MAK HILL Publications Journal of Engineering and Applied Sciences

Research Article
doi: jeas.2022.52.60

Estimation of Optimum Slope Angles on the South Directions of Photovoltaic Panels in Khartoum, Towards to a Sustainable Design

[1]Zeinab A. Elhassan, [2]Arafa A. Abbass, [3]Mona D. Abdalrazig and [3]Faiga Magzoub

[1]Department of Interior Design College of Architecture and Design, Prince Sultan University, Riyadh, Kingdom of Saudi Arabia

[2]Department of Archieture College of Architecture and Urban planning, Omdurman Islamic University, Sudan

[3]Department of Interior Design College of Architecture and Design, Jazan University, Kingdom of Saudi Arabia

OPEN ACCESS

Key Words
Optimum, slope, angles, orientations, photovoltaic, panels, Khartoum, sustainable, design

Corresponding Author
Zeinab A. Elhassan
Department of Interior Design, College of Architecture and Design, Prince Sultan University, Riyadh, Kingdom of Saudi Arabia

Received: 10 September 2022
Accepted: 22 September 2022
Published: 27 September 2022

Citation: Zeinab A. Elhassan, Arafa A. Abbass, Mona D. Abdalrazig and Faiga Magzoub, 2020. Estimation of Optimum Slope Angles on the South Directions of Photovoltaic Panels in Khartoum, Towards to a Sustainable Design. J. Eng. Applied Sci., 17: 52-60, doi: jeas.2022.52.60

ABSTRACT

This article examines the ideal tilt angle for photovoltaic (PV) modules to capture its most power. The tilt and slope angles of a photovoltaic solar panel (PV) array affect the amount of solar energy that is incident on the array. The most important of advantage of PV panels were High safety and reliability and it has low maintenance costs this beneft make it as a first choices of sustainable design. The analysis is based on the most power-generating measured values of daily global and diffuse solar radiation on a horizontal surface. Various ideal tilt angles (23°) for each direction during sunny days per year are demonstrated. Permit maximum power energy collection for Khartoum location on an annual and monthly basis. Also explored are the affects of PV roofing orientation on the power output of PV modules, with the module surface assumed to be facing basic orientation at varying angles and difneoptimum direction which generate the maximum power by experimental process and found south and 23° degree the most optimum one for location. The annual optimal tilt angle was determined to be unevenly 23° degrees south of the latitude of the location. In comparison to the various optimal tilt and four directions. Results provide realistic solutions for optimal BIPV tilt angles for grid-connected systems.

INTRODUCTION

One realistic way to figure out the best angle for a fixed roof to collect the most energy is to use monthly global and diffuse radiation on a horizontal surface. The building's rating is an important consideration when determining whether to help pay for a photovoltaic system. Furthermore, the type and amount of radiation in different places depend on the weather and other conditions[1,2]. So, the angle of inclination of the photovoltaic modules' fixed structure was carefully looked at in different places and at different times to give the General Assembly the most power. First, the position of the sun in the sky, which changes as the earth spins on its axis, or solar energy geometry, which is used to figure out the best tilt angle for PV modules[3].

Preferred the attitude of solar orientation in Khartoum: Many of the technologies for renewable energies have been powered by the sunlight. This resource has a wide range of ways it could be used around the world, either directly or indirectly through solar, biofuels, wind and water power. Sudan is one of the best places in the world to use solar power. Omer[4] found The sunlight for between 8.5 and 11 h a day and the average amount of solar radiation on the horizontal surface anywhere between 20 and 24 Mj/m^2 day^{-1}. The average daily radiation around the world is between 3.05 and 7.62 kWh/m^2 year^{-1}. Sudan, on the other hand, has an average of 7-9/m^2 year^{-1}, which is the same as 436-639 W/m^2 year^{-1}. According to the Wazed *et al.*[5], the country works hard to use technologies related to renewable energy sources in rural areas where it makes sense and is useful to do so. Sudan has already been using solar thermal energy for a long time.

Orientation of optimum direction tilt roof for slope roof design: Designers' interest has been stimulated by a few rare architectural advances, like the Solar House. Although successfully integrating a solar house in Khartoum can be compared to the diagram, this is essentially a building oriented and constructed to admit a minimum amount of direct sun organize is simpler to do where the module faces True South. The module can be positioned slightly east or west of True South and True North on the roof. As depicted in Figure east of True South, solar radiation will be stronger in the morning. found in the study and that probably applies, obviously, if the module is positioned west of True South, greater capture will occur in the afternoon if it is oriented west of True South. Additional electricity, if available, may be delivered between 4:00 and 6:00 AM. On Saga Deep Island, India, if it is available. Inverters (3-15 kVA) are used to convert DC electricity to AC power in 28°[6]. The configuration includes three feeders, one for the plant and the other two for consumer loads In Khartoum, the optimal angle was discovered to be 23.5 degrees. The researcher should clarify this result practically in order to identify this angle and acquire the data that will confirm the optimality of this angle. The width of the overhang increases dramatically with each degree of orientation away from True South. In Khartoum, the Position of the Sun for a number of distinct hours on each day is used to determine the Sun's azimuth. compare In his research and findings about systems, system dependability is a crucial factor. Winter is characterized by reduced irradiance in most regions. Consequently, the most unreliable season might be utilized as a design benchmark. Optimal slopes can be identified. The maximum value of annual total irradiance occurs at a south-facing orientation with a slope angle of 41° and 18.5°, while the value decreases by 4.32%. The optimal direction to tilt the slope to capture the maximum solar radiation for PV modules was determined based on seasonal conditions, architectural design and roof slope design.

Optimums tilt angle and orientations of PV for building-integrated photovoltaic (BIPV) application systems: Module orientation has a significant impact on the performance of photovoltaic modules and building integrated photovoltaic systems (BIPV). The orientation and angle of the photovoltaic modules must maximize direct sunlight and prevent unnecessary shading. Most previous studies dealing with the problem of quality and quantitatively at a given location. For solar energy applications, optimum orientation is usually in the presence of the South the Northern hemisphere and the optimum tilt angle depends only the local latitude:

$$\beta_{opt} = f(\theta)$$ [6]

Surface inclination angle and azimuth angle can be varied over a considerable Area without significantly reducing the amount of the annual incoming solar radiation. There are limits to the former quantitative studies. The hourly clearness index was not considered and simplified Sky models were used in the rule, while accurate anisotropic sky models. We can specify more precise results than the[6]. An experimental study to investigate the effect of using different types of sun systems in monitoring Power generation and discovered that there is more power Up to 43.87%, 37.53, 34.43 and 15.69% for two axes, east, west, vertical and North in the South and tilted relative to the fixed surface 32° to the South in Jordan[7]. A photovoltaic system must installed to maximize the solar contribution to a certain load. The optimum tilt angle and orientation depend on the local PV Climate, latitude and time load profile[8]. The optimum tilt angle is thus dependent on the side, therefore, require the calculation of this angle solar radiation data these pages for the entire year[9]. The inclination angle and azimuth of a photovoltaic (PV) effect Amount of solar radiation in the womb. develops a new mathematical model for calculating the optimum tilt angle and azimuth angle for the integrated design Photovoltaic (BIPV) applications in Hong Kong for the annual season and monthly basis[10]. The influence of PV facades guide in the performance of photovoltaic modules is also investigated. The Correlations between the degree of slope and the local climate Conditions or the local environmental conditions studied[10].

MATERIALS AND METHODS

Solar geometry: A PV module's position is defined by its tilt angle and orientation, which also is expressed as the azimuth angle, γ. Figure 1 represents a fixed PV module that is oriented due south and tilted at an angle. is the angle formed by the tilted surface and the horizontal, whereas γ is the angle formed by the tilted surface's normal projected on a horizontal surface from the local meridian. A surface facing south has γ = 0°, while a surface facing north has γ = 180°[11]. The sun's angular displacement from the Earth's center, or angle of declination 5, is expressed in degrees by (S) the sun's declination the angle made with latitude that is horizontal.

$$23.45° > S > -23.45°$$

$$S = 23.45 \sin\left[\frac{360(284+m)}{365}\right]$$

where, N is the duration of the year in days. Where m is one day of the year, i.e., January 1st is n = 1. As the Earth rounds the sun, 5 fluctuate between 23.5 and -23.5° during the year. Day and darkness are equal at 5 o'clock, with the northern summer solstice at 12 o'clock and the southern summer solstice at -12 o'clock. The angular position of the sun with respect to the local meridian, often known as the solar hour angle. Is either calculated as follows: t is for time and for T min. Is positive for the time after solar noon and negative for the min before solar noon. Solar time: Standard time:

$$+(4\times(L_{ST}-L_{loc})+E)$$

Where:

L_{ST} = Longitude for the local time zone.
L_{loc} = longitude of the location in the question (Khartoum) = 15.6°N-32.6°E
E = Equation of time in minutes per day

$$E = 229.2°(0.000075+0.001868 \cos B-0.032077° \sin B- 0.014615° \cos 2B-0.04089° \sin 2B)$$

$$B = 360 \times \frac{n-1}{360}$$

The sunset hour angle is ω_s of the angle of the sun corresponds to the time when the sun goes down, that is, if ω_z is 90° As follows:

$$\omega_s = \cos^{-1}(-\tan cp \tan_8)$$

The angle of incidence, θ is the angle between the beam Radiation on a surface and the normal. For a solid surface to the north or south, where θ by:

$$\theta = \cos\text{-}1[a-b+c+d]$$

Where:

A = sin S Q sin B
b = sin S cos Q sin B cos Y
c = cos S cos Q cos B cos W
d = cos S sin Q sin B cos γ cos W

Zenith angle, θ_Z is the angular displacement between the line of the sun's rays to the vertical and is given by:

$$Q_{z = \cos\text{-}1\,(\cos S\cos Q\cos W+\sin S\sin Q)}\ Q \quad (3.11)$$

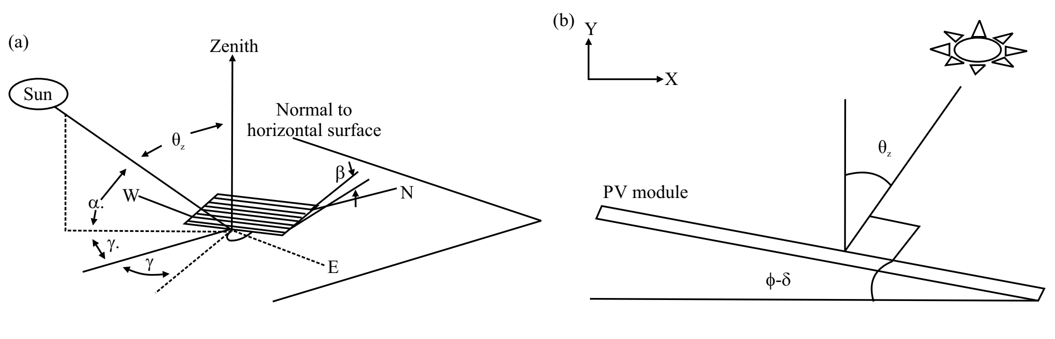

Fig. 1(a-b): (a) PV Module angled at an angle, facing south and (b) PV Module with $\beta_{optimum}$

Fig. 2: Module (basic unit)

Fig. 3: Module at angle 33° at North direction

During solar maximum, the most radiation is out in the world. At this point, the sun's rays travel the shortest distance through the air. So, it's best for the PV modules to be tilted at a right angle to their plane around the sun at noon. According to solar noon, the best tilt angle for photovoltaic modules is found to be (23°). Figure 4 shows that the best tilt angle is when a plane is parallel to Z at noon). When the optimum is positive, PV modules face south (=23°) and when it is negative, they face north (= 180°). When the $\beta_{optimum}$ is negative.

The monthly mean daily diffuse radiation, is then estimated using the calculated as in the following correlation[11]:

$$\bar{H}_d = (I - 1.13\bar{K}_t\bar{H})$$

Then, the overall incidence during the day, the H_T determined by the amount of radiation per hour, tips for the day and is given by:

$$H_T=\sum I_t \quad (3.26)$$

Experimental work: This part contains the experimental design and the process of getting solar radiation data for maximum performance, the experiments were carried out in two different geographical areas in Khartoum with another tool to the optimum angle will the roof be appropriate, compare the optimal slope angle in Kuala Lumpur on instruments, the optimal direction. In any process of experimenting with different angles investigators use the same specification of the module as experimenting module. The multi-crystal (Kyocera module) Khartoum is to retrieve the data using the software view of Adam and optimization analysis using the Matlab software and using Excel Khartoum for analysis. The follow of experimental work details in Fig. 2.

Portray the system in the experiments: The system used in this experiment was conceived by the Solar Institute in Khartoum, is mainly due to the optimum sunlight and viewing angles, tilt angle and azimuth angle, correlated to define the direct sunlight and performance. The system was using was a simple design, because the practice is used to read data telling you, read the character of the leadership in defining the angle and tilt angle was manufacturing and design researchers all metal parts separated angle frame and then the module in Fig. 3, the most important element of these systems has been fixed on module positions are steel frame in a manner such angle was fixed it has received your information, this module with screw Skelton in Fig. 4, the slope of the optimum direction of solar radiation in this direction as in figure, that the maximum power generated to direct sunlight collection modules collect equipped. The contact module is inaccessible, a special instrument to the sun and the voltage and current (force) of the digital millimeter Fig. 4, create read in Fig. 5 and temperature sensor contact with the circle of the module in Fig. 5 and solar radiation sensor in Fig. 6.

Modules requirement: In this article used the same specification of the module as follow in Fig. 2.

RESULTS

Determing optimum slope angle in Khartoum: The optimum of photovoltaic module of slope angle β of a maximum average of solar radiation and power at south direction

The result in this Table 4 was search out, by get an average for each angle during seven sunny days and the data was taken for every angle every 15 min and take an average for every hour, then take this average for seven days, for all angle, to get the average of solar radiation in Khartoum, to be more correct as a practical experiment, it more detailed than[12] acquire the data for solar radiation every hour and take the average per 3 sunny days in Khartoum and

Fig. 4: Module at angle 23° at north direction

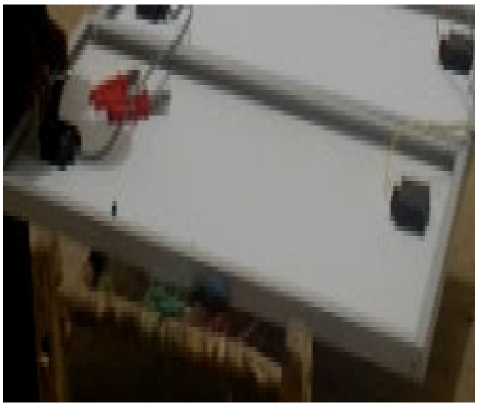

Fig. 5: Connect the system

Fig. 6: A Digital temperature sensor joint

also take the data every 30 min in Libya, that obtained the result was gotten of solar radiation was more specific and details to get the power to use as energy in domestic using in Khartoum. The describe of result, shown in the table the researcher originate that at 10 am the slope angle β 23° plot the maximum solar radiation from the different angle was 890.908 kWh/m^2, at 11 am slope angle β 23° was plot the maximum solar radiation 786.236 kWh /m^2 and at 12 noon angle 13° was plotted maximum 1161.867 kWh/m^2, at 1pm the maximum solar radiation was plotted at slope angle β 13° it 1330.685 (kWh), at 2 pm the plot of maximum solar radiation was 1230.987 kWh/m^2 at slope angle β 23°, at 3 pm the plotted of solar radiation 987.987 kWh/m^2, was the maximum at slope angle β23°, the average of the maximum solar radiation at slope angle β23° was 876.987 kWh/m^2, at 4 pm, this result was obtained that the slope angle β 23° was record the maximum average of solar radiation per sunny day, for Khartoum was 884.2531 kWh/m^2 as observe in Table 4. That signify this angle could capture the most of solar radiation whilst arrange the slope of the roof to integrated the photovoltaic array at the building in the normal climate condition at Khartoum. This result was deal with[4,12]. The monthly average daily solar radiation in Khartoum is 800-120 kWh/m^2. The result was found at Fig. 6, the solar radiation at slope angle β 23°was increase rapidly with the time until arrive maximum at 1 pm then decrease until 4 pm it record 1330.685 kWh/m^2 the maximum solar radiation was capture at slope angle β 23° at 1 pm in Khartoum this value was the maximum of all slope angles per whole day, this result was deal with[13] discussed the optimum angle for mounting the array is 30° and as the angle varies from the optimum the efficiency of the PV reduces, The angle of the roof is determined by the exposure of the site and local weather conditions. The tile and slope roofs depend on the size and overlap of the individual tiles or slates, they find this result in UK, with different position of PV and different orientation, other than Omer[12] found in Khartoum from 20°-25° that obtained we implemented the main principles of optimum slope of angle for whole housing with different input of location on the earth as longitude and latitude, consequently that mean can charge this energy at 1 pm to using in domestic using in Khartoum per clearly sunny day, this result was related with that angle which generated the maximum power at same direction in Fig. 6, when we compare between angles of average of maximum solar radiation in Fig. 7 was found as discussed above was 23°.

The result in Fig. 8 as the real data in Fig. 5 was obtainable obviously and the researcher was acquire it, to search for the optimum slope angle β to generate the average of maximum power, which was positioned in Khartoum for seven sunny days[13] and uses this experiment for 3 days, it different from researcher, because the data will be more credible as Collins and Abulkhair[13] establish when we increase the selection

Table 1: Specifications of the module

Maximum strength (Pmax)	54W (15% 5%)
Voltage at maximum power (Vmpp)	17.4V
Power current maximum (Impp)	3.11A
Voltage in an open circuit (Voc)	3.31A
Current In a short circuit (Isc)	600V
System voltage maximum	8.21×10-2 V/°C
Voc temperature coefficient Isc coefficient	8.21×10-2 V/°C
Maximum strength (Pmax)	1.33×10-3 A /°C
Cells: Number per module 36	
• **Module Specifications**	
Width, depth and length	639 mm×652 mm×54 mm
Weight	5.0 kg

Table 2: Average of solar radiation (kWh/m^2) at south direction day in Khartoum

Time	Angle 13	Angle 23	Angle 33	Angle 43	Angle 53
10:00	427.011	890.908	256.148	104.493	88.692
11:00	705.065	786.236	327.869	177.638	232.816
12:00	1161.867	781.25	573.771	313.48	144.124
1:00	1330.685	635.417	747.951	595.611	310.421
2:00	587.987	1230.987	112.705	498.98	121.951
3:00	587.098	987.987	327.869	303.03	222.941
4:00	329.096	876.987	576.98	83.595	309.675
Average	704.1156	884.2531	417.6133	296.6896	204.3743

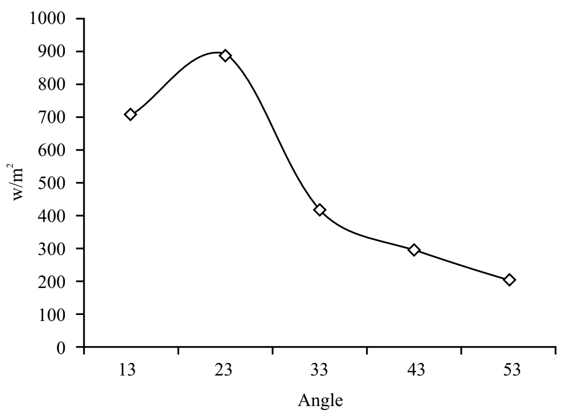

Fig. 7: Maximum average of daily solar radiation (kWh/m^2) in different slope angles at south direction

of getting data, he find his data for 12 days define day 15 the of 12 month per year. The data was gotten by the researcher, for all angles isolate β (13°, 23°, 33°, 43° and 53°) and combined the average of solar radiation result using Excel in Table 2-3 and the result was gotten and plotted by excel in Fig. 5, in the South direction the researcher found that the slope angles β (13°, 23°, 33°, 43° and 53°), at time 10 am, initially slope angle β 13° the average of the maximum power was plotted was 29.933 kWh, this result is approximately equivalent in the value of power, with slope angle β 43° at same time it was 29.833 kWh, other than slope angle β 23° was plot 27.251 kWh and slope angle β 33° plotted small value when compare between the other angle was record 1.729 kWh and slope angle β 53° also evidence small value at this time it 2.089 kWh, that obtain the most optimum angle for 10 am in this direction was slope angle β 23°, as seen in more details and we seen in this table the maximum power which generated in slope angle β 23° was a maximum power for different angles was 31.958 kWh and Omer[12] found in his result agree with the researcher found that slope angle β between 20-25°.

Acquire, can oriented the slope of roof in this direction at 10 am in slope of slope angle β 23°. In table the researcher establish that the average of the power which was generated from different angles the maximum average was plot was 31.49 kWh at angle 23° at the south direction, however this angle was optimal angle to tilt slope of roof when integrated photovoltaic upon the roof related to the Khartoum location in Fig. 5 and also proposed that the optimal slope tilt angle is +15°, 15°. Optimum slope tilt angle 8° where is the location's latitude[10]. For a specific area According to reports, the optimum slope tilt angle for a grid-connected PV system in Tehran is 30°, which is lower than the local latitude of 35.7°[13]. The surface tilt angles were discovered to be variable over a wide range without significantly reducing the amount of annual incident solar radiation. Furthermore, for the same latitude area, the clearness index and its yearly distribution can be quite different, resulting in completely different optimum tilt angles.

At 11 am, slope angle β 13° the average of the maximum power was plotted was 24.722 kWh, the slope angle β 23° at same time it was 31.92 kWh and the slope angle β 33° was plot 18.978 kWh and slope angle β 53° plotted small value when compare between the other angle was record 2.512 kWh and angle 43° evidence high value at this time it 15.484 kWh/m^2, that obtain the most optimum angle for 11 am in this direction was slope angle β 23°, in more details in Fig. 6 and that apparent in this table the maximum power which generated in slope angle β 23° was a maximum average of power for different angles was 31.958 and suggested that optimal slope angle +15°-15°[14]. Yang and Lu[10] suggested ±8° where is the latitude of the location, For a specific area that was

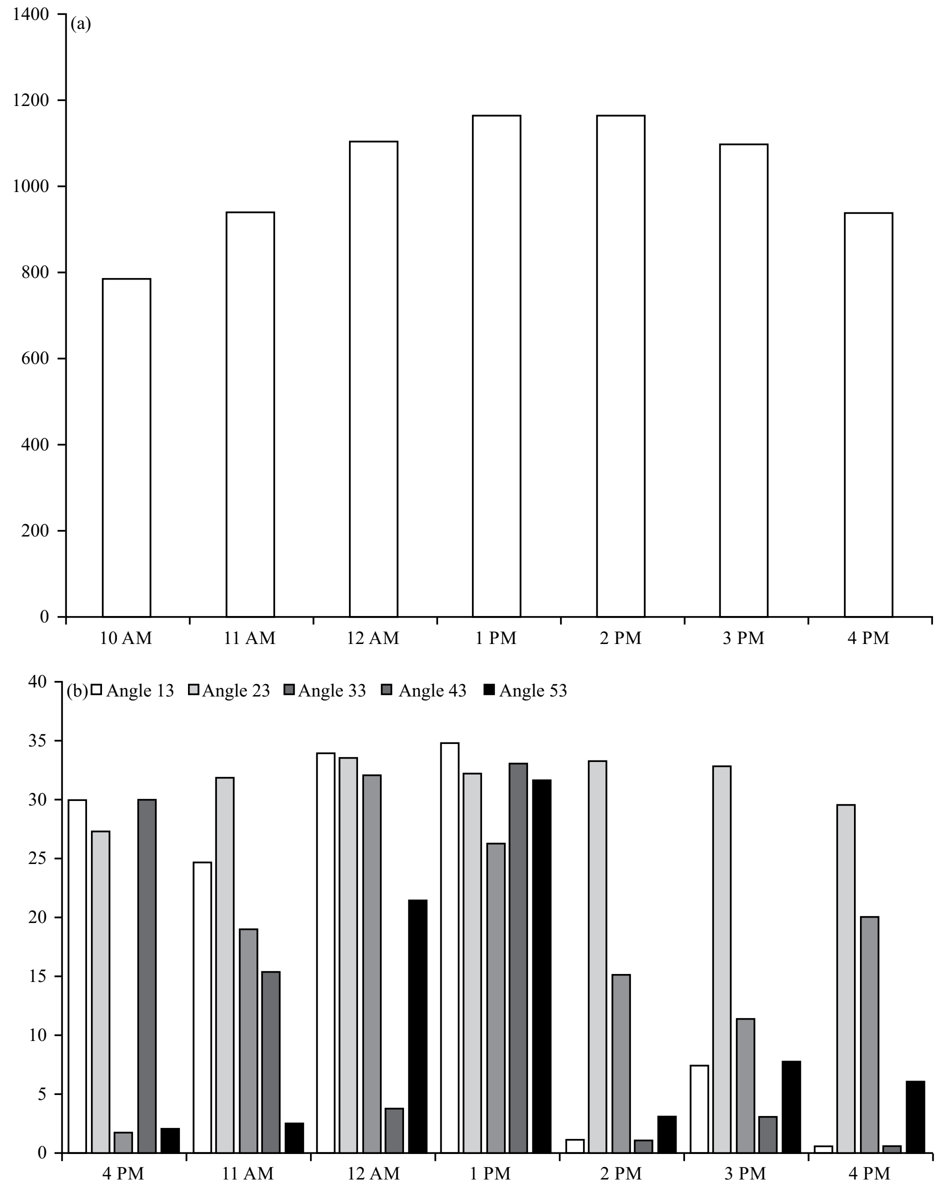

Fig. 8(a-b): (a) Average of daily solar radiation (kWh/m^2) at slope angle β 23°as the optimum angle at South direction and (b) Average of power at slope angles β, (13°, 23°, 33°, 43° and 53°), in the South direction

Table 3: Average of maximum power in kl

	Angle 13°	Angle 23°	Angle 33°	Angle 43°	Angle 53°
10:00 AM	29.933	27.251	1.729	29.933	2.089
11:00 AM	24.722	31.920	18.978	15.484	2.512
12:00 AM	33.938	33.649	31.958	3.862	21.494
1:00 PM	34.700	32.154	26.250	33.095	31.760
2:00 PM	1.094	33.206	15.156	1.009	3.022
3:00 PM	7.300	32.709	11.352	3.057	7.744
4:00 PM	0.538	29.543	20.145	0.539	6.069
Average	18.889	31.490	17.657	12.654	10.670
Maximum	34.700	33.649	31.958	33.095	31.760

match with the researcher found that obtained, to opportunity to oriented the slope of roof in this direction south, at 11 am in slope of slope angle β 23°. 12 noon, at north direction firstly slope angle β 13° the average of the maximum power was plotted was 33.938 kWh and slope angle β 23° at same time it was 33.649 kWh and slope angle β 33° was plot 31.958 kWh and slope angle β 43° plotted 3.862 kWh which was the lowest value at this time 12 noon and angle 53° evidence 21.494 kWh, that obtain the most optimum angle for 12 noon in the north was slope angle β 23°, in more details in Fig. 5 and that evident in this table the maximum power which generated in slope angle β 23° was a maximum power for different angles was 33.958 kWh, provenance, in his result uses 60 PV modules with a power output of 2.7 kW, giving an average of PV electricity output is 255 kWh, the average energy produced by the BIPV system is 240 kWh m^2, or total in a year is 2800 kWh, we compared the result in Fig. 1 and 5 and we can conclude that PV electricity output is proportional with solar irradiation energy which received by PV modules and the average energy produced by the BIPV system is optimally with slope angle was arrange between 0-15°, in Kuala Lumpur in any direction. That was agree with the researcher found that obtained, to possibility with efficiently to oriented the slope of roof in this south direction as O'Cathain *et al.*[15].

At 1 pm, the slope angle β 13° the average of the maximum power was plotted was 34.7 kWh, this result is about the same in the value of power, with slope angle β 23° at same time it was 32.154 kWh, slope angle β 33° was plot 26.25 kWh and slope angle β 43° plotted 33.095 kWh and angle 53° also evidence a value at this time it 31.76 kw/m^2 which was the minimum value, that obtain the most optimum angle for 1 pm at north direction was slope angle β 23°, as seen in more details in Fig. 6 and Khorasanizadeh and Mohammadi[15] that apparent in this table the maximum power which generated in slope angle β 23° was a maximum power for different angles was 32.958 kWh and Yang and Lu[10] and Chukwujindu[16] found, in his result 30 deg, South-facing 0 deg South-West facings that was agree with the researcher found that obtained, to possibility with efficiently to oriented the slope of roof in this south direction.

This result was parallel with the increase of solar radiation in Fig. 5, that define the optimum angle when compared with the other angle found that 23° was the optimum angle was plotted the maximum of solar radiation in Fig. 6 at 1 pm, was comparable also with plotted maximum plotted the maximum power as in Fig. 6 at 1 pm that mean the maximum solar radiation generated maximum power, as Khorasanizadeh and Mohammadi[14], O'Cathain[15], Babatunde *et al.*[16].

At 2 pm the slope angle β 13° the average of the maximum power was plotted was 11.094 kWh, the slope angle β 23° was 33.206 kWh, which was the maximum power at 2 pm in the south direction and plotted the big different between the other slope angles, slope angle β 33° was plot 15.156 kWh and slope angle β 53° plotted 3.022 kWh and angle 43° evidence small value at this time it 1.009 kWh, that obtain the most optimum angle for 10 am in this direction was slope angle β 23°, in more details in Fig. 6 and that apparent in this table the maximum power which generated in slope angle β 23° was a maximum power for different angles was 33.958 kWh Zell[17] found in his result. The methods employed here have made it easier to derive sophisticated monthly sunshine-based equations of the models for other sites without solar radiation sensors.in Khartoum the optimum direction was north and south that was agree with the researcher found that obtained, to opportunity to oriented the slope of roof in this direction (South).

The study found in the result for different angle which describe the maximum power was plotted was 34.7 kWh at angle 13° as seen in Table 5 and the average of this angle was 18,888 kWh which was lower when we compare between angle 23° which was record of the average that 33.649 kWh that mean the optimal angle was not determined with plotted of the maximum Power Point but we must put the average as the main factor of evaluate the optimum angle, as seen in Fig. 5-6 and Table 5 and also Yang and Lu[10] was agree with this result he found that The annual collected irradiance from the sun is 598.19 kWh/m^2 90°, down 54.55% from the greatest value of 1316.07 kWh, if the PV modules must be mounted vertically to meet building facades. When compared to the best alternative, the vertical installation of PV modules reduces power output by almost 50% and Zell *et al.*[17] was agree this result he found that the most optimum angle of slope angle to arrange the module upon the roof in Khartoum between 20-25°, that obtain slope angle β 23° was the most optimum angle to get the average maximum daily solar radiation at direction to generate the maximum power.

In this figure the result was founded that the average of power which was generated in south direction at angle 23° was plot as the maximum power, that obtained the optimum angle which was be suitable to arrange the slope of roof, to integrated photovoltaic array at direction south was 23°, evidence as the maximum average 31, that was more value than, found at the same angle record 40 kWh has a maximum power in Kuala Lumpur, they calculated the correlation between PV performance and its direction and tilt angles, at the same specific module, at slope angle between 0°-15 as he found in his case study but the researcher found that of that the optimal angle was 23° in Khartoum that obtained the raise of maximum value of power deals with the location and slope angle, in Fig. 10 and the researcher found as the result that the maximum power as point was plotted in 13° it was 34.7 kWh and the maximum point of 23° was 33.6 kWh after that angle 43° was plotted 33.095 kWh, after that angle 33° and finally angle 53°. It was discovered that simulation method was used to calculate the best tilt angles and direction for a PV panel in Khartoum. The ideal PV module tilt angle (inclination) in Malaysia is between 0° and 15° and the system can be installed with any of the four directions: north, south, east, or west. Zell *et al.*[17] and Chukwujindu[20] was obesity this result he found that the most optimum angle of slope angle to arrange the module upon the roof in Khartoum between 20-25° but in Khartoum this result was record for angle 43° to get this value that obtain that the angle which generate the maximum power may not be suite for arrange integrated the photovoltaic up on the roof but when we put the maximum power in our mind to evaluate the maximum angle to get the optimal angle which suitable to BIPV, the researcher get that, angle 23° was can be the optimum angle to tilt the slope of roof in the south direction in Fig. 9.

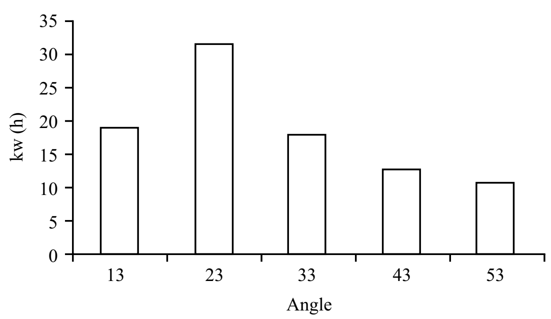

Fig. 9: Average of power at different slope angles, at South direction

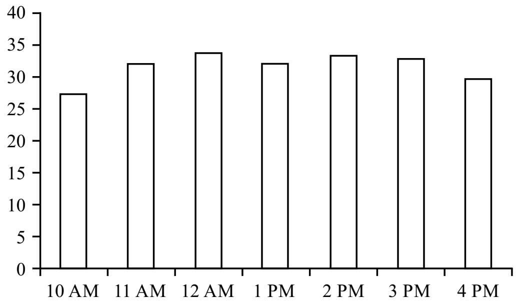

Fig. 10: Average of power energy in slope angle 23° in South direction

CONCLUSION

The experimental work in Khartoum to find out the optimum slope angle to capture a solar a maximum solar radiation to generate a maximum power using for electricity appliances in all sector of using BIPV and considers of influences of temperature of the module parameter, for generating the maximum power. Results Khartoum found that the optimum angle was generate the maximum power per period of sunny days and take an average of data of three different parameters, solar radiation, power of energy and temperature of the module, at the same time, in all different direction north south east west and compared with all different variables to find that optimum slope angle in optimal direction, after compare between 13°, 23°, 33°, 43° and 53° slope angle into two direction North and South, end resulted that the optimum angle was 23° in the south direction and the optimum direction was south direction this increasing goes rapidly with the solar radiation and temperature of the module. The value of maximum power produce from the optimal slope angle β with uncovered the time in the consideration for final result when we see that the power generated from, because when we use the module to generate energy we need output of this power per day but when we look for design of the roof to generate the maximum power in optimal direction and angle we must put the time in our concern when we analysis the data. Consequently the result in this diagram confirmed that the maximum power is 33.7720 kWh in the south direction.

ACKNOWLEDGMENTS

I would like to express my greatest gratitude and deep appreciation to Prince Sultan University college of architecture and design department of interior design The Dean of college, vice dean and chairperson of interior design, for their support and outstanding facilities.

REFERENCES

1. Handoyo, E.A., D. Ichsani and Prabowo, 2013. The optimal tilt angle of a solar collector. Energy Procedia, 32: 166-175.
2. Pradhan, S., R. Chakraborty, D.K. Mandal, A. Barman and P. Bose, 2021. Design and performance analysis of solar chimney power plant (SCPP): A review. Sustainable Energy Technol. Assess., Vol. 47. 10.1016/j.seta.2021.101411.
3. Chang, T.P., 2009. Output energy of a photovoltaic module mounted on a single-axis tracking system. Applied Energy, 86: 2071-2078.
4. OMER, A., 2007. Renewable energy resources for electricity generation in Sudan. Renewable Sustainable Energy Rev., 11: 1481-1497.
5. Wazed, S.M., B.R. Hughes, D. O'Connor and J.K. Calautit, 2018. A review of sustainable solar irrigation systems for sub-saharan Africa. Renewable Sustainable Energy Rev., 81: 1206-1225.
6. Lawan, S.M. and W.A.W.Z. Abidin, 2020. A Review of Hybrid Renewable Energy Systems Based on Wind and Solar Energy: Modeling, Design and Optimization. In: Wind Solar Hybrid Renewable Energy System, Okedu, K.E., A. Tahour and A.G. Aissaoui, (Eds.)., IntechOpen, London, United Kingdom, ISBN-13: 9781789845914, pp: 1-5.
7. Lin, L., 2004. Investigation on Characteristics and Application of Hybrid Solar-Wind Power Generation Systems. PhD.
8. Kaddoura, T.O., M.A.M. Ramli and Y.A. Al-Turki, 2016. On the estimation of the optimum tilt angle of PV panel in Saudi Arabia. Renewable Sustainable Energy Rev., 65: 626-634.
9. Chang, Y.P., 2010. Optimal the tilt angles for photovoltaic modules using PSO method with nonlinear time-varying evolution. Energy, 35: 1954-1963.
10. Yang, H. and L. Lu, 2005. The optimum tilt angles and orientations of PV claddings for building-integrated photovoltaic (BIPV) applications. J. Solar Energy Eng., 129: 253-255.
11. Duffie, J.A., W.A. Beckman and N. Blair, 2020. Solar Engineering of Thermal Processes, Photovoltaics and Wind. 5th Edn., Wiley, New York, United States, ISBN-13: 9781119540281, Pages: 928.
12. Omer, A.M., 2008. Energy, environment and sustainable development. Renewable Sustainable Energy Rev., 12: 2265-2300.
13. Collins, M.R. and H. Abulkhair, 2014. An evaluation of heat transfer and effectiveness for unglazed transpired solar air heaters. Solar Energy, 99: 231-245.
14. Khorasanizadeh, H. and K. Mohammadi, 2016. Diffuse solar radiation on a horizontal surface: Reviewing and categorizing the empirical models. Renewable Sustainable Energy Rev., 53: 338-362.
15. O'Cathain, A., E. Murphy and J. Nicholl, 2010. Three techniques for integrating data in mixed methods studies. BMJ, Vol. 341. 10.1136/bmj.c4587.
16. Babatunde, A.A., S. Abbasoglu and M. Senol, 2018. Analysis of the impact of dust, tilt angle and orientation on performance of PV plants. Renewable Sustainable Energy Rev., 90: 1017-1026.
17. Zell, E., S. Gasim, S. Wilcox, S. Katamoura and T. Stoffel *et al*., 2015. Assessment of solar radiation resources in Saudi Arabia. Solar Energy, 119: 422-438.
18. Chukwujindu, N.S., 2017. A comprehensive review of empirical models for estimating global solar radiation in Africa. Renewable Sustainable Energy Rev., 78: 955-995.