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MODELING GLOBAL, DIRECT, DIFFUSE SOLAR RADIATION AND THE OPTIMUM TILT ANGLE IN SOME SELECTED LIBYAN CITIES

Ali S. Al-Nuaimi[1*] and Nassira M. Barrou[2]
Department of physics, Faculty of Science, Omar Al-Mukhtar University

[*]***Corresponding author:- E-mail:***
Nuaimiett@yahoo.com

Abstract:-
Solar system devices and photovoltaic panels are widely used all over the world to produce household heating and electricity. In this work two models were developed to estimate global, direct, diffuse solar radiation and the optimum tilt surface in five selected Libyan cities (Tripoli, Benghazi, Ejdabia, Misratah and Alkufra). It is found that the daily mean of sunshine hours in Tripoli is 9.01 hours. As for Benghazi city, the daily mean is 8.84 hours. In Misratah it is 8.57 hours. In Edjabia the daily mean is 9.46 hours, while in Alkufra, it is 10.10 hours of sunshine. The maximum beam radiation in Tripoli occurs in July (6.26 kw/m^2), while the minimum is in January (2.54kw/m^2). The maximum diffuse radiation occurs in June (1.85kw/m^2), while the minimum is in December (0.73kw/m^2). The maximum beam radiation in Benghazi occurs in July (6.26 kw/m^2), while the minimum is in December (2.02kw/m^2), the maximum diffuse radiation occurs in June (1.78 kw/m^2), while the minimum is in November (0.97kw/m^2). The maximum beam radiation in Misratah occurs in July (6.24kw/m^2), while the minimum is in December (2.23kw/m^2). The maximum diffuse radiation occurs in June (1.93 kw/m^2), while the minimum is in December (0.94kw/m^2). The maximum beam radiation in Edjabia occurs in July (6.19kw/m^2), while the minimum is in December (2.59kw/m^2). The maximum diffuse radiation occurs in May (1.83 kw/m^2), while the minimum is in December (0.93kw/m^2). The maximum beam radiation in Alkufra occurs in June and July (5.85kw/m^2), while the minimum is in December (3.33kw/m^2). The maximum diffuse radiation occurs in May (1.83 kw/m^2), while the minimum is in December (1.03kw/^{2}). Results also showed that the annual optimum tilt angles to receive maximum solar radiation for Tripoli is 31.21^o and decreases gradually to 23.33^o in Alkufra city. The higher optimum angle for all cities occur in winter and decreases in spring and summer, while it reincreases in autumn.

Keywords:- *Solar radiation, direct, diffuse, optimum tilt angle, Libya.*

INTRODUCTION

Knowledge of global solar radiation is essential in the prediction, study and design of systems which use solar energy, solar energy is one of the most important types of renewable energies sources. Libya is one of the countries that receives an abundant energy from the sun. It extends from the longitudes of 9° to 25 ° east and the latitudes 18.45° to 32.57° north, and is exposed to the sun rays through the year with long hours during the day. It boasts a very high daily solar radiation rate on a flat coastal plain, which is about 7.1 kw/m²/day**,** and in the southern regions it is about 8.1 kwh/m²/day [1]. Libya is considered as the 16 largest country in the world in terms of land mass according to opec.org [2]. Many solar energy conversion devices require information about solar radiation at a specific location. Unfortunately, there is a big shortage in the data of solar radiation in Libya. Estimating solar radiation incident on a tilted surface is very important for the design and performance of solar collectors, and the optimum title angle of the solar collector is also important from point of view of electrical and thermal energy gained, and to ensure fall the maximum of direct solar radiation on its surface on orbit of year. Many methods and physical models have been developed for estimating different parameters of solar radiation on horizontal surface and tilted surfaces. The tilt angle is also very important for solar collectors. Many models are simple and easy to apply, while others are very sophisticated. Flat-plate solar collectors are fixed and are generally not equipped by heliostats they therefore should be positioned with an angle faced towards the south to ensure maximum direct incidence of solar radiation around the year. For example if the solar collector is required for water heating during winter, the angle must be chosen so as to receive maximum solar energy during this season. If it is used for cooling during summer months we choose the optimum angle that maximum solar energy is received during summer. If it is to be used for the whole year the angle should be used so as to receive the maximum solar energy around the year [3]. Hideki UEYAMA estimated hourly direct and diffuse solar radiation for the compilation of solar radiation distribution maps in Japan, and showed that distribution maps of solar radiation will be used for various agricultural purposes such as environmental control of greenhouses [4]. Abbasi and Qureshi estimated global and diffuse solar radiation for Nawabshah, Sindh, Pakistan [5]. Mokri *et al.* assessed the potential of solar energy as an essential energy source in the United Arab Emirates [6]. Yunlin *et al.* analyzed monthly mean daily total global direct and diffuse radiation on horizontal surface and the relation between global, direct, diffuse radiation, and sunshine total cloud cover over Nanjing region in recent 40 years [7]. AL-Rawahi and Azari predicted hourly solar radiation on horizontal and inclined surface for Muscat. Oman, and found that the models and the computer code developed form the back bone of any computer**-**aided building thermal design and solar systems design calculations [8]. Sebaii *et al.* developed empirical correlations to estimate the monthly average daily global solar radiation on horizontal surface in Jeddah (Saudi Arabia) using the available meteorological data, and estimated diffuse radiation on horizontal surface and calculated the total solar radiation incident on tilted surface facing south with different tilt angles [9]. Notton used two estimation methods for monthly mean hourly total irradiation on tilted surface from monthly mean daily horizontal irradiation from solar radiation data of Ajaccio-Corsica [10]. Jamil and Tiwari investigated a tilt angle for the flat -plate collectors used at ten different stations in the world, and the calculations were based upon the measured values of monthly mean daily global and diffuse solar radiation on a horizontal surface [11]. Kent *et al.* determined global solar radiation incident on tilted surfaces with different tilt angles at the department of physics Makerere University, Uganda [12]. Kasawneh *et al.* determined the optimum tilt angle for solar applications in northern Jordan [13]. Udoakah and Okpura determined the optimum tilt angle for maximum solar insolation for PV systems in Enugu–southern Nigeria [14]. Hafez *et al.* made a simulation and estimation of a daily global solar radiation in Egypt [15]. Kumar *et al.* estimated the average solar radiation on horizontal and tilted surfaces for Vijayawada location, India [16]. Zaid *et al.* presented clear sky models applied for PV production assessment from solar irradiance [17]. Markam and Sudhakar estimated optimal tilt angle for solar photovoltaic installations in India [18]. Karkee *et al.* made a comparison and optimization of solar insolation on yearly, monthly and seasonal basis for solar devices performance in Nepal [19]. Tijani *et al.* made an optimization of tilt angle for solar panel in Tunisia [20]. Wessley *et al.* studied through modeling the optimum tilt angle for solar collectors across eight Indian cities [21].

The main objective of this study is to develop two simplified models one for estimating the global, direct and diffuse solar radiation on a horizontal surface and the other to calculate the optimum tilt angle to receive the maximum amount of solar radiation by a solar collector at five cities in Libya.

MATERIALS AND METHOD

Data of the sunshine duration hours for five selected cities (Tripoli, Misratah, Ejdabia, Benghazi, and Alkufra) in Libya were obtained from the National Libyan Meteorological Authority, and from the world climate center. Two models were developed one for calculating the global, direct and diffuse solar radiation on a horizontal surface, while the other model was developed to calculate the optimum tilt angle to receive maximum radiation.

The theoretical models:

The first model was developed to estimate the global, direct and diffuse solar radiation incident on a horizontal surface. It had been built and developed as follow:

The clearness index (K_T) is defined as the ratio of the measured horizontal terrestrial solar radiation ($\bar{H}$) to the calculated horizontal extraterrestrial solar radiation ,($\bar{H}_0$) and is calculated from the following relation:

$$K_T = \frac{H}{H_0} \quad (1)$$

$$\frac{H_d}{H} = 1.00 - 1.13K_T \quad (2)$$

Where $\bar{H}_d$ is the monthly mean daily diffuse fraction of solar radiation

$$\bar{H}_b = \bar{H} + \bar{H}_d \quad (3)$$

Where $\bar{H}_b$ is the beam (direct) solar radiation incident on a horizontal surface.

The second model is to calculate the optimum tilt angle for a flat–plate solar collector south facing the equator to receive the maximum solar radiation, the following equation is used

$$\beta_{opt} = \tan^{-1}\left\{\frac{\sum_{i=1}^{n} \bar{I}_b \tan(\phi - \delta)}{\sum_{i=1}^{n} \bar{I}_b}\right\} \quad (4)$$

Where I_b is the mean monthly solar beam (direct) radiation, ϕ is the latitude, δ is the Solar declination angle and is calculated from the following relation

$$\delta = 23.45 \sin[\frac{360(284 + n)}{365} \quad (5)$$

$$I_d = (1 - 1.097\frac{I_g}{I_0})I_g \quad (6)$$

Where I_g is the mean monthly daily average global radiation and I_0 is mean monthly daily average extraterrestrial radiation and is given by the following equation:

$$\bar{I}_0 = \frac{24}{\pi} I_{sc}[1 + 0.033\cos\frac{360n}{365}][\cos\phi\cos\delta\sin\omega_s + \frac{\pi}{180}\omega_s\sin\phi\sin\delta] \quad (7)$$

I_{sc}

Where is the solar constant (= 1367 Wm-2), s□is the mean sunrisehour angle for the given month, and n is the number of day of the year starting from the first of January.The mean sunrise hour angle (□$_s$) can be calculated, as follows:

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \quad (8)$$

The average monthly daily global radiation $\bar{I}_g$ calculated by the following equation:

$$\frac{\bar{I}_g}{\bar{I}_0} = a + b(\frac{\bar{n}}{\bar{N}}) \quad (9)$$

Where $\bar{I}_g$ the monthly average daily global radiation is $\bar{I}_0$ the monthly average daily extraterrestrial radiation, $\bar{n}$ is the monthly average daily hours of bright sunshine(in hours), $\bar{N}$ is the monthly average day length (in hours), and (a) and (b) are empirical constants obtained from the relationship given by Lewis [10] as follows:

$$a = -0.110 + 0.235\cos\phi + 0.323(\bar{I}/\bar{I}_0) \quad (10)$$

$$b = 1.449 - 0.553\cos\phi - 0.694(\bar{I}/\bar{I}_0) \quad (11)$$

RESULTS AND DISCUSSION

Table 1 shows the location of the five selected cities under study.

Table 1: The location of the five selected cities

City	Latitude $^\circ N$	Longitude $^\circ E$	Elevation (m)
Tripoli	32 89	13 18	12.0
Benghazi	32 50	20 23	132.0
Misratah	32 19	15 03	81.0
Ejdabia	30 45	20 14	61.0
Alkufra	24 13	23 18	435.0

Table 2 gives the monthly average sunshine hours for the five cities under study.

Table 2: The monthly average sunshine hours for the five selected cities

Month	Tripoli	Benghazi	Misratah	Ejdabia	AlKufra
Jan	6.63	6.25	6.02	7.36	9.00
Feb	7.57	6.93	7.53	7.80	9.27
March	7.63	7.60	7.93	8.80	9.48
April	8.33	8.73	8.30	8.70	9.53
May	10.15	10.73	10.05	9.80	9.87
June	10.42	11.03	9.77	11.10	11.40
July	12.12	12.48	12.18	12.62	12.38
Aug	11.35	11.87	11.45	11.70	12.05
Sept	9.00	9.53	9.07	10.80	10.33
Oct	7.87	8.35	7.77	8.90	9.60
Nov	8.38	7.23	7.17	8.10	9.73
Dec	8.72	5.35	5.97	6.80	8.57
mean	9.01	8.84	8.57	9.46	10.10

It can be seen that the sunshine hours in Tripoli range from 6,63 hours in January to 12.12 hours in July with a mean annual of 9.01 hours. There is an average of 3285 hours of sunshine per year. In Edjabia the sunshine hours range from 6.80 in December to 12.62 in July with a mean annual of 9.46 hours of sunshine. There is an average of 3453 hours of sunshine per year. As for Benghazi city, the sunshine hours range from 5.35 hours in December to 12.48 in July with a mean annual of 8.84 hours. There is an average of 3227 hours of sunshine per year. In AlKufra, the sunshine hours range from 8.57 in December to 12.38 hours in July, with a mean annual of 10.10 hours. There is an average of 3693 hours of sunshine per year. In Misratah the sunshine hours range from 5.97 hours in December to 12.18 hours in July, and the mean annual is 8.57 hours. There is an average of 3128 hours of sunshine per year.

Figure 1 shows the global H, beam Hb and diffuse and diffuse solar radiation for Tripoli. It can be seen that the maximum beam radiation occurs in July (6.26 kw/m^2), while the minimum is in January (2.54 kw/m^2). The maximum diffuse radiation occurs in June (1.85 kw/m^2), while the minimum is in December (0.73 kw/m^2).

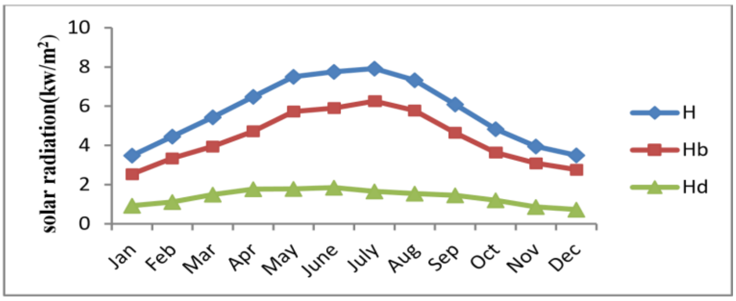

Figure 1: The global, beam, and diffuse solar radiation for Tripoli.

Figure 2 shows the globa H, beam Hb and diffuse Hd and diffuse solar radiation for Benghazi .It can be seen from table 4.11 and figure 4.77 that the maximum beam radiation occurs in July (6.26 kw/m^2), while the minimum is in December (2.02 kw/m^2), The maximum diffuse radiation occurs in June (1.78 kw/m^2), while the minimum is in November (0.97 kw/m^2).

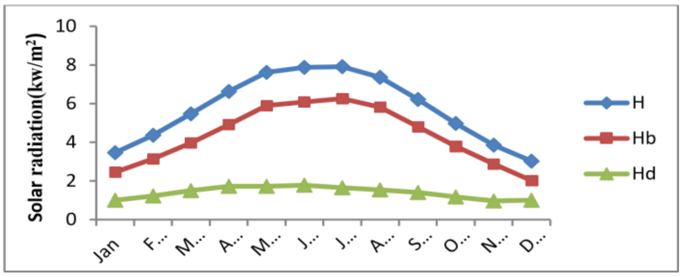

Figure 2: The global, beam, and diffuse solar radiation for Benghazi.

Figure 3 shows the global H, beam Hb and diffuse and diffuse solar radiation for Misratah. It can be seen from table 4.25 and figure 4.89 that the maximum beam radiation occurs in July (6.24 kw/m^2), while the minimum is in December (2.23 kw/m^2). The maximum diffuse radiation occurs in June (1.93 kw/m^2), while the minimum is in December (0.94 kw/m^2).

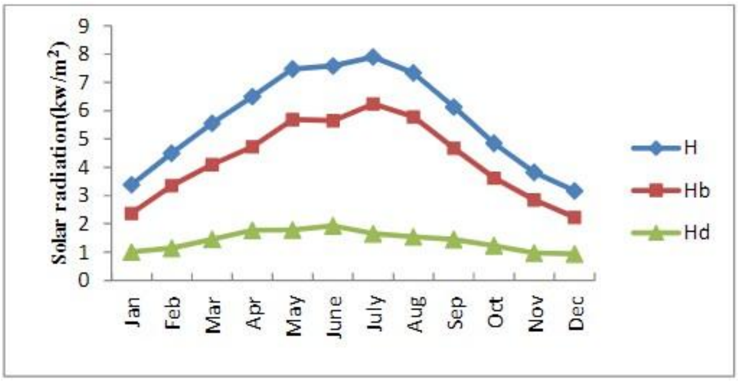

Figure 3: The global beam and diffuse solar radiation for Misratah.

Figure 4 shows the global H, beam Hb and diffuse and diffuse solar radiation for Edjabia. It can be seen table 4.18 and figure 4.83 that the maximum beam radiation occurs in July (6.19 kw/m^2), while the minimum is in December (2.59 kw/m^2). The maximum diffuse radiation occurs in May (1.83 kw/m^2), while the minimum is in December (0.93 kw/m^2).

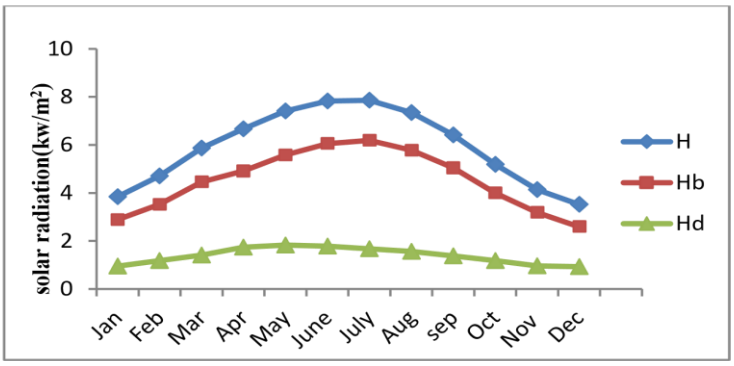

Figure 4: The global beam and diffuse solar radiation for Edjabia.

Figure 5 shows the global H, beam Hb and diffuse and diffuse solar radiation for Kufra. It can be seen from table 4.32 and figure 4.95 that the maximum beam radiation occurs in June and July (5.85 kw/m^2), while the minimum is in December (3.33 kw/m^2). The maximum diffuse radiation occurs in May (1.83 kw/m^2), while the minimum is in December (1.03 kw/^{2}).

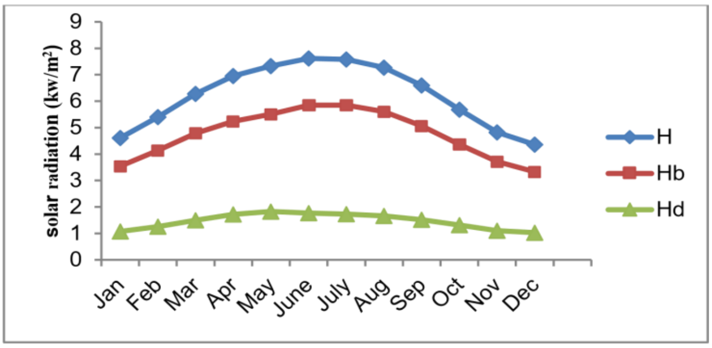

Figure 5: The global, beam, and diffuse solar radiation for Alkufra.

Table 3 gives the monthly average sunshine hours for the five cities under study. It can be seen from this table that the annual optimum angles to receive maximum solar radiation for Tripoli, Benghazi, Misratah, Ejdabia, and Kufra are 31.22, 29.46, 30.11, 28.77 and 23.32 respectively.

Table 3: The optimum tilt angle for the five cities under study

	Tripoli	Benghazi	Misratah	Ejdabia	Kufra
Beta optima Annually	31.215	29.462	30.110	28.776	23.326
Beta optima average (6)month(1,2,3,4,5,6)	28.612	27.251	28.015	26.571	21.007
Beta optima average (6)month(7,8,9,10,11,12)	33.682	31.651	32.155	30.940	25.654
Winter (12,1,2)	52.132	51.39	51.059	49.534	43.297
Spring (3,4,5)	23.506	22.999	22.944	21.521	15.331
Summer (6,7,8)	13.385	12.968	12.74	10.907	4.575
Autumn (9,10,11)	41.542	40.766	40.521	38.825	32.824

On the seasonal basis, the optimum angles for these cities in winter ranges from 52.13 in Tripoli to 43.30 in Kufra. The same picture is seen for spring as the angles varies from 23.51 in Tripoli to 15.33 in Kufra. In summer the angles for Tripoli is 13.39 and decreases gradually to 4.58 in Kufra city. As for autumn it varies from 41.5 to 32.8.

A comparison of the optimum angle for the five cities under consideration, show that the higher optimum angle for all cities occur in Winter 52.132, 51.39, 51.059, 49.534, and 43.297 for Tripoli, Benghazi, Misratah, Ejdabia, and Alkufra, respectively, and decreases in Spring ,Summer and Autumn.

CONCLUSION

It can be concluded from this study that **t**he maximum beam radiation in Tripoli occurs in July (6.26 kw/m^2), while the minimum is in January (2.54 kw/m^2). The maximum diffuse radiation occurs in June (1.85 kw/m^2), while the minimum is in December (0.73 kw/m^2). The maximum beam radiation in Benghazi occurs in July (6.26 kw/m^2), while the minimum is in December (2.02 kw/m^2), the maximum diffuse radiation occurs in June (1.78 kw/m^2), while the minimum is in November (0.97 kw/m^2). The maximum beam radiation occurs in July (6.24 kw/m^2), while the minimum is in December (2.23 kw/m^2). The maximum diffuse radiation occurs in June (1.93 kw/m^2), while the minimum is in December. The maximum beam radiation in Misratah occurs in July (6.24 kw/m^2), while the minimum is in December (2.23 kw/m^2). The maximum diffuse radiation occurs in June (1.93 kw/m^2), while the minimum is in December (0.94 kw/m^2). The maximum beam radiation in Edjabia occurs in July (6.19 kw/m^2), while the minimum is in December (2.59 kw/m^2). The maximum diffuse radiation occurs in May (1.83 kw/m^2), while the minimum is in December (0.93 kw/m^2).

The maximum beam radiation in Alkufra occurs in June and July (5.85 kw/m^2), while the minimum is in December (3.33 kw/m^2). The maximum diffuse radiation occurs in May (1.83 kw/m^2), while the minimum is in December (1.03 kw/^{2}). It can also be concluded that the annual optimum angles to receive maximum solar radiation for Tripoli, Benghazi, Misratah, Ejdabia, and AlKufra were 31.22°, 29.46°, 30.11°, 28.77° and 23.32° respectively. The optimum angle of the first half of the year for Tripoli, Benghazi, Misratah, Ejdabia, and Alkufra were 28.62°, 27.25°, 28.01°, 26.57°, and 21.01° respectively. For the second half of the year they were 33.68°, 31.65°, 32.15°, 30.94°, and 25.65° for the same cities respectively. In summer the angles for Tripoli were 13.39° and decreases gradually to 4.58° in AlKufra city. As for autumn it varies from 41.5° to 32.8°. In winter they range from 52.13° in Tripoli to 43.30° in AlKufra. The same picture is seen for spring as the angles varies from 23.51° in Tripoli to 15.33° in AlKufra.

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