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Optimization of PV array to supply petroleum lab at Tripoli University by Electricity

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تحسين أداء منظوم الألواح الكهروضوئية لتزويد مختبر النفط بجامعة طرابلس بالطاقة الكهربائية

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Abstract

This paper presents the design and performance improvement of a standalone photovoltaic (PV) system to supply the Drilling Fluids Laboratory at the Faculty of Engineering, University of Tripoli.

Frequent power outages in Libya negatively affect laboratory operations and experimental accuracy. The study is based on real climatic data for Tripoli in 2024, including global, direct, diffuse, and reflected solar radiation.

A detailed electrical load analysis was conducted, followed by solar radiation calculations on horizontal and tilted surfaces to evaluate the effect of tilt angle on energy capture.

The PV system components, including PV modules, batteries, inverter, and cables, were sized to ensure system efficiency and reliability. The results highlight the strong solar potential of the study site and the feasibility of photovoltaic systems for educational facilities

Keywords: Solar energy, Photovoltaic system, Tilt angle, Drilling fluids laboratory, University of Tripoli.

الملخص

تهدف هذه الورقة البحثية إلى تصميم وتحسين أداء منظومة شمسية كهروضوئية مستقلة لتغذية معمل سوائل الحفر بكلية الهندسة – جامعة طرابلس، في ظل الانقطاعات المتكررة للتيار الكهربائي وتأثيرها السلبي على سير التجارب المعملية.

اعتمدت الدراسة على بيانات مناخية حقيقية لمدينة طرابلس لعام 2024، شملت الإشعاع الشمسي الكلي والمباشر والمشتت والمنعكس. تم إجراء تحليل تفصيلي للأحمال الكهربائية للمعمل، وحساب الإشعاع الشمسي على الأسطح الأفقية والمائلة، وتقييم تأثير زاوية ميل الألواح الشمسية على كمية الطاقة المستقبلة.

كما تم تصميم مكونات المنظومة الشمسية من ألواح وبطاريات وعاكس كهربائي وكابلات. توضح الدراسة أن الإمكانات الشمسية العالية في موقع الدراسة تجعل من الطاقة الشمسية خيارًا فعالًا ومستدامًا لدعم البنية التحتية التعليمية.

الكلمات المفتاحية: الطاقة الشمسية، الخلايا الكهروضوئية، زاوية الميل، معمل سوائل الحفر، جامعة طرابلس.

Introduction

The growing global energy demand and environmental concerns associated with fossil fuels have accelerated the transition toward renewable energy sources. Among these, solar photovoltaic technology has gained widespread adoption due to its availability, low operating costs, and ease of integration into buildings and facilities. In Libya, electricity generation relies heavily on fossil fuels, resulting in frequent power outages, particularly in educational institutions. These interruptions directly affect university laboratories that require stable power for accurate and efficient experimentation.

The Drilling Fluids Laboratory at the Faculty of Engineering, University of Tripoli, is a critical facility that depends on sensitive electrical equipment such as viscometers, mixers, ovens, and filtration units. Therefore, this study aims to propose a standalone photovoltaic system to enhance power reliability and ensure uninterrupted laboratory operation.

Study Site Description

The Drilling Fluids Laboratory is located within the Faculty of Engineering at the University of Tripoli, a region characterized by high solar radiation throughout the year. The site was selected due to the laboratory's importance and continuous need for reliable electrical power.

Figure 1. Location of drilling fluid lab in Tripoli university

Electrical Load Analysis

An electrical load analysis was conducted to determine the total daily energy consumption of the Drilling Fluids Laboratory. All electrical equipment used in the laboratory was identified, including their rated power and daily operating hours. The daily energy consumption was calculated using:

Daily Energy (Wh/day) = Rated Power (W) × Operating Time (h/day) (1)

The total daily energy demand was obtained by summing the energy consumption of all devices.

Table 1. Electrical Loads of the Drilling Fluids Laboratory..

Device	Rated Power(w)	Daily hours(h/day)	Wh/d	%
Fann viscometer	100	4	400	1.724138
Standard API Filter pressure	150	2	300	1.293103
Retort Kit	300	3	900	3.87931
Air compressor	2000	2	4000	17.24138
Mixer	500	1.5	750	3.232759
Oven	1200	3	3600	15.51724
Hot plate	300	1.5	450	1.939655
Pressurized consistometer	500	1.5	750	3.232759
Ph meter	50	1	50	0.215517
analytical balance	50	4	200	0.862069
Large shaker / mixer	800	2	1600	6.896552
Led Ceiling Panel	40	10	400	1.724138
computer + monitor	200	4	800	3.448276

Solar Radiation Analysis

Solar radiation data for Tripoli for the year 2024 were used in this study. The analysis included global, direct, diffuse, and reflected solar radiation components. Standard solar geometry equations were applied.

The solar declination angle was calculated using:

$$\delta \ = \ 23.45 \sin\left(\frac{360}{365}(n + 284)\right) \qquad (2)$$

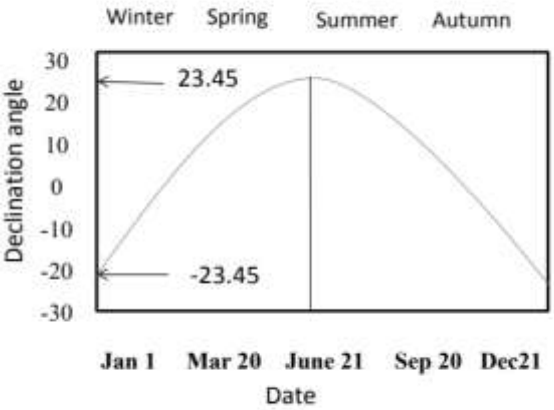

Figure 2. Monthly variation of the solar declination angle through the year

The sunset hour angle was calculated as:

$$\omega s = \cos^{-1}(-\tan\varphi \tan\delta) \qquad (3)$$

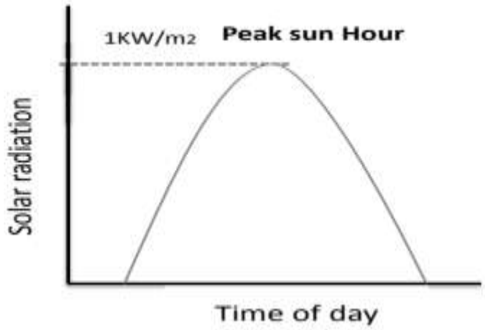

Figure 3. Peak sun hour during the day

The Solar Radiation outside the atmosphere (H_0) This represents the theoretical solar energy incident outside the Earth's atmosphere.

$$\mathrm{Ho} \ = \ \frac{24 \times 3600\mathrm{Gsc}}{\pi} \left(1 \ + \ 0.033 \cos \frac{360\mathrm{n}}{365} \right) \times \left(\cos \phi \cos \delta \sin \omega s \ + \ \frac{\pi \omega s}{180} \sin \phi \sin \delta \right) \qquad (4)$$

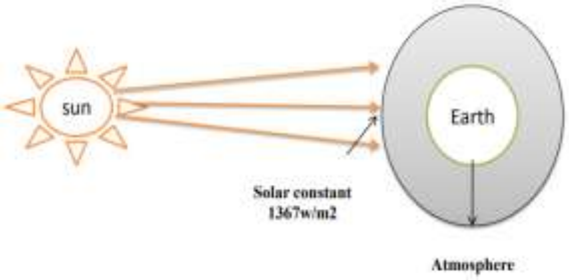

Figure 4 . Solar Radiation outside the atmosphere

The extraterrestrial solar radiation and the clearness index were calculated using:

$$\mathrm{KT} \ = \ \frac{\mathrm{H}}{\mathrm{Ho}} \qquad (5)$$

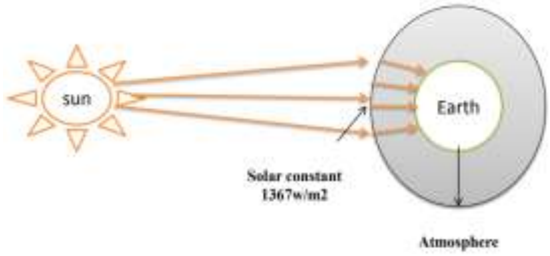

Figure 5. Solar Radiation reaching the Earth's surface

The diffuse component of global radiation is estimated using the empirical correlation of Erbs et al.

$$\frac{\mathrm{Hd}}{H} = 1.391 - 3.560\mathrm{KT} + 4.189\mathrm{K}\,2\,\mathrm{T} - 2.137\mathrm{K}\,3\,\mathrm{T} \qquad (6)$$

The total radiation incident on a tilted PV module includes beam, diffuse, and ground-reflected components:

$$\mathrm{HT} = \mathrm{Hb.Rb} + \underbrace{\mathrm{Hd}\,\frac{(1+\cos\beta\,)}{2}}_{\text{Diffuse Sky Component}} + \underbrace{\mathrm{H}\,\rho\mathrm{g}\,(\frac{1-\cos\beta}{2})}_{\text{Ground-Reflected Component}} \qquad (7)$$

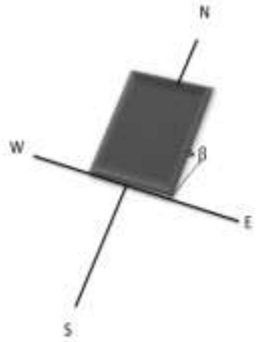

Figure 6 . tilted surface

$$R_b = \frac{\cos\emptyset - \beta}{\cos\emptyset}\left(\frac{\sin\omega_{srt} - (\pi/180)\,\omega_{srt}\cos\omega_{srt}}{\sin\omega_{sr} - (\pi/180)\,\omega_{sr}\cos\omega_{sr}}\right) \qquad (8)$$

Solar radiation values were calculated for different tilt angles in order to determine the optimal tilt angle.

Optimal Tilt Angle

The optimal tilt angle was determined by comparing the annual solar radiation values for different tilt angles.

Table 2 .Monthly Solar Irradiance Components and Meteorological Data for Tripoli**.**

Month	Ta	RH	Ha	Hb	Hd	HR	KT	Ws	Wd	Albedo	Dp
2024	C⁰	%	kwh/m^2/day					m/s	m/s		C⁰
Jan	15.43	68.45	3.1841	4.5079	1.1988	0.764184	0.58	6.51	279.1	0.24	9.53
Feb	15.3	70.42	4.0502	4.5041	1.6248	1.053052	0.59	5.65	268.9	0.26	9.79
Mar	17.31	65.52	5.7766	5.8819	1.961	1.675214	0.67	4.79	249.9	0.29	10.37
Apr	18.45	73.56	5.9947	4.5048	2.5433	1.618569	0.59	5.76	56.7	0.27	13.27
May	22.02	68.86	7.2149	5.7684	2.6287	2.16447	0.65	4.44	72.7	0.3	15.58
Jun	25.38	71.15	7.8845	6.4762	2.6611	2.286505	0.69	4.27	51.7	0.29	19.27
Jul	28.05	66.53	7.973	7.8271	2.0659	2.3919	0.71	3.94	33.3	0.3	20.87
Aug	29	67.08	7.1782	7.2634	1.8854	2.225242	0.69	3.94	55.4	0.31	21.98
Sep	27.94	67.35	5.3076	4.5199	2.173	1.433052	0.59	4.42	52.8	0.27	21.13
Oct	25.4	67.31	4.6738	5.0806	1.6178	1.355402	0.63	5.53	110.9	0.29	18.58
Nov	21.18	65.72	3.7829	5.544	1.1208	1.021383	0.65	4.18	272	0.27	14.33
Dec	17.04	69.29	2.8454	3.8292	1.176	0.682896	0.56	6.91	302.9	0.24	11.22
Yearly	21.9	68.43	5.4938	5.4833	1.8869	1.538264	0.63	5.03	150.525	0.28	15.51

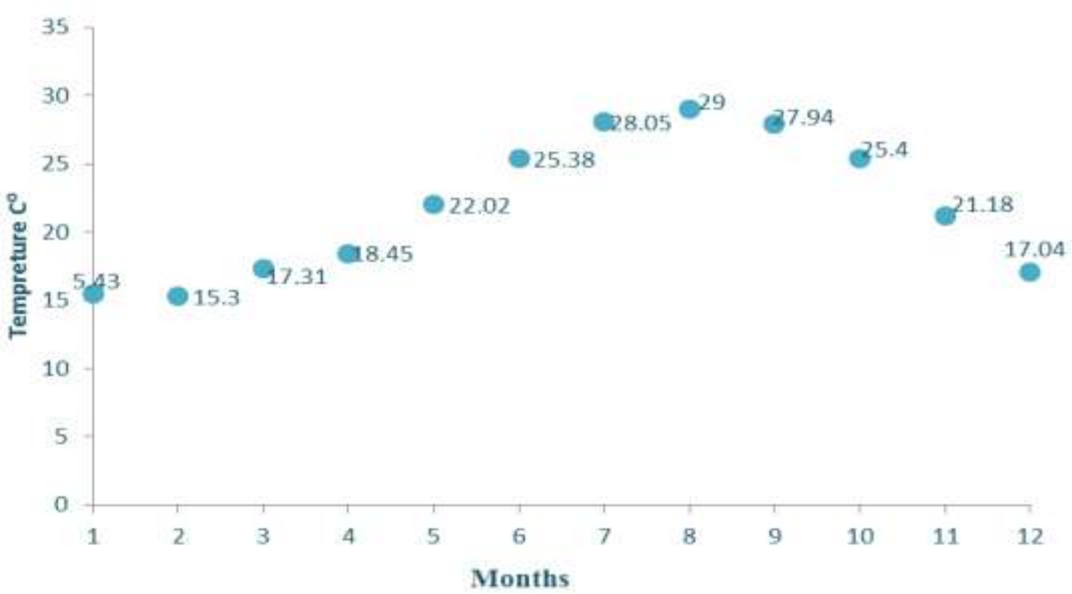

Figure 7 : Monthly Variation of Average Air Temperature in Tripoli (2024)

From the results show in Figure 7,it can be observed that th e air temperatures follows the typical climatic pattern of Tripoli, with temperatures increasing during the spring and summer months, reaching their highest levels in August, while recording their lowest values during December and January. This data is important in the design of photovoltaic systems , given the effect of temperature on the efficiency of solar Panels ,whose efficiency typically decreases as temperature rises.

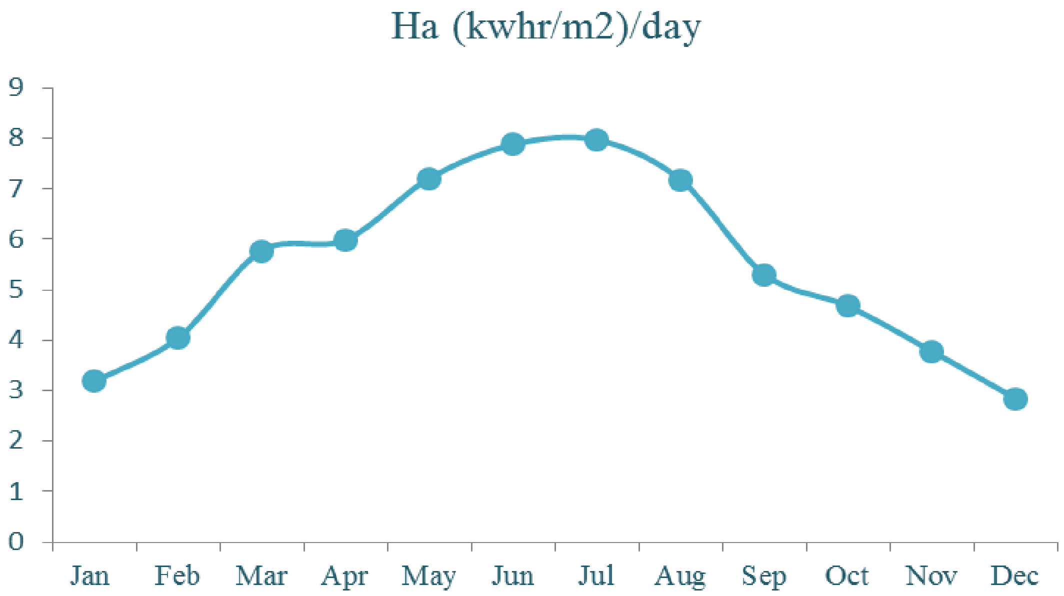

Figure 8 . Monthly Global horizontal radiation

Figure 8. shows the monthly variation of global solar irradiance (Ha) at the University of Tripoli. Values reach their highest levels during the summer months due to the higher angle of the sun and increased hours of sunshine, while they decrease significantly during the winter. Global horizontal irradiance (Ha) is the basis for estimating the solar energy available to the university site. The solar irradiance results confirm that the University of Tripoli has an excellent solar resource during the summer, with a relative decrease in winter, which directly affects the system's productivity.

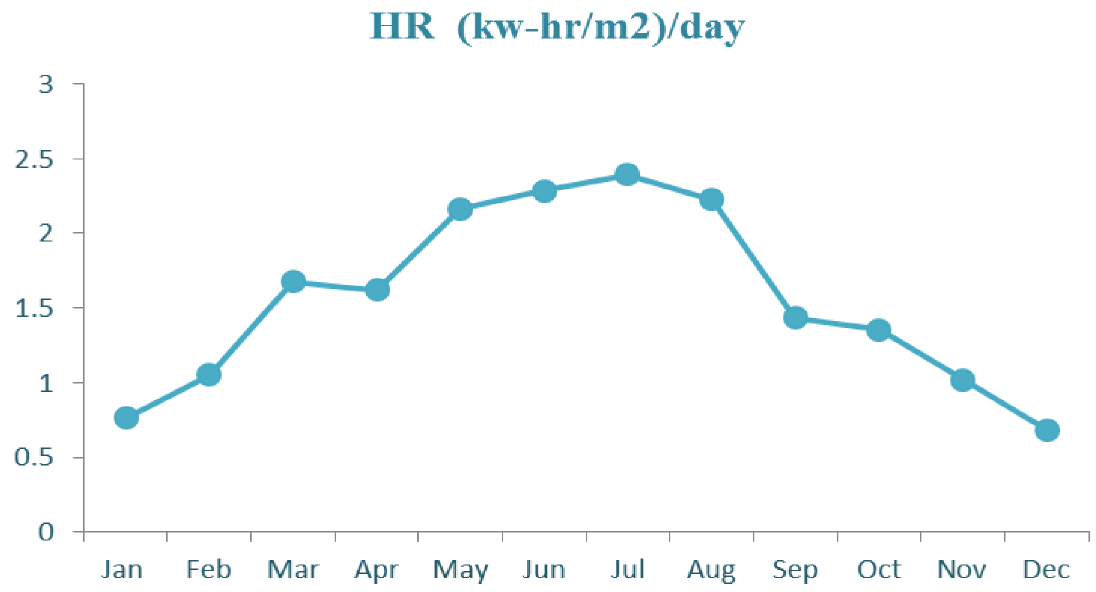

Figure 9. Monthly Reflected Radiation (HR)

Figure 9. shows the values of reflected HR calculated using the monthly reflectance coefficient Albedo. The results show that HR is higher in months with greater radiation. Although HR values are small compared to Ha, they Still contribute to the total incident energy reaching the inclined surface.

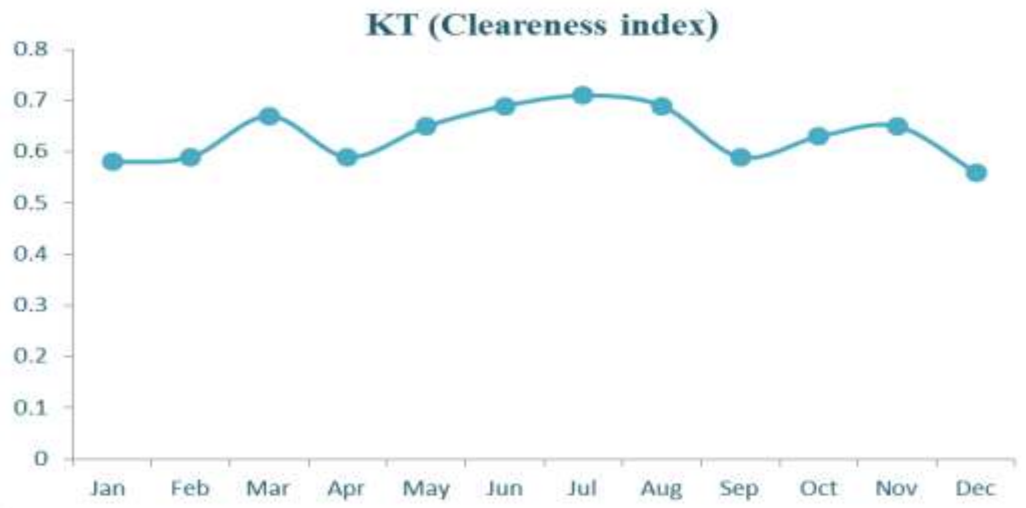

Figure 10 . Comparison Between Hb and Hd throughout the year

Figure 10. shows the variation of direct irradiance (Hb) and diffuse irradiance (Hd) throughout the year. Hb is observed to be higher in the summer months due to clear skies, while Hd is higher in winter due to increased cloud cover and humidity.

These behaviors are important when calculating solar radiation on an inclined surface, especially in months when direct radiation is lower and diffuse radiation is more prevalent.

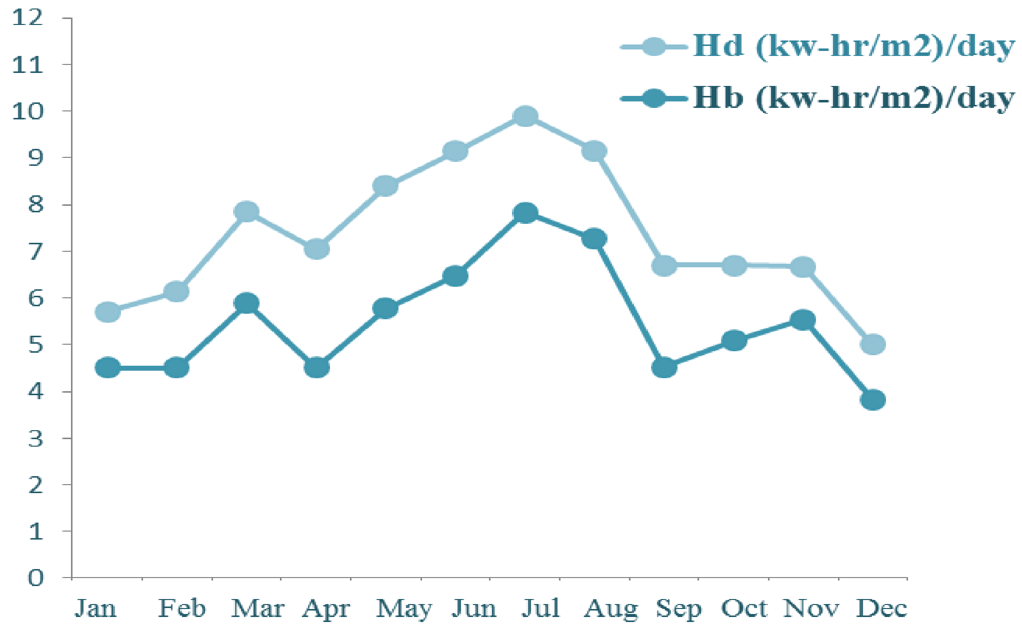

Figure 11. monthly Clearness Index (KT)

Figure 11.shows the monthly change in the KT (Monthly Clearness Index). Its values increase in the summer, indicating clear skies, while they decrease during the winter due to cloud cover. KT is a key indicator for selecting the appropriate tilt angle and for assessing the quality of incoming solar radiation. It is directly related to Ha (High) values.

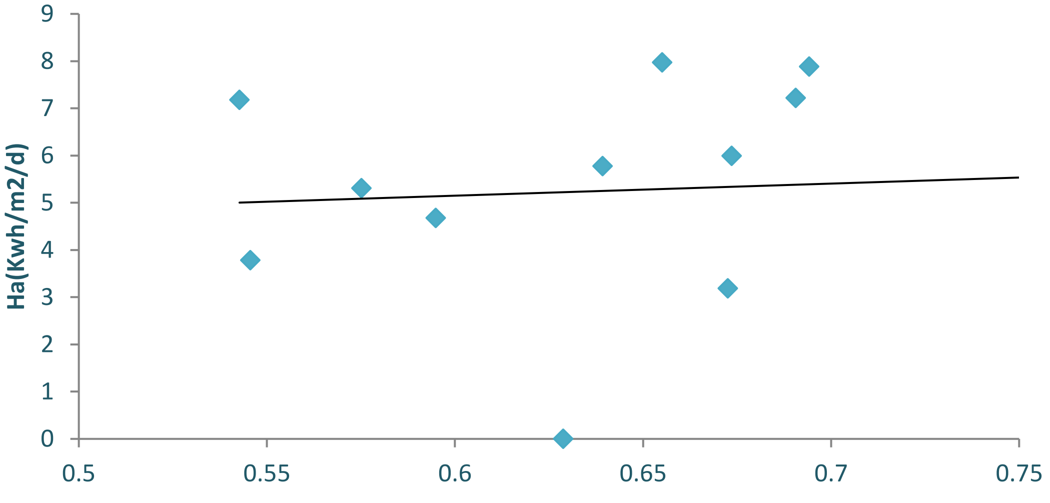

Figure 12. Relationship Between Global Radiation (Ha) and Clearness Index (KT)

Figure 12. illustrates the relationship between global radiation (Ha) and the atmospheric clarity index (KT). The data shows a direct relationship between Ha and KT, as the KT value increases, the Ha value also increases. It is evident that the months with high KT values June, July, and August record the highest global radiation (Ha) values due to stable weather conditions and clear skies. Conversely, values decrease during January and December due to increased cloud cover and humidity.

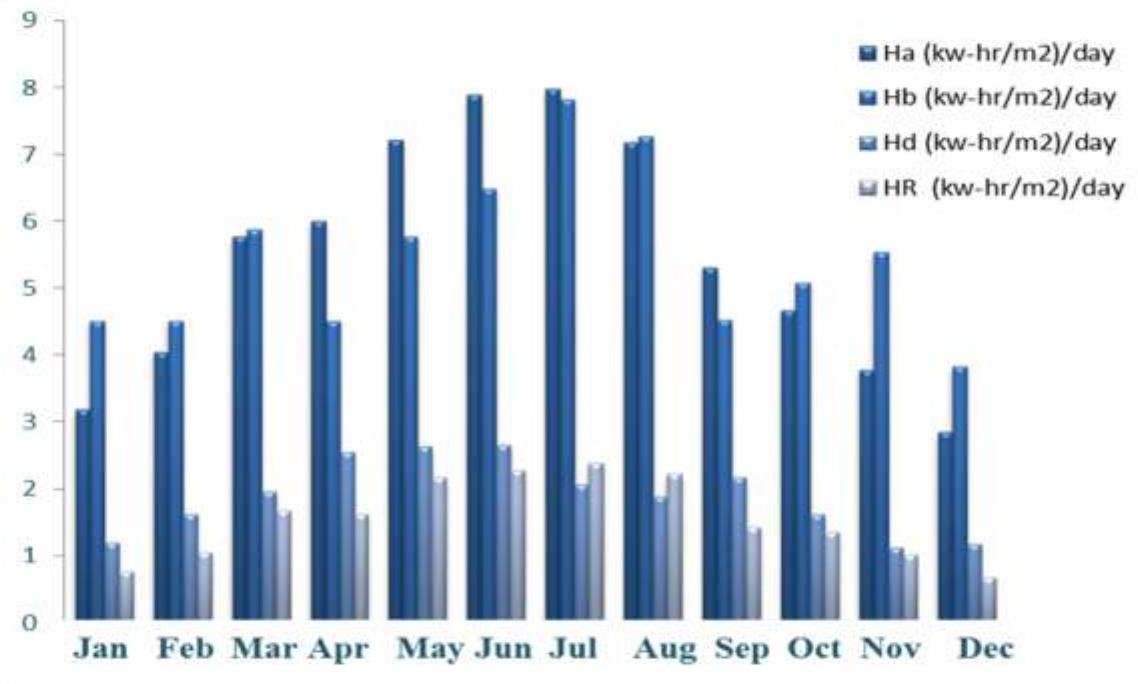

Figure 13. Comparison Between (Ha) , (Hb), (Hd), and (HR)

Figure 13 illustrates the monthly variation of solar irradiance components on the horizontal surface, including global irradiance (Ha), direct irradiance (Hb), diffuse irradiance (Hd), and reflected irradiance (HR). The results show that Ha and Hb values are higher during the months of May to August due to increased atmospheric clarity and longer sunshine hours, while diffuse irradiance (Hd) values are higher during the months of April, May, and June due to cloud cover and humidity. HR, however, appears at relatively low levels.

Solar radiation on tilted surfaces was calculated for several tilt angles, assuming a south-facing orientation. The resulting values were compared to determine the tilt angle that maximizes solar radiation and improves system performance.

Table 3.Average Daily Incident Solar irradiance (HT) on Tilted surfaces for different tilt angles.

Month	**No. of Days**	H_a	β = 90° Vertical	β =47.88° φ -β =-15°	β =42.88° φ -β =-10°	β =37.88° φ - β =-5°	β =32.88° φ - β =0°	β =27.88° φ - β =5°	β =22.88° φ - β =10°	β =17.88° φ - β =15°
			HT1	**HT2**	**HT3**	**HT4**	**HT5**	**HT6**	**HT7**	**HT8**
		kWh/m^2 - day								
Jan	31	3.18	6.06	6.44	6.26	6.05	5.79	5.48	5.14	4.77
Feb	28	4.05	6.24	7.11	6.98	6.80	6.57	6.30	5.98	5.62
Mar	31	5.77	6.21	8.17	8.15	8.07	7.96	7.74	7.50	7.21
Apr	30	5.99	3.63	6.29	6.44	6.55	6.62	6.64	6.62	6.56
May	31	7.21	2.56	6.03	6.32	6.58	6.80	6.98	7.12	7.21
Jun	30	7.88	1.95	5.66	6.04	6.39	6.71	7.00	7.24	7.45
Jul	31	7.97	1.86	5.59	5.98	6.35	6.68	6.98	7.24	7.47
Aug	31	7.17	2.21	5.62	5.94	6.22	6.47	6.69	6.86	7.00
Sep	30	5.30	2.70	5.09	5.26	5.39	5.49	5.55	5.59	5.58
Oct	31	4.67	4.05	5.81	5.85	5.85	5.81	5.74	5.63	5.48
Nov	30	3.78	5.20	6.14	6.06	5.93	5.76	5.56	5.32	5.04
Dec	31	2.84	5.04	5.45	5.32	5.15	4.94	4.70	4.43	4.13

January and February: The highest energy output values appear at large angles (β = 42.88° and 47.88°). This is because the sun is low, resulting in a greater inclination.
March–April: Medium angles (27.88°–37.88°) begin to produce the highest energy output values.
May–June–July: (peak summer) Smaller angles (17.88°, 22.88°, and 27.88°) show the highest HT because the sun is close to overhead; the slight inclination allows for maximum direct beam reception.
August–September: Medium angles (27.88°–32.88°) perform well and produce the highest energy output values.
October–November: Angles (47.88° and 37.88°) are a balanced option.
December :(typically the lowest annual output) Larger angles (47.88° and 42.88°) give relatively high HT.
Optimal annual energy balance achievedat a tilt angle of β : 32.88° (latitude angle) — yields the highest cumulative HT throughout the year with no significant loss in any season. This angle provides the best annual balance between summer and winter energy production.

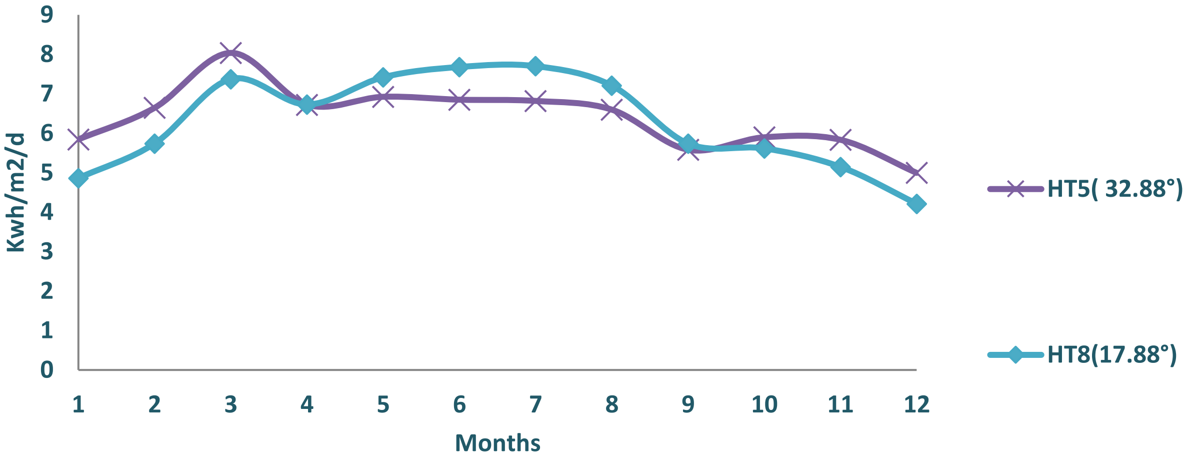

Figure 14. Monthly variation of average daily solar irradiation (kWh/m²/day) for tilt angles of 90° and 47.88°

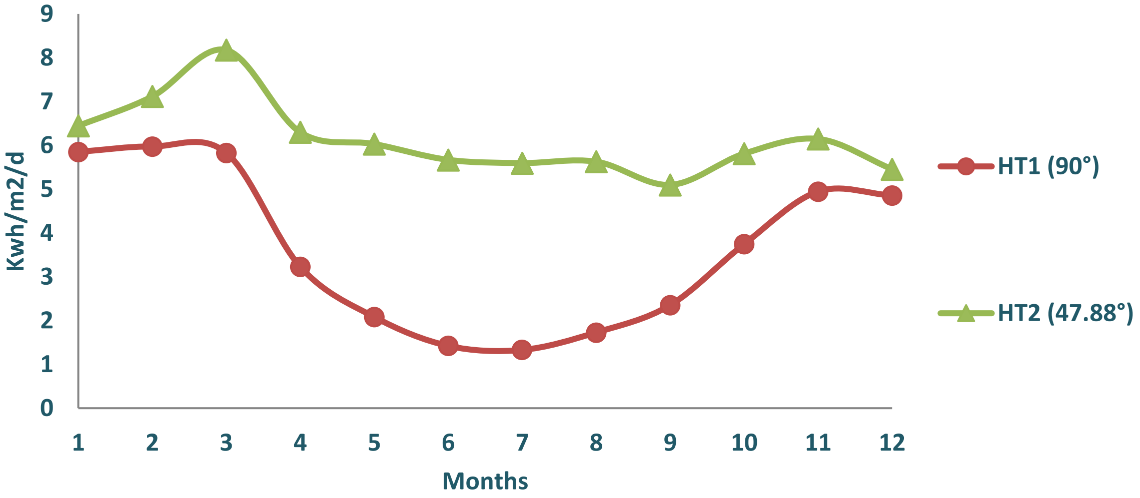

Figure 15. Monthly variation of average daily solar irradiation (kWh/m²/day) for tilt angles of 32.88° and 17.88°.

PV System Components Design

Based on load analysis and solar radiation calculations, the PV array capacity, battery storage size, inverter rating, and cable dimensions were determined to ensure efficient and safe system operation.

Component	Parameter	Value
Site Location	Latitude (φ)	32.88°
Optimal Tilt Angle	β	32.88°
Average Solar Irradiance	Peak Sun Hours	5.2 kWh/m²/day
Total AC Load	Daily Energy Consumption	23,200Wh/day
Inverter Efficiency	η_inv	0.85
Required DC Energy	After Inverter Losses	27,294 Wh/day
System DC Voltage	V system	48V
Daily DC Load	Load current	568.6 Ah/day
Battery Type	Model	Trojan T-105
Battery Nominal	V_bat	6
Battery Capacity	C/20	225Ah
Depth of Discharge	MDOD	0.8
Storage Days	Autonomy	2.3days
Total Battery Capacity	Bank Capacity	1,800Ah
Battery Configuration	Series × Parallel	8×8
Total Batteries	Number	64
PV String Current	I string	14.99A
Daily PV Energy (per string)	Contribution	63.13Ah/day
Number of PV Strings	Required	9strings
DC Cable Size	Cross-sectional Area	35mm²
Cable Standard	AWG	1

Figure 16: 3D schematic layout of the designed a photovoltaic system for the drilling fluids laboratory

Conclusions

The results of this study confirm that the proposed standalone photovoltaic (PV) system is technically feasible and capable of supplying reliable electrical energy to the Drilling Fluids Laboratory at the University of Tripoli. The laboratory has a total daily electrical energy demand of 23,200 Wh/day, which was fully covered by the designed PV system after accounting for inverter losses and system inefficiencies. Solar resource assessment for Tripoli in 2024 showed that the site receives an average annual global horizontal irradiance of approximately 5.49 kWh/m²/day, with maximum values reaching 7.97 kWh/m²/day in July and minimum values of about 2.85 kWh/m²/day in December. These values demonstrate the availability of sufficient solar energy throughout the year to support a standalone PV system.

The analysis of solar radiation on tilted surfaces indicated that an optimal annual energy balance is achieved at a tilt angle equal to the site latitude, $\beta = 32.88°$. This tilt angle provided the highest cumulative annual solar irradiation without significant seasonal losses, ensuring stable energy production during both summer and winter months.

The PV system design was based on a 48 V DC system voltage, with a total required DC energy of approximately 27,294 Wh/day after accounting for inverter efficiency. The battery bank was sized to provide an autonomy period of about 2.3 days, using 64 deep-cycle batteries with a total capacity of 1,800 Ah, ensuring uninterrupted laboratory operation during periods of low solar irradiance.

Overall, the numerical results demonstrate that the proposed PV system is reliable, efficient, and well suited to meet the energy requirements of the Drilling Fluids Laboratory. The system represents a sustainable and environmentally friendly alternative to the unstable public electricity grid and diesel generators.

Compliance with ethical standards

Disclosure of conflict of interest

The author(s) declare that they have no conflict of interest.

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