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Optimal Orientation of Solar Collectors to Achieve the Maximum Solar Energy in Urban Area: Energy Efficiency Assessment Using Mathematical Model

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Abstract*— Solar panel collectors are considered a highly promising technology for renewable energy in urban areas. In this study, the optimization of solar collector orientation to achieve maximum energy efficiency in Sohar, Oman, and Hillah, Iraq, is investigated. A novel approach is introduced, where optimal deflection angles are determined using a mathematical optimization model, incorporating rigorous numerical calculations based on sun position, solar radiation models, and non-isotropic models. Dynamic variations in solar radiation patterns are revealed, emphasizing the significance of tailored approaches. Optimal tilt angles are identified in Sohar and Hillah, resulting in notable increases in annual energy intake. Additionally, nuanced insights into solar panel orientation optimization are provided through the inclusion of non-isotropic models. The numerical findings illustrate a dynamic interaction among monthly, seasonal, and yearly fluctuations in solar radiation patterns, underscoring the importance of tailored approaches. In Sohar and Hillah, optimal tilt angles are identified, demonstrating significant enhancements in annual energy intake when aligned with these variations. Moreover, the incorporation of non-isotropic models offers nuanced insights into the influence of azimuth angles on radiant energy, stressing the necessity to optimize solar panel orientation toward the equator for improved energy capture. The outcomes indicate a boost of 22%, 8%, and 4% in Sohar, achieved by aligning panels with optimal angles for optimal monthly, seasonal, and yearly performance, respectively. Similarly, in Hillah, a corresponding increase of 23%, 9%, and 4% is observed. Importantly, the study emphasizes that the zenith of energy reception aligns with a zero azimuth angle. As the azimuth angle deviates from zero, both positively and negatively, the quantity of received energy exhibits a proportional increase. The findings contribute to the advancement of solar energy optimization and offer valuable insights for the design of sustainable solar energy systems in urban environments.

***Keywords*—**Solar energy, energy efficiency, mathematical model, optimal orientation, solar collectors.

1. INTRODUCTION

With the gradual depletion of non-renewable energy sources and the rising concerns over global warming and climate change, the demand for renewable energy sources like solar energy has surged tremendously in recent years [1]. Studies have explored economic optimizations of wind, solar, and battery storage systems to achieve grid-independent power supply, demonstrating practical applications of renewable energy technologies [2]. Additionally, research on trajectory tracking using optimized adaptive PID controllers contributes to broader applications of control systems in renewable energy contexts [3]. Evaluations of groundwater pollution pathways highlight integrated modelling approaches that are relevant to environmental sustainability and renewable energy development [4]. These efforts underscore the importance of innovative strategies and interdisciplinary approaches in addressing energy challenges while mitigating environmental impacts.

Solar panels, known for their efficiency and widespread use, represent a leading technology for harnessing solar energy. Research has explored simulation methods for maximizing solar panel efficiency through fuzzy logic control [5], investigated factors influencing solar-powered UAV endurance [6], evaluated construction project progress using quantitative approaches [7], and optimized product configuration and process planning in manufacturing systems [8]. However, to make the most of solar energy, it is crucial to optimize the settings of solar panels according

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to environmental and operational factors. This involves considering solar photovoltaic energy optimization methods, challenges, and issues, as highlighted in a comprehensive review [9], exploring co-optimization strategies for concentrated solar power plant components like heliostat fields and receivers [10], critically analyzing hybrid renewable energy modeling tools and their potential inclusion of social indicators for system optimization in small communities [11], conducting risk assessment and mitigation strategies for large-scale solar photovoltaic systems, particularly in Pakistan [12], and designing sustainable electric vehicle sharing business models within the Brazilian context [13].

Humans have been utilizing solar energy for a significant period as a renewable and cost-free power source, yet this practice historically poses environmental concerns. Recent innovations aim to address these challenges by transforming agricultural waste into sustainable energy applications using green strategies [14], exploring multilevel governance and entrepreneurship in the context of photovoltaic solar energy to produce green hydrogen as a renewable fuel source [15], and enhancing the performance of polycrystalline solar panels through innovative cooling systems incorporating phase change materials [16]. These advancements represent a shift towards sustainable utilization of solar energy with reduced environmental impact. The development of solar collectors has enabled the utilization of this limitless, unaltered, and cost-free energy source to a greater extent, consequently reducing the reliance on fossil fuels. Countries like Iraq and Oman, situated in the solar belt, receive a substantial amount of solar energy annually, highlighting the potential for increased adoption of solar energy strategies in regions endowed with rich fossil resources [17]. The impact of renewable sources on electrical power systems is further evidenced by initiatives like peer-to-peer electricity trading in microgrids, which utilize uncertainty modeling to optimize renewable energy utilization and distribution [18, 19]. These advancements demonstrate a shift towards leveraging solar energy to meet energy demands while reducing dependency on traditional fossil fuel-based energy sources.

It is essential to make use of a variety of energy sources in the event that problems arise as a result of an unexpected occurrence; consequently, the adoption of solar energy is one more reason to pursue this course of action [20]. A further reason is the relatively high cost of utilizing fossil fuels, which is increasing, as well as the high cost of equipment, such as turbines, and their high depreciation due to the humid weather in the region. Another reason is that there is a shortage of alternative energy sources in the region. Information regarding solar radiation levels at different locations is typically obtained through measurements of total radiation on a horizontal surface, reported as accumulated daily radiation over the year. To maximize energy absorption, surfaces must be oriented close to perpendicular to the sun's radiation direction. This principle underscores the development of innovative technologies, such as solar panel cleaning robots utilizing Arduino platforms [21], and the evaluation of strategies for managing solar panel waste and heavy metal leaching under disposal conditions [22]. Additionally, advancements in solar panel cooling systems, integrating anodized heat sinks with thermoelectric modules, enhance efficiency by optimizing temperature, power, and overall performance [23]. These developments contribute to a growing understanding of the solar energy-water-food nexus, emphasizing interdisciplinary approaches to sustainable resource management [24]. This can be accomplished by the utilization of sun trackers, which are devices that track the sun for a limited amount of time; however, the primary challenge lies in the high cost of producing such devices. Adjusting the angle of inclination of the surface on a daily basis is a useful technique that can be applied to flat solar collectors and photovoltaic cells. Given that the information about solar radiation that is currently available is for a horizontal surface, the quantity of energy that should be used to calculate the amount of energy that should be fed to the surface should be based on the radiation information that is for a horizontal surface [25].

Several research studies have focused on optimizing the settings of solar panels to maximize solar energy utilization. One study derived the optimal daily direction of solar panels in highlands using an analytical approach, highlighting strategic orientation methods for enhanced efficiency [26]. Another investigation explored the optimal orientation of solar panels for multi-apartment buildings, emphasizing tailored solutions for diverse architectural contexts [27]. Additionally, research on solar panel orientation considered temporal volatility and scenario-based photovoltaic potential, offering insights into optimal configurations, such as those studied at Seoul National University [28]. Moreover, innovative designs like the solar-wind hybrid renewable energy tree exemplify integrated approaches to harnessing renewable resources efficiently [29]. These studies collectively contribute to advancing techniques for optimizing solar panel settings and maximizing energy generation. These studies have revealed that various environmental and operational factors significantly impact the performance of solar panels. Some of the critical factors include the orientation and tilt angle of solar panels, the angle of incidence, and the shading effect of surrounding objects. Research has shown that adjusting the orientation and tilt angle of solar panels based on the latitude and longitude of their installation site can enhance their energy output. Moreover, the angle of incidence, which is the angle of the incident sunlight with respect to the surface of the solar panel, also affects the efficiency of solar panels. Thus, optimizing the angle of incidence by adjusting the orientation and tilt angle of solar panels based on the position of the sun in the sky can improve the solar energy output. The shading effect of surrounding objects like trees, buildings, and other structures can also significantly impact the solar energy output of solar panels. Therefore, it is crucial to consider the placement of solar panels in shaded areas and design anti-shading systems to reduce the shading effect. Most of the studies conducted in this field indicate that the optimal tilt angle and tilt angle in the Northern Hemisphere for south-facing solar panels are dependent on latitude [30], [31].

The literature surrounding solar energy optimization in urban areas underscores the growing significance of harnessing renewable energy sources, particularly solar power, amid global concerns about climate change and the depletion of conventional energy resources. Ruan *et al.* [32] emphasized the influence of environmental and operational factors on solar panel performance, emphasizing the importance of adjusting orientation and tilt angles based on latitude and longitude. Chiteka *et al.* [33] highlighted the impact of the angle of incidence and shading effects on solar panels, stressing the need for site-specific considerations in design. The literature further supports the idea that solar panel efficiency is closely tied to the local climate, as demonstrated by Boccalatte *et al.* [34] in their examination of solar energy potential in hot and humid regions. Notably, the use of mathematical models to optimize solar panel angles has gained traction [35], who employed a Grasshopper plugin for deflection angle determination.

This study presents a pioneering method for optimizing solar collector orientation in urban environments, focusing on the distinct geographic contexts of Sohar, Oman, and Hillah, Iraq. Departing from traditional approaches, our methodology integrates a Grasshopper plugin to compute optimal deflection angles, employing precise numerical calculations derived from sun position data, solar radiation models, and non-isotropic models with variable apex side angles. This innovative strategy offers a detailed understanding of the dynamic interplay among monthly, seasonal, and annual variations in solar radiation patterns. Aligning solar panels according to these optimized angles significantly enhances annual energy intake, underscoring the efficacy of tailored approaches in maximizing solar energy capture. Furthermore, the incorporation of non-isotropic models introduces a novel dimension, examining the influence of azimuth angles on radiant energy and providing nuanced insights into solar panel orientation optimization. These findings not only advance the discourse on solar energy optimization but also lay a foundation for designing sustainable and efficient solar energy systems customized to the specific environmental conditions of Sohar and Hillah. By introducing innovative methodologies and delivering valuable insights for effective solar energy system design in urban settings, this research contributes significantly to the field of renewable energy.

2. METHOD

The optimal angle for placement of solar panels is subject to variation due to the discrepancy in the sun's radiant energy across different geographical locations and is dependent on several variables. Therefore, it is not feasible to provide a universal recommendation for the angle of placement that would be optimal for all panels. Consequently, a parametric solution was devised and implemented to compute the optimal deviation angle and the relevant metrics outlined in Grasshopper. This approach enables the assessment of the impacts of variable modifications in conjunction with the computation. This section will introduce the position of the sun in the sky, the calculation of solar radiation outside the earth's atmosphere, and solar radiation on the surface of the earth.

2.1. Sun position

It is required to evaluate the position of the sun at different times of the day in order to establish the best angle at which solar panels should be positioned in order to obtain the most amount of energy. This can be done by observing the sun's path across the sky. Equations are provided specifically for this application. The position of the sun is investigated with the help of spherical coordinates in Fig. 1. In order to determine the angles and position of the sun, Eqs. (1) and (2) are employed in the calculation.

$$\sin\ \alpha = \cos\ \varphi \cos\ \delta \cos\ \omega + \sin\ \varphi \sin\ \delta \tag{1}$$

$$\sin\ \theta = \frac{\cos\ \delta \cos\ \omega}{\cos \alpha} \tag{2}$$

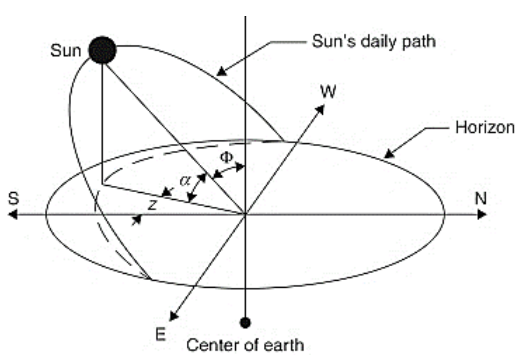

Fig. 1. The position of the sun in the atmospher.

where, φ is the latitude of the place and δ is the sun's deviation angle, which is the position of the sun at solar noon relative to the equatorial plane, and ω is the solar hour angle, which are obtained by Eqs. (3) and (4), respectively.

$$\delta = 23.45 \sin\ \left(360 \frac{\pi}{365}\right) \tag{3}$$

$$\omega = 15(t - 12) \tag{4}$$

2.2. Solar radiation model

The amount of solar energy radiation that is received on a plane that is outside of the atmosphere at any given time can be computed with the help of Eq. (5) [36].

$$\begin{array}{l} G_{\text{oh}}\ = G_{sc} \left[1 + 0.033 \cos\ \left(\frac{360(n+81)}{365}\right)\right] \times \\ (\sin\ \varphi \sin\ \delta + \cos\ \varphi \cos\ \delta \cos\ \omega) \end{array} \tag{5}$$

In this regard, G_{oh} is the intensity of the solar radiation on a horizontal plane in m, and G_{sc} is the solar radiation, which shows the average amount of solar radiation per unit of time per unit of surface, perpendicular to the direction of radiation on the outer surface of the earth's atmosphere [37].

From the time of sunrise to the time of sunset, as determined by Eq. (6), the radiation is equal to the integral of Eq. (5), which is equal to one day's worth of radiation.

$$\begin{array}{l} H_{oh} = \\ \frac{24\times 3600}{\pi} G_{Sc} \left[1 + 0.033 \cos\ \left(\frac{360(n+81)}{365}\right)\right] \times \\ \left(\cos\ \delta \cos\ \varphi \sin\ \omega_S + \frac{2\pi\omega_S}{360} \sin\ \varphi \sin\ \delta\right) \end{array} \tag{6}$$

The unite of the H_{oh} is J/m^2 day.

ω_s is the hour angle of sunrise and sunset is calculated from Eq. (7) and is negative for sunrise and positive for sunset.

$$\cos\ \omega_s = -\tan\ \delta \tan\ \varphi \tag{7}$$

Eq. (8) calculates the solar radiation in the atmosphere over a period of time (ω_1-ω_2).

$$\begin{array}{l} I_{oh} = \frac{24\times 3600}{2\pi} G_{sc} \left[1 + 0.033 \cos\ \left(\frac{360(n+81)}{365}\right)\right] \times \\ \left(\cos\ \delta \cos\ \varphi\left(\sin\ \omega_2 - \sin\ \omega_1\right) + \frac{2\pi(\omega_1 - \omega_2)}{360} \sin\ \varphi \sin\ \delta\right) \end{array} \tag{8}$$

The solar radiation breaks up into its component parts as it moves through the earth's atmosphere. Some of the light is absorbed and dispersed by ozone molecules, water particles, and other airborne particles, while the remaining light reaches the surface of the earth. As a direct consequence of this, the amount of solar energy that is absorbed by the surface of the earth is lower than the amount that is absorbed when the atmosphere is not present. According to Eq. (9), the total radiation that reaches the surface of the earth is equal to the sum of the direct and scattered components of that radiation.

$$I_d + I_b = I_h \tag{9}$$

I_h total radiation, I_b direct radiation and I_d scattered solar radiation on the horizontal surface or the earth in terms of J/m^2h [38].

On the other hand, the total radiation can be calculated using the Eq. (10), which takes into account both the radiation that is present outside of the atmosphere as well as the hourly coefficient of air purity, k_t.

$$K_t = I_h / I_{oh} \tag{10}$$

In addition, Eq. (11) is provided for k_t.

$$\begin{array}{l} K_t = \left[a + b \cos\ \frac{2\pi}{24}\left(t - 12\right)\right] \bar{K}_T \\ a = 0.404 + 0.5016 \sin\ \left(\omega_s - 60\right) \\ b = 0.6606 - 0.4767 \sin\ \left(\omega_s - 60\right) \end{array} \tag{11}$$

On an inclined plane, direct radiation, scattered solar radiation, and reflected radiation from the ground are the three components that make up the incoming radiation. Eq. (12) can be used to calculate the total solar radiation received by an inclined plane over the course of one hour.

$$I_T = I_b R_b + I_d \frac{1+\cos\ \beta}{2} + S_g \left(I_b + I_d\right) \frac{1-\cos\ \beta}{2} \tag{12}$$

Which S_g is the perception that the receiver has of the reflection coefficient of the ground that is all around them. The S_g is typically set to a low value; (S_g = 0.1) is chosen for normal days, and (S_g = 0.8) is chosen for the situation in front of the steam or dust receiver.

2.3. Optimization model

The optimization process aims to determine the optimal tilt angle (β_{opt}) for solar panels to maximize energy capture efficiency. This optimization model considers various factors such as sun position, solar radiation patterns, and geographical location. The objective function is formulated to maximize the total energy intake over a specified time period, typically annually. The decision variables include the tilt angle (β) and possibly other parameters related to panel orientation. The mathematical model can be expressed as $\sum_{t=1}^{T} E_t$. Subject to:

1) Geographical constraints: Latitude (φ), longitude, and site-specific factors.
2) Sun position constraints: Incorporating equations to determine the sun's position in the sky at different times of the day.
3) Solar radiation models: Utilizing appropriate equations to calculate solar radiation incident on the panel surface.
4) Non-isotropic model considerations: If applicable, incorporating additional constraints or variables related to azimuth angles and radiant energy distribution.

The optimization problem can be solved using mathematical programming techniques such as linear programming, nonlinear programming, or metaheuristic algorithms like genetic algorithms or simulated annealing. The objective is to find the optimal tilt angle that maximizes energy intake while satisfying all constraints.

This mathematical model provides a systematic framework for determining the optimal orientation of solar panels, taking into account various environmental and operational factors. By incorporating this model into the optimization process, it becomes possible to design solar energy systems that are tailored to specific geographical locations and maximize energy efficiency.

3. RESULT AND DISCUSION

To acquire the necessary parameters for the mathematical models, the data utilized in the preceding section was obtained from the Meteorological Organization located in Sohar and Hillah. Sohar, Oman, is situated at a geographic coordinate of 55.69° longitude and 24.35° latitude. Hillah, Iraq, is situated at a longitude of 44.43° and a latitude of 32.48° (Fig. 2).

The investigation into solar energy potential in the urban areas of Sohar and Hillah revealed insightful findings. The region, characterized by a hot and humid climate, experiences abundant sunlight throughout the year. Leveraging this climatic advantage, it becomes possible to significantly contribute to the energy demands of cities by optimizing the orientation of solar panels to harness solar power efficiently.

This study relies on meticulous data collection, with monthly average values obtained through daily measurements on a horizontal surface. It is essential to note that the reflection coefficient of the Earth (ρ_g) is assumed to be 0.3. All radiation values on the horizontal surface stem from radiometric data collected in 2017 for Sohar and 2019 for Hillah. These datasets were sourced from the Sohar Meteorological Department.

Fig. 3 illustrates the monthly variations in solar radiation energy received by a horizontal surface in Sohar and Hillah. Notably, the amount of maximum solar energy received at its peak is 1034 W/m^2 for Hillah and 1050 W/m^2 for Sohar in the month of May, highlighting the substantial solar potential in these regions. The observed patterns in solar radiation throughout the year underscore the importance of understanding the optimal angles for solar panel orientation. By aligning solar panels with these angles, urban areas can tap into the maximum available solar energy, thereby contributing significantly to their energy requirements. The variations in solar radiation between the two locations, Hillah and Sohar, indicate distinct seasonal patterns. These variations are crucial in tailoring solar energy systems to local conditions, emphasizing the need for site-specific approaches in the design and implementation of solar technologies.

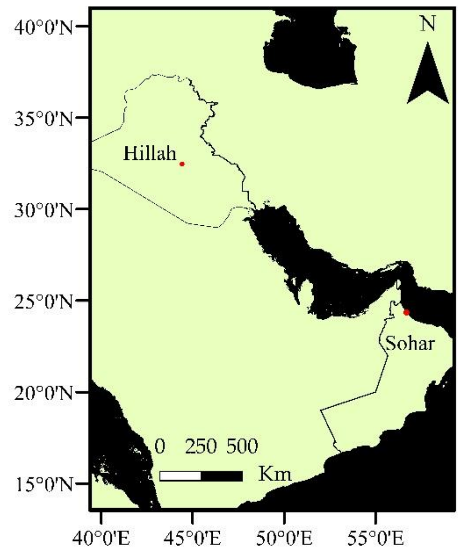

Fig. 2. The case studies location.

Table 1. The values of the optimal tilt angle and the monthly average daily energy reached to the surface of the solar panel based on the optimal angle.

Month	Sohar		Hillah	
	$\beta_{opt(m)}$ (°)	Hopt(m) (MJ/m^2)	$\beta_{opt(m)}$ (°)	Hopt(m) (MJ/m^2)
January	50.67	20.91	57.91	19.40
February	40.62	22.64	48.51	22.39
March	28.35	20.44	36.48	20.34
April	14.35	22.53	22.48	22.02
May	-1.35	27.48	6.21	27.08
June	-12.82	30.15	-5.74	29.25
July	-8.33	28.95	-1.09	27.56
August	6.62	27.74	14.51	27.91
September	22.35	27.97	30.48	27.22
October	36.35	24.65	44.48	24.39
November	47.65	24.71	55.21	24.88
December	55.18	26.85	62.26	25.29

The data presented in Table 1 offers a comprehensive breakdown of optimal tilt angles and the corresponding monthly average daily energy reaching the surface of solar panels for Sohar and Hillah. The optimal angle values are further categorized by month, season, and year, providing valuable insights into the dynamic solar energy patterns in these regions. In Sohar, the optimal angles for May, June, and July are negative, indicating a preference for a downward tilt during these months. In contrast, the optimal angles

Table 2. Annual amounts of energy received from the sun on a surface under the optimal angle in Sohar, Oman and Hillah, Iraq.

Optimal angle		$\beta_{opt(m)}$	$\beta_{opt(s)}$	$\beta_{opt(y)}$	$\beta = 0$
$\mathbf{H_{total}}$ ($\mathbf{MJ/m^2}$)	Sohar	30.76	27.18	26.12	25.10
	Hillah	29.51	26.13	25.03	23.91

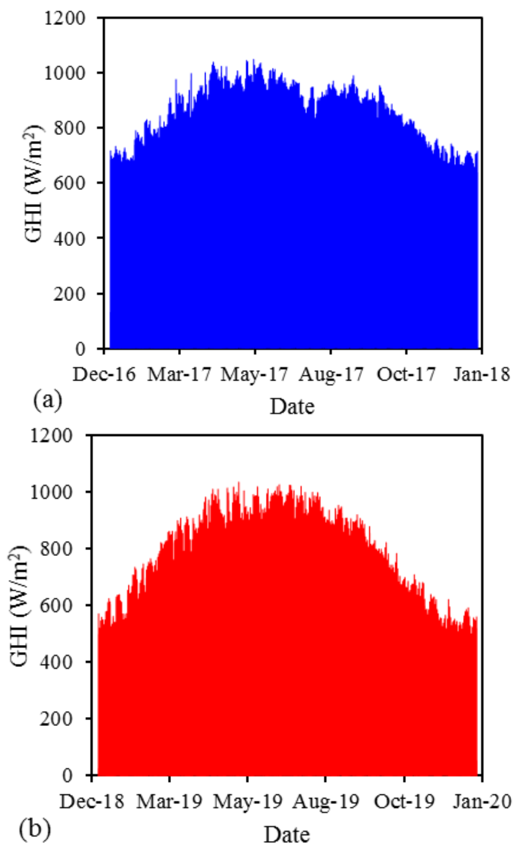

Fig. 3. Daily total radiant energy reached the surface in a) Sohar in 2017, b) Hillah in 2019.

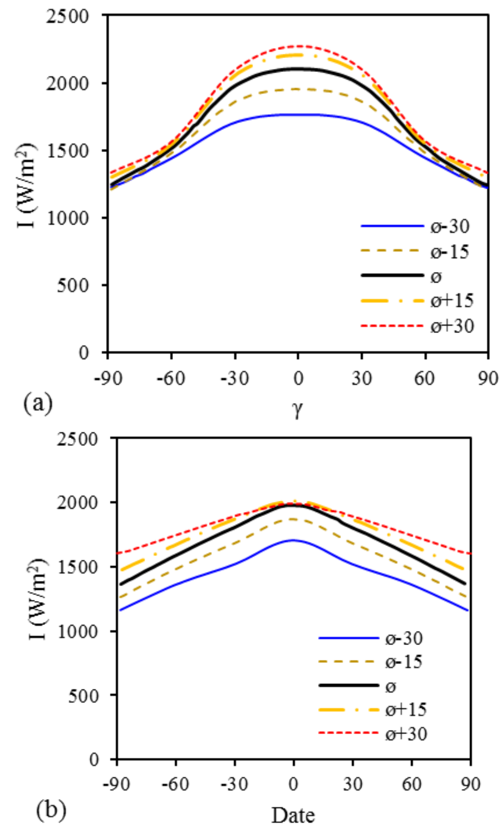

Fig. 4. Amounts of total radiant energy in January using the mathematical model a) Sohar, Oman and b) Hillah, Iraq.

for the remaining months of the year are positive. In Hillah, similar negative optimal angles are observed for June and July, while the rest of the months have positive optimal angles. The maximum energy received from the sun at its peak is 30.15 MJ/m^2 in June for Sohar and 29.25 MJ/m^2 in June for Hillah. On the other hand, the minimum energy received is 20.91 MJ/m^2 in January for Sohar and 19.04 MJ/m^2 in January for Hillah. To provide a more holistic view, the optimal angle values for each season are derived by averaging the optimal angle values for the respective months within that season. This approach allows for a better understanding of the seasonal variations in the optimal tilt angles. This detailed breakdown provides a foundation for understanding the optimal tilt angles and the corresponding energy potential in Sohar and Hillah throughout the year, facilitating informed decisions in the design and implementation of solar energy systems.

The system is to receive the maximum radiation energy annually, the months of maximum and minimum energy intake are September and January, with energy intakes of 21.27 MJ/m^2 and 20.15 MJ/m^2, respectively. It is possible to calculate the total energy received per year using various optimization methods and on the horizon surface, the corresponding results of which can be seen in Table 2.

- For Sohar, Oman, the annual total energy received is highest when considering the monthly optimal angle (30.76 MJ/m^2) in September, indicating the effectiveness of monthly optimization.
- In Hillah, Iraq, the annual total energy received is also highest in September, with a value of 29.51 MJ/m^2.
- The table further provides insights into the optimal angles for various optimization approaches, allowing for a comparative analysis of the energy received under different conditions.
- Notably, the system demonstrates the ability to capture maximum energy annually, with September and January representing the months of maximum and minimum energy intake, respectively.

These results underscore the importance of considering different optimization strategies in maximizing solar energy capture, with implications for the design and efficiency of solar energy systems in both Sohar, Oman, and Hillah, Iraq.

The data presented in Table 2 facilitates a comparative examination of the annual solar energy received on the horizon surface and the annual energy received under optimal angles related to the month, season, and year. This comprehensive analysis aims to assess the effectiveness of different optimization strategies in maximizing energy intake.

Setting solar panels to optimal angles corresponding to monthly, seasonal, and yearly variations results in notable increases in annual energy intake. In Sohar, Oman, the annual energy intake increased by 22%, 8%, and 4% when aligned with the optimal angles of monthly, seasonal, and yearly variations, respectively. In Hillah, Iraq, a similar trend is observed, with an increase of 23%, 9%, and 4%, respectively, under the same conditions.

To further investigate the impact of γ, two non-isotropic models were employed. Figs. 4 and 5 illustrate the values of average radiation energy reaching the inclined surface for the months of January and July, respectively. These values are depicted for five different angles of the apex side, γ (10, 20, 30, 40, and 50), utilizing the mathematical model for four slope angles (ϕ), (ϕ-10), (ϕ+10), (ϕ-30), and (ϕ+30).

These findings emphasize the significance of optimizing solar panel angles based on monthly, seasonal, and yearly variations, leading to substantial increases in annual energy intake. The exploration of non-isotropic models adds a nuanced dimension, considering the impact of the apex side angle (γ) on radiant energy. As mentioned earlier, the isotropic model remains valid when γ equals 0. These insights contribute to a more nuanced

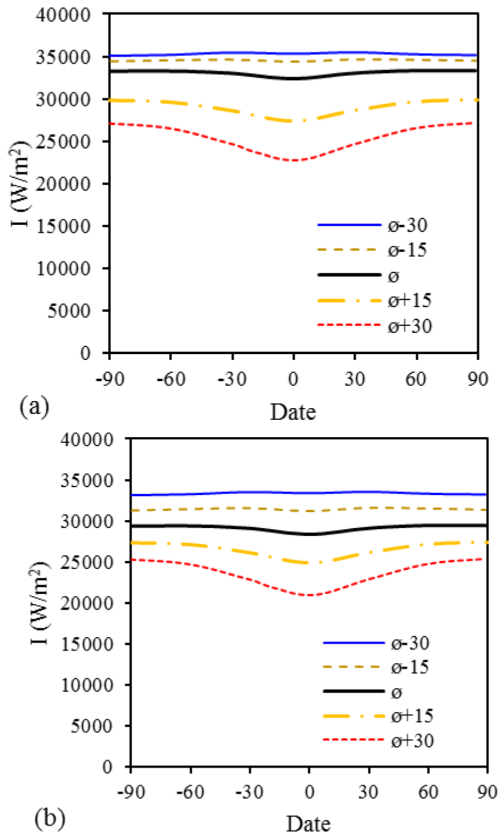

Fig. 5. Amounts of total radiant energy in July using the mathematical model a) Sohar, Oman and b) Hillah, Iraq.

understanding of solar energy dynamics, guiding informed decisions in the design and implementation of solar energy systems in varying geographical locations.

Examining Fig. 5 provides valuable insights into the relationship between azimuth angle and radiant energy, specifically focusing on the months of January and July. These findings contribute to understanding of how the azimuth angle influences the total radiant energy received by inclined surfaces. The analysis indicates that the maximum energy received is associated with the zero azimuth angle. In other words, when the solar panels are oriented to face the equator, they capture the highest amount of radiant energy. As the azimuth angle deviates from zero in both positive and negative directions, there is a corresponding decrease in the amount of received energy. This suggests that optimizing solar panel orientation towards the equator is crucial for maximizing energy intake. The observations align with the understanding that the azimuth angle plays a significant role in seasonal variations.

Adjusting solar panel orientation to face the equator during different seasons can enhance energy capture efficiency. Designing solar energy systems that incorporate the knowledge gained from these azimuth angle variations can lead to more efficient and reliable performance, ensuring optimal energy harvest throughout the year.

The findings of this study hold significant implications for the renewable energy industry, particularly in the design and implementation of solar energy systems. By investigating the dynamic interplay between solar radiation patterns and optimal panel orientation, our research provides valuable insights for enhancing energy capture efficiency.

Firstly, the identification of optimal tilt angles for solar panels in urban areas such as Sohar, Oman, and Hillah, Iraq, highlights the importance of tailored approaches to maximize energy intake. By aligning panels with these optimized angles, notable increases in annual energy intake can be achieved. This finding is crucial for industries seeking to harness solar energy as a cost-effective and sustainable alternative to conventional energy sources.

Furthermore, the incorporation of non-isotropic models offers nuanced insights into the impact of azimuth angles on radiant energy. By optimizing solar panel orientation towards the equator, industries can significantly enhance energy capture efficiency. This insight is particularly relevant for industries operating in regions with abundant solar resources, as it allows for the design of solar energy systems that capitalize on local climatic conditions and seasonal variations.

The observed correlation between azimuth angle and energy reception underscores the importance of strategic panel orientation in maximizing energy capture efficiency. Industries can leverage this understanding to optimize the placement of solar panels across different geographical locations, thereby increasing energy production and reducing reliance on non-renewable energy sources.

The findings provide actionable insights for the renewable energy industry, enabling informed decision-making in the design, implementation, and optimization of solar energy systems. By adopting tailored approaches based on our research findings, industries can enhance energy efficiency, reduce environmental impact, and contribute to the transition towards a more sustainable energy future.

4. CONCLUSION

This study examines how to optimize solar collector orientation in urban areas to maximize solar energy. Solar panels become a viable option as climate change and non-renewable resource depletion increase global demand for renewable energy. This study examines Sohar, Oman, and Hillah, Iraq, both solar belt cities with abundant solar energy potential. The discussion begins with orientation, tilt angle, incidence angle, and surrounding structures affecting solar panel efficiency. We study the urban areas' climates and energy needs because site-specific considerations are crucial. The study emphasizes the importance of understanding solar radiation patterns and panel orientation angles.

A new Grasshopper plugin determines the optimal vertical deflection angle of solar panels on all slopes. This novel approach addresses solar radiation variability across locations and provides a parametric solution for optimal deviation angles. Careful calculations using the sun's position in the sky and solar radiation models outside the Earth's atmosphere implement the parametric solution.

The system receives the most radiation energy annually, with peaks of 21.27 MJ/m^2 in September and troughs of 20.15 in January. Using optimization methods and the horizon surface, the annual energy received can be calculated. A single-axis system has grown by 22%, 8%, and 4% in Sohar by adjusting panels to the best angle for the month, season, and year. In contrast, Hillah variance increased 23%, 9%, and 4%. In double-axis, energy is greatest at azimuth angle zero and decreases as it increases (both positively and negatively). A detailed breakdown of optimal tilt angles for each month, season, and year in Sohar and Hillah shows the potential of solar panel angle optimization. The monthly variations in solar radiation energy and optimal angles show how dynamic solar energy patterns are in these regions. Optimizing for monthly, seasonal, and yearly variations increases annual energy intake, highlighting the impact of different optimization strategies. The use of non-isotropic models to study the impact of the apex side angle (γ) adds a unique dimension to the study.

This research helps urban planners, energy policymakers, and solar energy system designers. The study emphasizes tailoring to local climate and seasonal variations. Urban areas can maximize solar energy by aligning solar panels at optimal angles based on monthly, seasonal, and yearly variations.

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