and latitude 30.0269ºN. Table I summarizes the monthly global irradiation, diffused irradiation, temperature, and other relevant data from the (PVGIS) website (Photovoltaic Geographical Information System) [42]. Skelion software utilizes the PVGIS-SARAH database as a reference for conducting meteorological data simulations and generating reports.

C. Calculating the Sun angles

In the northern hemisphere, on 21 December of each year, when the shadowing from objects is at its maximum, it should be understanding the sun's path at the system's exact location. Considering and identifying the crucial solar radiation angles, elevation, and azimuth are key steps in designing a sun chart for a photovoltaic system. The two-dimensional sun path example in Fig. 3 demonstrates how these angles can be derived from the chart. The longest shading occurs between 9:00 a.m. and 3:00 p.m., as depicted in the image. By drawing the blue line in Fig. 3, it becomes evident that the sun's azimuth angle is approximately ≈ 45º and its elevation angle is approximately ≈ 21.5º on 21 December, the day with the most pronounced shadowing. It is also observed from Fig. 2 that Google Earth displayed an elevation angle value 21 meters, further validating the accuracy of the estimation.

The principle states that object shadows increase as the elevation angle decreases, reaching their minimum value during winter [43]. Therefore, when installing a photovoltaic system, it should be considered the elevation angle to avoid shading the PV array behind it. Extensive computation is required to calculate the optimal distance between array rows. This study presents a method for selecting the most effective location to minimize the occupied area and maximize energy output.

Fig. 2 Nile Secondary School Coordinates and Dimensions taken from Google Earth

Table I
PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM (PVGIS) [42] FOR EL MANYAL

Year	H(h)_m 2018	H(h)_m 2019	H(h)_m 2020	H(iO)m 2018	H(iO)m 2019	H(iO)m 2020	H(i)_m 2018	H(i)_m 2019	H(i)_m 2020	Hb(n)m 2018	Hb(n)m 2019	Hb(n)m 2020	Kd 2018	Kd 2019	Kd 2020	T2m 2018	T2m 2019	T2m 2020
Jan	115.54	120.21	107.26	165.64	174.4	150.32	154.3	162.09	140.65	155.87	168.76	135.13	0.35	0.33	0.4	13.7	12.6	12.8
Feb	127.55	126.94	120.32	163.9	165.17	152.48	156.41	157.23	145.92	145.94	155.48	130.57	0.37	0.33	0.41	17.3	13.9	14.3
Mar	188.62	178.43	170.03	219.28	206.5	195.31	214.55	202.24	191.55	208.07	193.86	174.47	0.29	0.31	0.35	20.6	16.4	17.1
Apr	209.31	206.99	214.18	215.98	212.74	220.16	218.08	215.02	222.51	211.82	209.19	215.29	0.28	0.28	0.29	22.9	20.6	21
May	225.45	246.71	248.21	211.41	231.2	233.04	219.11	239.84	241.71	213.71	253.52	254.28	0.31	0.25	0.25	27	27	25.8
Jun	249.77	244.18	250.69	222.92	219.31	224.7	234.37	230.2	235.96	267.28	252.18	265	0.22	0.23	0.21	28.9	29.2	27.9
Jul	251.84	253.56	251.72	230.89	231.94	230.7	240.93	242.2	240.77	262.87	267.2	261.93	0.22	0.22	0.23	29.7	30	29.2
Aug	232.45	235.74	234.8	230.66	233.84	232.88	235.37	238.68	237.73	239.13	247.7	246.1	0.26	0.24	0.24	29.3	29.9	29.5
Sep	194.52	194.34	194.13	215.44	214.87	215.23	213.44	212.94	213.18	207.3	205.26	207.34	0.28	0.29	0.28	27.7	27.1	28.9
Oct	160.73	154.89	163.41	201.51	191.48	205.33	193.52	184.48	197.13	186.81	173.91	196.29	0.31	0.33	0.29	24.1	24.5	25.4
Nov	124.48	128.83	116.63	175.69	184.23	162.69	164.27	171.82	152.45	170.34	184.89	151.72	0.31	0.28	0.35	19.5	20.9	19.1
Dec	103.25	111.53	112.12	150.35	168.34	169.47	139.54	155.19	156.18	136.36	166.35	168.28	0.39	0.32	0.32	14.7	15	15.9

H(h)_m: Irradiation on the horizontal plane (kWh/m^2/mo)
H(iO)m: Irradiation on an optimally inclined plane (kWh/m^2/mo)
H(i)_m: Irradiation on a plane at an angle (kWh/m^2/mo)
Hb(n)m: Monthly beam (direct) irradiation on a plane always normal to sun rays (kWh/m^2/mo)
Kd: Ratio of diffuse to global irradiation (-)
T2m: 24-hour average of temperature (degree Celsius)

D. Inter-row shading

It is assumed that the azimuth angle (Ψ) of the module shading with the horizontal. In Fig. 4, the estimated height (Y) is illustrated. The shade length can be calculated as (Z) since

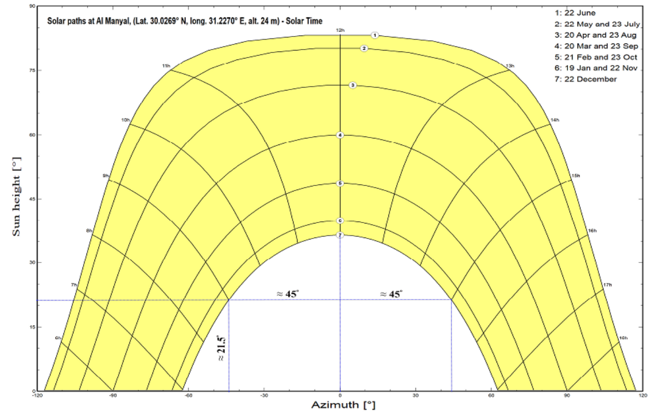


Fig. 3. Sunpaths in two dimensional with computed angles

the sun path provides the elevation angle (α), the module's dimensions are used to estimate the height and inclination angle (β). However, the slope of the shadow means that its apparent length (Z) can't be considered an accurate measure of distance.

When a triangle is positioned horizontally, Z-value and the azimuth angle can be used to calculate the spacing, denoted by (X). By computing these angles and the size of panel, it becomes feasible to determine the separations between rows of photovoltaic arrays. Once the angles have been estimated graphically, the inter-row spacing can be calculated using the following equation:

$$Y = L \sin \beta \tag{4}$$

Where (Y) represents the height of the module terminal, (L) represents the length of photovoltaic module, and (β) represents the module's inclination angle. The inter-row spacing can be predicted using the following formula:

$$Z = \frac{Y}{\tan \alpha} \tag{5}$$

Where (X) represents the shadow length and (α) is the sun's elevation angle as observed from the path of the sun.

$$X = Y \text{ x } \frac{\cos \Psi}{\tan \alpha} \tag{6}$$

In Fig. 5, we can see the two-dimensional layout for solar panel installation, which includes the height (Y), inter-row spacing (X), and installation angles (elevation angle α and inclination angle β). The elevation angle varies based on the geographical region and significantly affects self-shading. The inclination angle can also differ depending on the number of panels used, as determined by the system designer. Additionally, X, Y, and L represent the distance between successive arrays, the module's height in its vertical projection, and the module length, respectively.

E. Methods for Determining the Ideal Area

The size of solar panel, its inclination angle, and its geographical location all play a crucial role in determining the area of solar system. The shade duration and the row spacing are critical factors influenced by the geographical location. It is essential to calculate the ideal spacing between rows to minimize the space required for installing the system while optimizing the production of energy by selecting the optimal inclination angle for the site. Avoiding shade ensures the most efficient use of space, resulting in maximum energy production. Assuming a specific size for the solar panels and the spacing of the array, Fig. 6 illustrates the factors in estimating the area.

When the installed system is composed of (N) vertical modules that are W x L per (R) arrays and inclined at an angle (β), then the spacing between rows must be equivalent to (X). As a result, when modules are spread equally, the system's total occupied area equals:

$$\text{Area} = N \times W \times (R \times L \cos\beta + (R - 1) \times X) \quad (7)$$

F. *Inclination angle*

A solar module's inclination angle is the key to unlocking maximum solar energy. We can ensure minimal energy loss and maximum efficiency by strategically positioning the panels to face the sun. Our complex is designed for flexibility, allowing easy modification of the inclination angle to adapt to seasonal changes. However, we've implemented a yearly average inclination to keep costs down without sacrificing performance. Every day, the sun's position changes, impacting the angles at which the panels receive sunlight. By aligning the inclination angle with the site's latitude and calculating the ideal slope angle, we can harness the greatest possible solar energy [44].

This differs by country, with the inclination angle peaking in winter and falling for optimal energy capture. Our photovoltaic systems have demonstrated remarkable improvements when employing the optimal yearly inclination angle, showcasing the power of this design choice. Conversely, tracking systems pose maintenance challenges in poor nations, making the fixed yearly inclination angle an attractive and practical option for maximizing solar energy [45]. Based on the study's findings [25] [44], a well-positioned solar installation can capture approximately 10% more solar energy annually compared to a collector mounted horizontally. This study has revealed the precise angles at which solar collectors should be installed to maximize solar energy absorption throughout the year. The optimal fixed inclination angle aligns with the location's latitude, while the best fixed

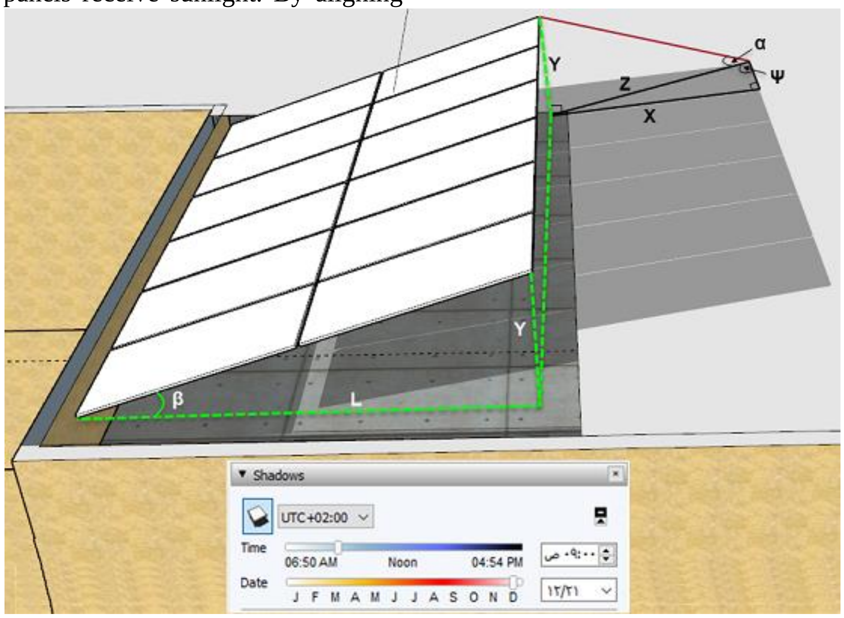


Fig. 4 PV module placement dimensions and shadow angles

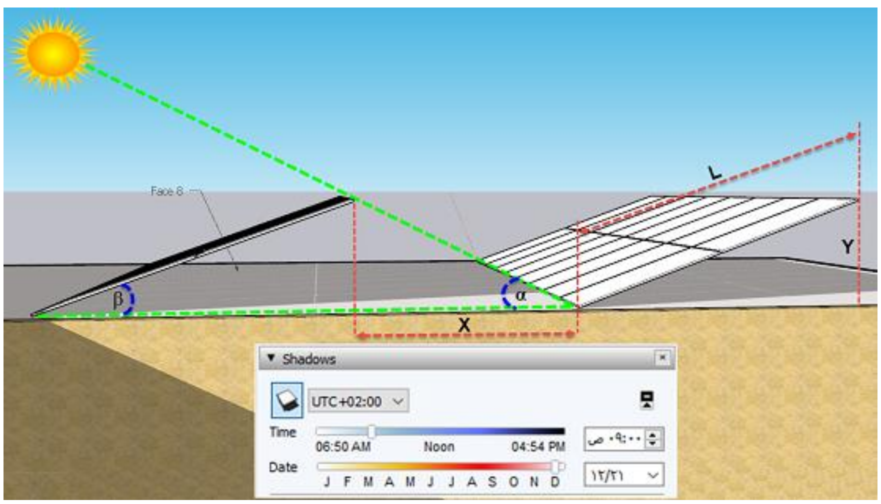


Fig. 5 The solar panels' two-dimensional design

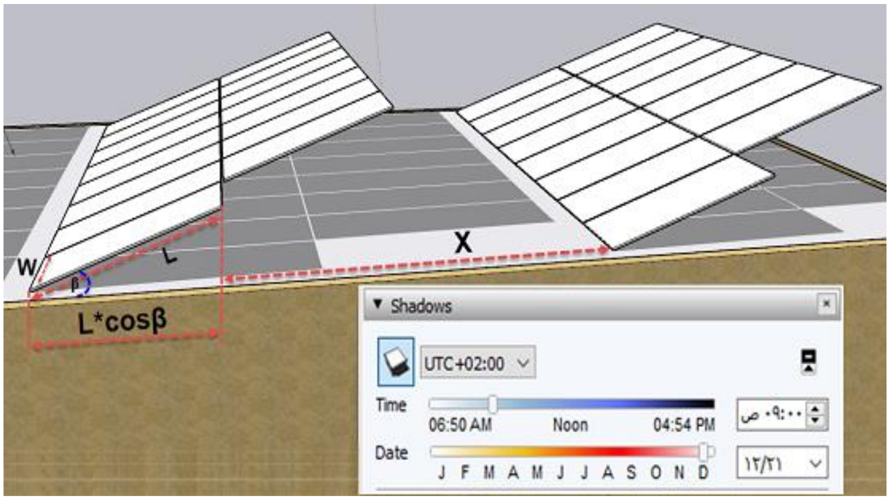


Fig. 6 Geometrical dimensions of components for area estimation

azimuth angle depends on the difference between the longitude angle and the absolute latitude angle. These findings underscore the importance of strategic positioning for maximizing solar energy capture.

G. *Suggested inclination angle*

Based on earlier studies, the perfect inclination angle for solar modules is 30º, which coincides with the facility latitude (30.0269ºN). Nevertheless, recent research suggests that the optimal inclination angle may vary depending on a location. Therefore, it utilizes a sun map to identify the ideal inclination angle, which should align with an elevation angle that creates most shadows through year. This approach ensures maximum solar efficiency and energy generation.

The ideal inclination angle for positioning the panel at this location is 21.5º, as illustrated in Fig. 3, where an elevation angle on 21, December between 9am, 3pm is 21.5º. Furthermore, multiple tests will be carried out using the SKELION program to vary the panel inclination angle between 0º, 40º to verify the accuracy of the assumption.

To accurately compare the impact of shadow on photovoltaic panels with different inclination angles, it's crucial to standardize certain factors. We ensured a consistent spacing of 0.6 m between the solar panel arrays to obtain reliable results. Our findings revealed that, regardless of an inclination angle, there were consistently 13 fixed arrays of modules, with a maximum of 411 panels at this fixed distance. This vital information was thoroughly discussed in an inter-row shading section.

- The main building boasts 214 modules arranged horizontally on the roof. The impressive setup includes:
  4 arrays of 2 rows x 8 columns, totaling 64 modules
  1 array of 2 x 6, with 12 modules
  1 array of 2 x 15, with 30 modules
  1 array of 2 x 41, with 82 modules
  1 array of 1 x 26, with 26 modules
- In a southern building: 133 panels total, 7 rows by 19 columns were arranged horizontally on the roof in a single array.
- The Western Building: Four arrays of 64 panels, each with 2 rows and 8 columns, were arranged horizontally on the roof.

V. VALIDATION PROCEDURES AND CASE STUDIES (SIMULATION)

A. *Conducting Experiments*

The X-axis in SketchUp is represented by the red line, the Y-axis by the green line, and the Z-axis by the blue line. True North is indicated by the green axis in the "Plan View" whereas the Z-axis represents the vertical axis. Fig. 7A, created using SketchUp features, illustrates the geographic patterns and school's location. True North is indicated by the arrow and the green line. The figure also displays the GPS coordinates of the school: longitude 31.22708ºE and latitude 30.0268887ºN, along with the date & time (noon, 21 December) in the time zone UTC+02:00. On this date, dawn occurs at 06:50 and sunset at 14:55. So, Fig. 7B depicts the school structures on the precise same site after their design. The PV station is built on the roofs of these structures, with the photovoltaic modules oriented towards the geographic south, as indicated by a green arrow and line pointing towards the geographic north.

The only thing hidden from view to show the design elements is the geolocation map. This makes it easy to see the building's size, slope, and borders, as well as the roofs of the buildings with photovoltaic modules and the different shadow patterns and their effects. Fig. 8 illustrates this.

B. *Distances 0.6 m, changing inclination angles.*

Fig. 9 illustrates the profound impact of shadow on solar panel efficiency based on varying inclination angles. The data reveals that at inclination angles between 0º, 18º, the shadow-induced loss is negligible, ranging from 0.25% to 0.47%. However, as the inclination angles increase beyond 22º, the loss consistently and significantly rises, reaching 1.74% at angles between 24º, 40º. Furthermore, the graph showcases how the inclination angle influences the yield, with a steady increase 1500 to 1597 between 0º, 15º. At inclination angles of 22º, 21.5º, 21º, 20º and,18º, the yield stabilizes at 1603, indicating a critical balance point. Beyond 22º, the yield decreases as the inclination angle increases, ranging from 1600-1510 between 24º, 40º. This data underscores the crucial role of inclination angles in maximizing solar panel efficiency and should be considered in solar panel installations.

Fig. 10 illustrates the impact of shadow on energy loss due to changes in inclination angle. It also shows how the inclination angle affects the energy generated, with the output increasing as the inclination angle rises. Between inclination angles 0 and 15º, the energy generated increases linearly from 333 MWh to 354.429 MWh. After reaching 15º, the energy generated approaches almost constant value 356 MWh, particularly at inclination angles of 18, 20, 21, and 21.5º, where changes in inclination have little effect on energy output. However, as the inclination angle increases from 24 to 40 degrees, the generated energy begins to decline, dropping from 355.142 MWh to 335.23 MWh.

Figure 11 compares the energy output and yield to determine the optimal angle for installing the solar modules on the institution's building roofs. The graph shows that the value of yield remains nearly constant at its maximum 1603 for angles of 22º, 21.5º, 21º, 20º and,18º. At these angles, the generated energy values are also close together, ranging from 355.677 MW to 355.837 MW. Notably, the highest power output occurs at angle 21º, reaching 355.837 MW. This suggests that installing PV panels at angle 21º would be the most efficient choice for optimizing the production of energy. By optimizing the installation angle, the institution can ensure greater solar energy capture, ultimately enhancing its sustainability efforts and reducing its carbon footprint.

Ignoring the module's inclination angle, Fig. 12 shows that the energy yield is proportional to the average monthly radiation received by the solar panels. This highlights that the quantity of solar radiation in the chosen location for the PV station is a crucial factor influencing the electrical energy produced by the photovoltaic panels. Additionally, it emphasizes the importance of selecting optimal locations for solar installations, as regions with higher average radiation levels can significantly enhance energy production. Consequently, thorough site assessments and solar radiation mapping should be integral steps in the planning process for any photovoltaic project.

Fig. 13 illustrates the impact of solar radiation on photovoltaic panels. It demonstrates that no matter how the panels are angled, the energy produced is proportional to the yearly average of radiation they receive. This clear relationship highlights the importance of optimizing panel positioning to maximize energy output, making a strong case for the efficiency of solar technology in harnessing renewable energy. Furthermore, as the data suggests, even slight adjustments in the angle of panels can lead to significant increases in energy production. This underscores the necessity for ongoing research and development in solar technology to enhance its effectiveness and sustainability.

The impact of inclination angles on shadow loss is illustrated in Figures 14a, 14b, and 14c as follows:

- Throughout the year

When evaluating the optimal inclination angle, it’s clear that a 0º angle stands out as the best choice throughout the year. This angle significantly minimizes shadow loss, with only a mere 0.06% in May and reaching just 0.76% in February and December. By selecting this angle, you can ensure the highest efficiency and performance, making it an intelligent and strategic decision for maximizing your energy output. Moreover, maintaining a 0º inclination angle simplifies installation and reduces maintenance costs, further enhancing its appeal for both residential and commercial solar energy systems. This optimal configuration not only supports consistent energy generation but also contributes to the overall longevity of the PV panels.

- During January, February, November, and December

The optimal angles for installing photovoltaic panels are 5º, 10º. These angles minimize shadow-related losses during that period, with losses ranging from 2.7% in December to 1.92% in November. Additionally, these optimal angles enhance the overall energy capture efficiency of the panels throughout the winter months, ensuring that solar energy production remains maximized even when daylight hours are shorter. Proper installation at these angles can significantly improve the return on investment for solar energy systems.

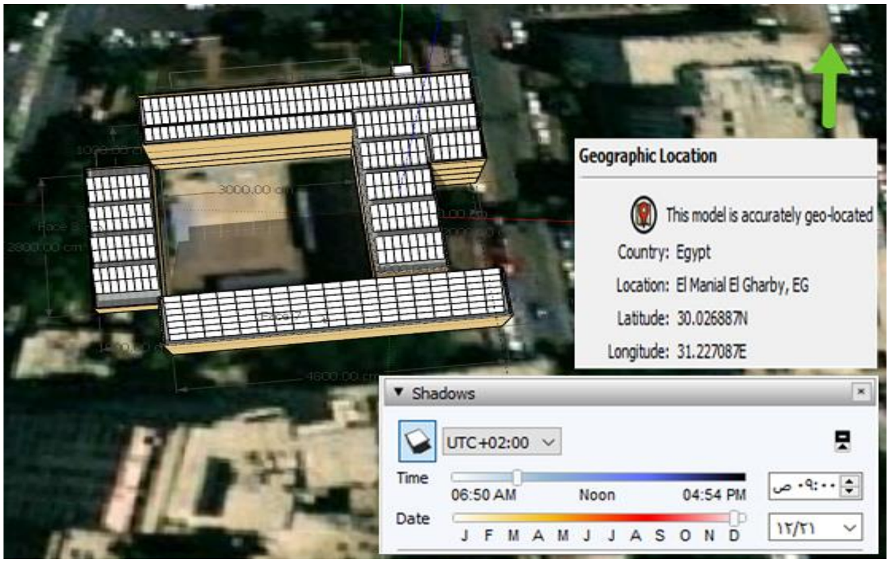
- During October and March.

For optimal solar module performance, consider installing them at angles of 21.5º, 21º, 20º, 18º, 15º, 12º, 10º, or 5º. These carefully chosen inclinations are proven to significantly reduce shadow losses, ensuring your investment in solar energy operates at its best. In fact, you can expect losses as low as 0.8% in March but in October only up to 1.5%. Choosing the right angle not only maximizes energy efficiency but also enhances your overall savings—making it a smart, sustainable choice for your energy needs. These advantages culminate in a more reliable energy output throughout the year, allowing homeowners and businesses alike to benefit from a steady return on their solar investments. Furthermore, optimal inclination angles contribute to prolonging the lifespan of photovoltaic panels, ultimately reducing maintenance costs and enhancing overall return on investment.

- During September and April.

To maximize energy efficiency, it's crucial to consider the impact of shadow on solar panel performance. Research has shown that energy loss due to shadow can be as low as 0.23% in April but in September rise to 0.77%. By strategically mounting your photovoltaic panels at angles of 22º, 21.5º, 21º, 20º, 18º, 15º, 12º, 10º, or 5º, you can significantly reduce energy loss and harness the maximum potential of sunlight throughout the year. By carefully assessing the seasonal sun path and local shading conditions, homeowners can enhance their system's efficiency even further. Implementing such strategies not only maximizes energy production but also prolongs the lifespan of the PV panels, ensuring a more sustainable energy solution.

(A)



(B)

Fig. 7 Location of School and Geographic Trends

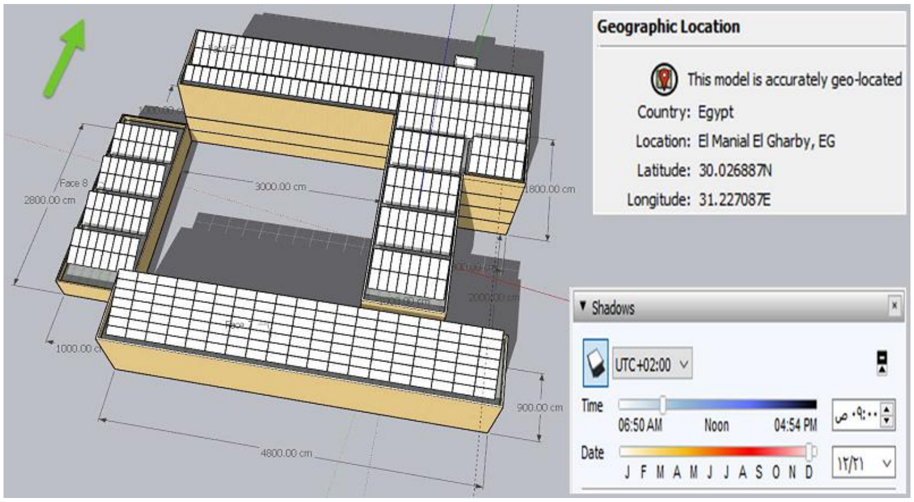


Fig. 8 School's Structures and Solar panels mounted on their Roofs

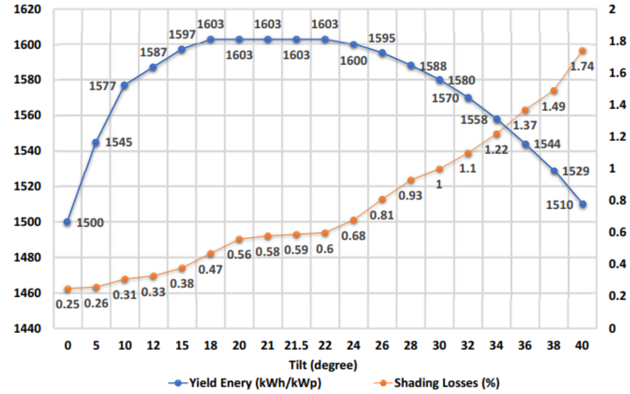


Fig. 9. Shading Losses with Yield Energy

Fig. 10. Shading Losses with Energy Yearly

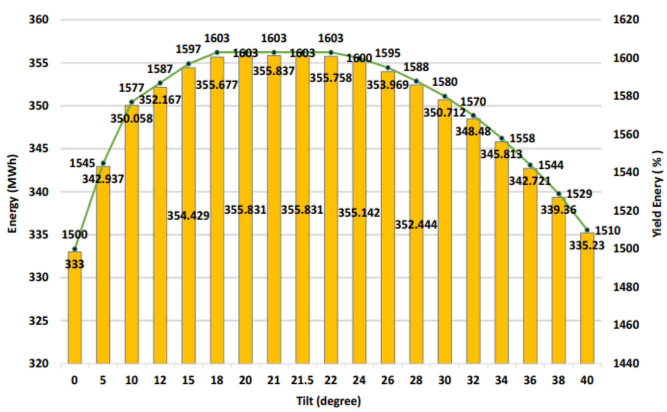


Fig. 11. Energy and Yield

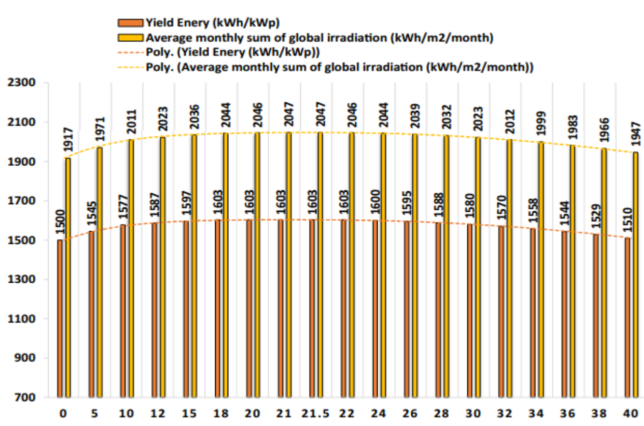


Fig. 12. Global Irradiation with Yield Energy

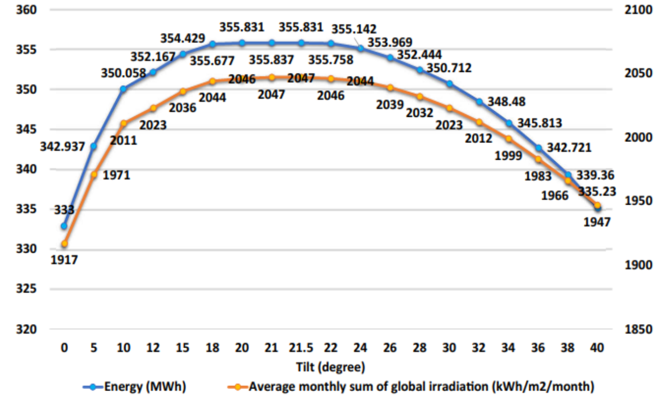
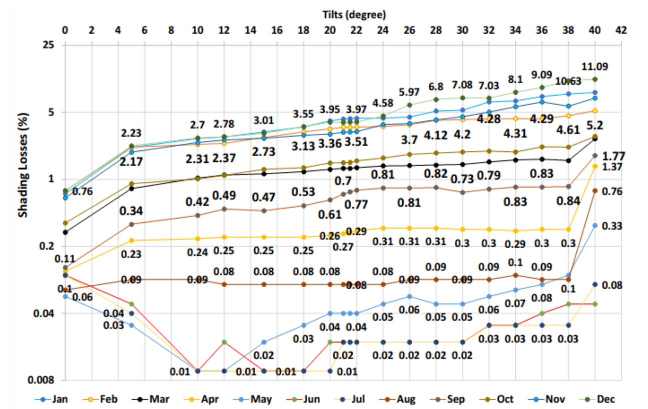
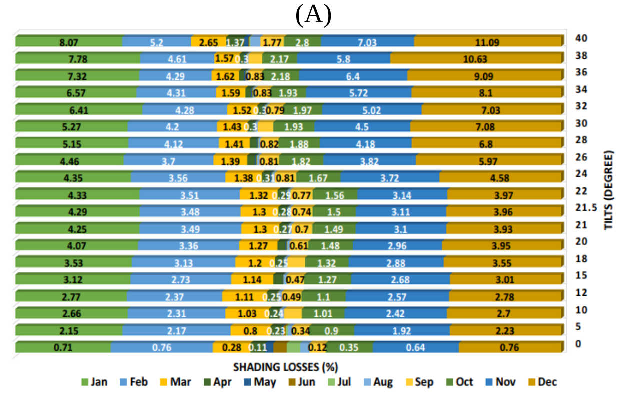


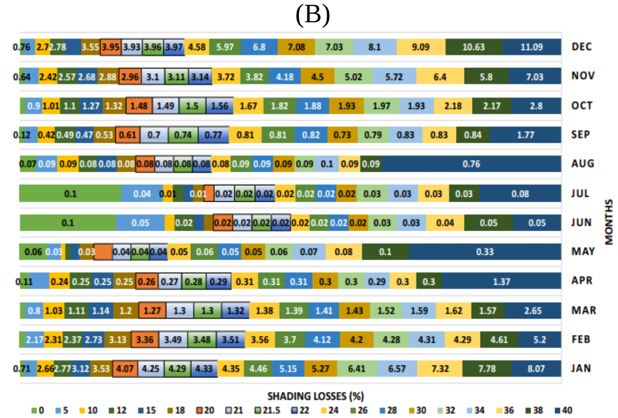
Fig. 13. Global Irradiation with Energy



(A)



(B)



(C)

Fig. 14. Losses from Shading each Month

Table II

SUMMARY OF RESULTS

Tilt	Azimuth	No. of panel	Energy (MWh)	Yield Energy (kWh/kWp)	Average monthly sum of global irradiation (kWh/m2/month)	Shading Losses (%)	Efficiency
0	180	411	333	1500	1917	0.25	17.371
5	171	411	342.937	1545	1971	0.26	17.399
10	171	411	350.058	1577	2011	0.31	17.407
12	171	411	352.167	1587	2023	0.33	17.408
15	171	411	354.429	1597	2036	0.38	17.408
18	171	411	355.677	1603	2044	0.47	17.401
20	171	411	355.831	1603	2046	0.56	17.392
21	171	411	355.837	1603	2047	0.58	17.383
21.5	171	411	355.831	1603	2047	0.59	17.383
22	171	411	355.758	1603	2046	0.6	17.388
24	171	411	355.142	1600	2044	0.68	17.375
26	171	411	353.969	1595	2039	0.81	17.360
28	171	411	352.444	1588	2032	0.93	17.345
30	171	411	350.712	1580	2023	1	17.336
32	171	411	348.48	1570	2012	1.1	17.320
34	171	411	345.813	1558	1999	1.22	17.299
36	171	411	342.721	1544	1983	1.37	17.283
38	171	411	339.36	1529	1966	1.49	17.261
40	171	411	335.23	1510	1947	1.74	17.218

- During August, July, June and May.

To minimize energy loss from shadow during the summer months (August, July, and June), the optimal angles for installing solar modules relative to a horizontal surface are as follows: 32º, 30º, 28º, 26º, 24º, 22º,21.5º, 21º, 20º, 18º, 15º, 12º, 10º, and 5º. Energy loss levels vary between 0.09% in August and 0.01% in July and June.

- During July and June.

In summer, the sun's position creates minimal shadows between solar arrays, leading to a remarkable efficiency loss of only 0.08% in July and 0.01% in June. Modules tilted between 5º, 40º perform effectively with little concern for shading. Choosing this optimal inclination range can significantly enhance energy production and maximize solar investment.

VI. CONCLUSION

Egypt boasts a substantial number of public schools, with the total of 31,290 schools. Each school typically has an average roof area of 1,500 square meters. According to statistics, the average solar capacity for every square meter is between 180 and 300 Watts/year. This variation depends on the location of the PV station, its performance, and the local climate conditions. As a result, the average energy production from photovoltaic systems installed on school rooftops ranges from 270 to 450 Kilowatts annually. By utilizing the rooftops of public schools for this purpose, it is anticipated that renewable electrical energy production could be between 8,448 megawatts and 14080 megawatts per year.

The research used many artificial intelligence software, like Google Earth, to infer the following variables: building dimensions, site coordinates, surface area available for building the station, elevations in the area during the year, and daily sun angles. Using SketchUp, we developed an accurate building model at the exact site coordinates and dimensions. To maximize efficiency, we incorporated Skelion to analyze key variables, such as calculating daily shade patterns, determining sun angles and heights, and identifying the best inclination angles for photovoltaic panels. Additionally, we calculated the optimal distance between module rows, assessed solar radiation levels, monitored module temperatures, and estimated the annual production loss at the station. This comprehensive approach ensures an effective and sustainable energy solution. To calculate the energy loss, we need to evaluate the annual production decline at the station, the total electrical energy produced, the quantity of solar radiation received by the photovoltaic panels, and the climate factors specific to the regions, and these analyses can be performed using the PVSYST application. The research findings demonstrated that the optimal inclination angle of photovoltaic panels plays a crucial role in enhancing the productivity of photovoltaic stations. As the inclination angle increases, so does the energy output, with the optimal range for roof-mounted panels identified between 18º, 22º. In this range, the effects of shading are minimized, ensuring maximum electrical energy generation. Shadows have an impact on the electrical power produced when the solar panels are angled between 24º, 40º, and the electrical energy produced falls as the inclination angle increases. By optimizing the tilt, we can harness more energy and improve overall efficiency. The research findings confirmed the significance of solar radiation on the photovoltaic panels. The electrical energy produced is proportional to the average monthly solar radiation that falls on these modules, regardless of their angle of inclination.

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