Global Journal of Engineering and Technology [GJET].
ISSN: **2583-3359** (Online)
Frequency: Monthly
Published By GSAR Publishers
Journal Homepage Link- https://gsarpublishers.com/journal-gjet-home/

Optimum tilt angle for the installation of solar sensor in some cities in Cameroon

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Article History

Received: 15/01/2025
Accepted: 22/01/2025
Published: 24/01/2025

Vol – 4 Issue – 1

PP: - 10-15

Abstract

The sun is the most accessible source of energy on earth. For the development of solar energy in Cameroon, knowledge on solar potential and solar technologies is indispensable. The aim of this work is to find out the optimal tilt angle for solar sensor in the headquarters of the ten regions of Cameroon. In this work, the average solar radiation received annually by various cities (head-quarters of the ten Regions) of Cameroon has been evaluated using the RETScreen software, then the data obtained were used to simulate the performances of a thermal solar collector for two standard days (least sunny and sunniest days) through MATLAB 2014 a software. The results show that in Cameroon, the annual average of insolation on a horizontal surface varies between 4.43 Kwh/m^2/day and 5.88 Kwh/m^2/day. The optimal tilt angle of solar sensor is between 5° and 15° depending on the position of the Region. These results provide valuable guidelines for designers and installers of solar thermal and photovoltaic systems in Cameroon, allowing them to maximize the energy efficiency of these installations depending on the specific weather conditions of each location. This will contribute to better exploitation of the significant solar potential available in the country.

***Keywords**: Cameroon, Solar potential, Solar sensor, Tilt angle, Optimization*

INTRODUCTION

The sun is the most accessible and available source of energy in the world. The simplest and most effective way to use solar energy is to convert it into thermal or photovoltaic energy through the use of solar sensors. However, the production of energy from a solar thermal or a photovoltaic panel varies with the angle of incidence of the sun's rays. To capture the maximum amount of energy, it is therefore necessary to follow the daily and seasonal movement of the sun, thanks to a solar tracking system which is not always practically and economically feasible. In domestic installations, a fixed installation is therefore commonly used, which requires defining the tilt angle and orientation of the panel [1].

As a general rule, for installations aiming at maximum annual production, the tilt angle given to the panel corresponds to the angular value of the latitude of the installation site, with an orientation towards the Equator, that is to say due South for locations in the Northern Hemisphere, and an orientation towards the North for locations in the Southern Hemisphere [1].

For a better exploitation of solar system, the assessment of solar potential and the optimum tilt and orientation angle is necessary. In the ESMAP Technical paper 117/07 [2], approximate values of solar potential in the ten regions of Cameroun were given in 2007. Poneabo and Tchawa [3] has studied the photovoltaic solar potential in the littoral region of Cameroon in 2022.

To the best of the authors' knowledge, no study has been conducted in the literature on solar potential and optimization of solar sensors production in Cameroon. The general objective of this work is to contribute to the optimal installation of solar devices, specifically through the evaluation of the solar potential and the determination of the optimal tilt angle for each headquarter of the ten regions of Cameroon. In order to obtain reliable results, a reference year is defined for each case.

MATERIAL AND METHODS

A. Material

Case Study

Cameroon is a country located at the center of Africa and at the North of the equator. It extends in latitude between 1°40' and 13° (north) and in longitude between 8°80' and 16°10' (west) with a total surface area of 475,440 Km^2 carrying a population of about 24 million inhabitants. It has a triangular shape that stretches from the south to Lake Chad over nearly

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1200 km, while the base spreads from west to east over 800 km. It has a 420 km maritime border along the Atlantic Ocean to the southwest. It is bordered to the west by Nigeria, to the south by Congo, Gabon and Equatorial Guinea, to the east by the Central African Republic, and to the northeast by Chad. It is subdivided in ten administrative units as presented on figure 1 called Regions created by the decree of the 12/11/2008**.**

Figure 1: The 10 Regions of Cameroon

Softwares

The RETScreen and MATLAB 2014 software were used respectively for the collection of meteorological data and simulations.

B. Methods

Definition of reference year

A reference year based on the weather conditions for 10 consecutive years (2009 to 2018) as reported by ([4]; [5]; [6]): Data from 10 consecutive years (2009 to 2018) were considered; For each year, the average temperature for the 12 months is calculated; Regardless of the year, the month whose average temperature is closest to the overall average over 10 years is selected.

Assessment of solar energy

Yves Jannot's [7] model was used to simulate the hourly solar density. According to him, the total hourly radiation G*(i, γ) received by a plane surface tilted of an angle "i" (in degrees) and directed towards a direction forming an angle "γ" (in degrees) with the Southern direction (γ counted positively towards the West) is the sum of the hourly direct radiation S*(i, γ), the hourly diffuse radiation D*(i, γ) and the hourly reflected radiation R*(i, γ) as presented in equations 1 to 4.

$$G^*(i,\gamma) = S^*(i,\gamma) + D^*(i,\gamma) + R^*(i,\gamma) \quad (1)$$

$$S^*(i,\gamma) = S^*/\sin(h)\ x\ [(\cos(h)\sin(i)\cos(a-\gamma) + \sin(h)\cos(i)] \quad (2)$$

$$D^*(i,\gamma) = D^*/2\ x\ [1+\cos(i)] \quad (3)$$

$$R^*(i,\gamma) = G^*/2\ x\ \rho[1-\cos(i)] \quad (4)$$

where "ρ" is the Albedo, "a" the Latitude and *S****,** *D** and *G* *are* respectively direct, diffus and global hourly solar radiation on an horizontal wich expressions are given [7].

Effects of the tilt angle on the power received by the solar sensor

The effects of the tilt angle of the solar sensor on the received power was simulated for two standard days in each city: the least sunny and the sunniest.

RESULTS AND DISCUSSIONS

A. Solar Potential

Figures 2 gives the daily average of the solar radiation and the temperature respectively in each city. The analysis of this graph shows that the average radiation is 5.03 kWh/m^2 / day in Cameroon with a minimum of 4.43 kWh/m^2 / day in the South-west Region (Buea) and a maximum of 5.88 kWh/m^2/day in the Far-North Region (Maroua). The average temperature is 23.7°C with a minimum of 21.07°C in the North-West Region (Bamenda) and a maximum of 27.8°C in Far-North Region (Maroua). The Far-North Region is thus the sunniest and hottest area. The Littoral and South-west Regions are the least sunny with a daily average radiation of 4.44 KWh/m^2/day and 4.43 KWh/m^2/day respectively. The North-West Region is the coldest with a daily verage temperature of 21.07°C. Similar results were reported by [8], [9] and [10].

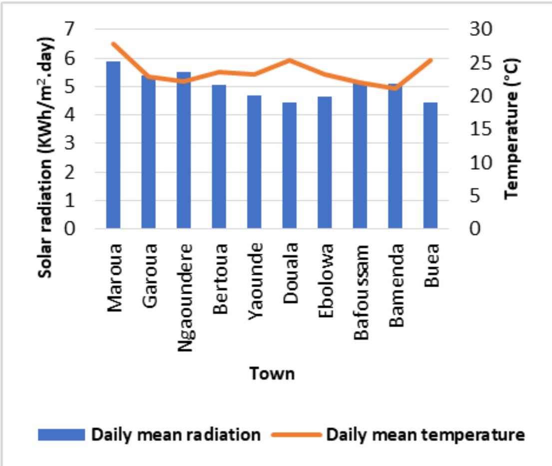

Figure 2: Daily average of the solar radiation and temperature in some cities of Cameroon

The monthly average of solar radiation is shown in figure 3. It is noted that the maximum values of the radiation are registered in February, march and April and the minimum values are registered in July, august and September.

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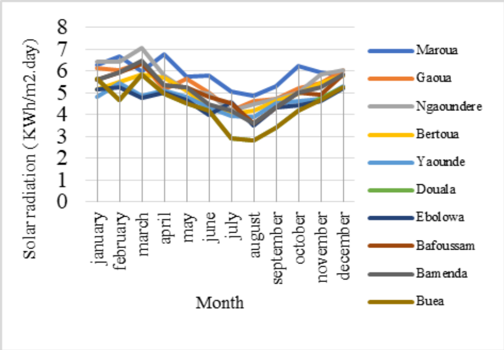

Figure 3: Monthly average of the solar radiation in some cities of Cameroon

Table 1 gives the summary of the extreme values reached by the solar radiation and the temperature. Out of the ten Regions, seven receive the maximum of sunning in March and the minimum in August. The hottest months are March and February. The thermal variations are more important in the septentrional Regions than in the meridional Regions.

Table 1: Months corresponding to the extreme values of the solar radiation and the temperature in the ten Regions

Town	SM	LSM	HM	CM	TD
Ma	Apr (6.79)	Aug (4.88)	Apr (32.7)	Jan (24.3)	8.4
Ga	Mar (6.39)	Jul (4.19)	Mar (25.5)	Dec (21.8)	4.0
Ndere	Mar (7.07)	Jul (4.18)	Mar (25.6)	Aug (20.9)	4.6
Be	Mar (5.84)	Jul (4.03)	Mar (25.9)	Aug (22.7)	3.2
Yde	Feb (5.47)	Aug (3.88)	Feb (24.8)	Aug (22.4)	2.4
Dla	Mar (5.84)	Aug (2.84)	Feb (26.4)	Aug (24.0)	2.4
Ebwa	Feb (5.26)	Aug (3.49)	Feb (24.5)	Aug (22.4)	2.1
Bsam	Mar (6.31)	Aug (3.60)	Mar (23.2)	Aug (21.0)	2.2
Bda	Mar (6.48)	Aug (3.60)	Mar (22.3)	Aug (19.9)	2.4
Buea	Mar (5.84)	Aug (2.84)	Feb (26.4)	Aug (24.0)	2.4

B. Power received by a thermal solar sensor

Table 2 below shows the maximum Global instantaneous powers reached in each area for a zero value of both ι and γ during the sunniest day

Town	l (°)	R (kwh/m^2/day)	MP (w/m2)
Ma	10.6	7.6	1454
Ga	9.3	7.33	1359
Ndere	7.3	7.46	1342
Be	4.6	7.05	1249
Yde	3.9	6.23	1067
Dla	4.1	6.94	1195
Ebwa	2.93	6.1	1047
Bsam	5.48	7.16	1214
Bda	6.0	7.08	1262
Buea	4.15	6.94	1195

C. Influence of tilt angle on the solar power

Figures 4-13 show the results of the variation of the instantaneous power attracted by the solar sensor with respect to the variation of the tilt angle in the headquarters of the regions. In each case, the optimum tilt angle does not exceed 45°, which is in conformity with the recommendations of [11] and [12] according to which it is necessary to choose the tilt angle close to the latitude of the place considered but not exceeding 45° in any case. Table 3 gives the summary of the maximum tilt angle of a thermal solar sensor for each region in Cameroon.

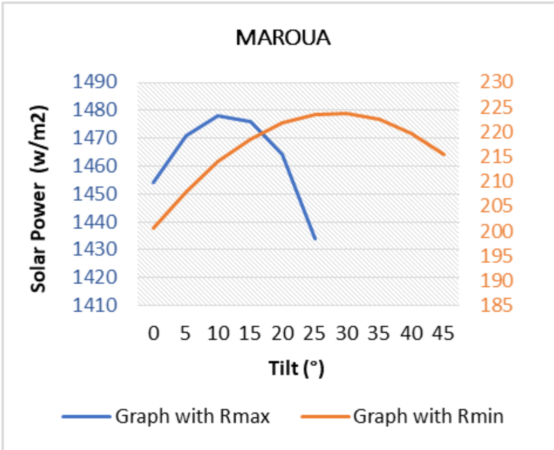

Figure 4: Power attracted by a solar sensor in Maroua

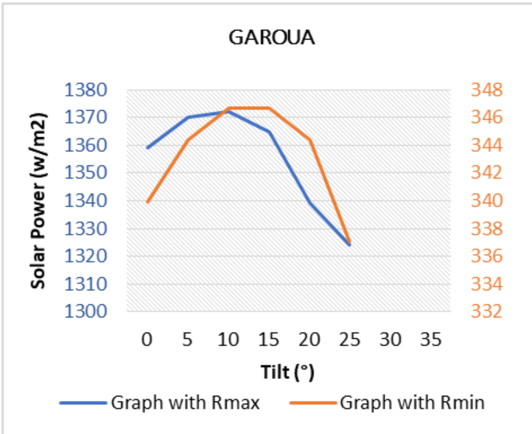

Figure 5: Power attracted by a solar sensor in Garoua

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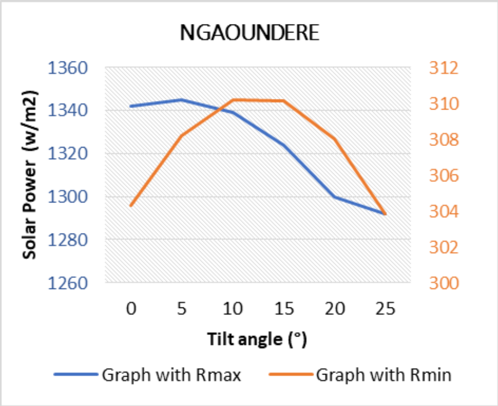

Figure 6: Power attracted by a Solar sensor in Ngaoundere

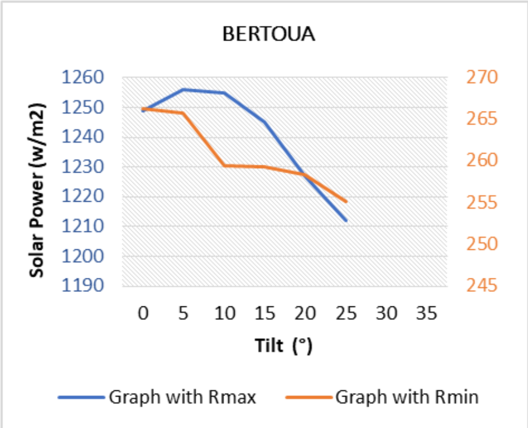

Figure 7: Power attracted by a Solar sensor in Bertoua

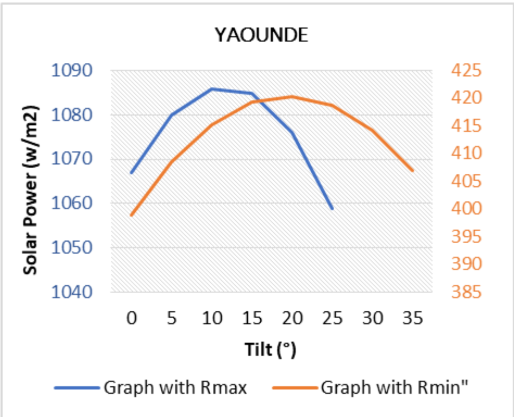

Figure 8: Power attracted by a Solar sensor in Yaoundé

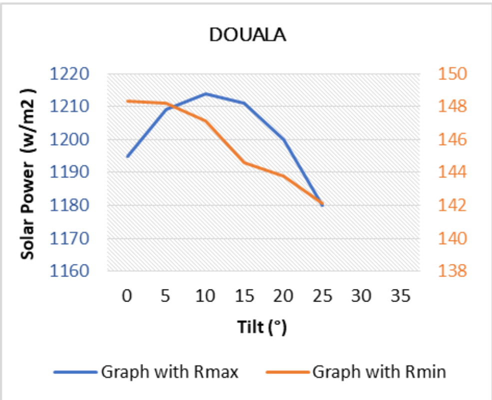

Figure 9: Power attracted by a Solar sensor in Douala

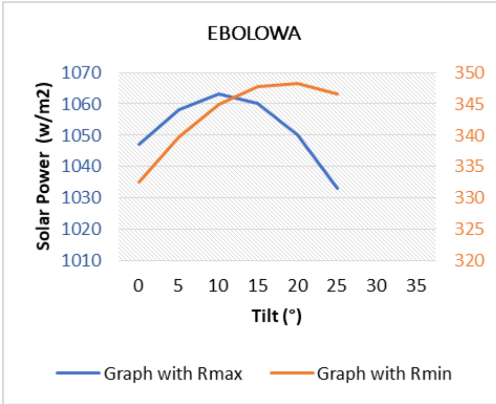

Figure 10: Power attracted by a Solar sensor in Ebolowa

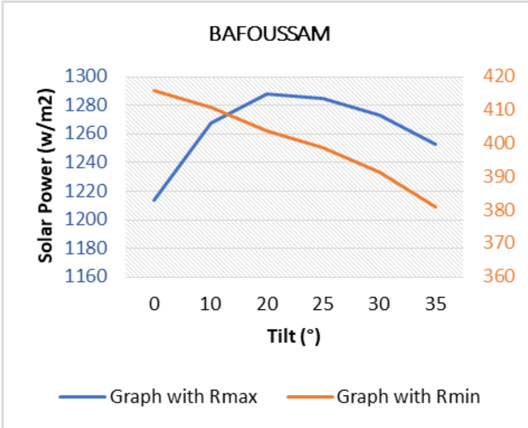

Figure 11: Power attracted by a Solar sensor in Bafoussam

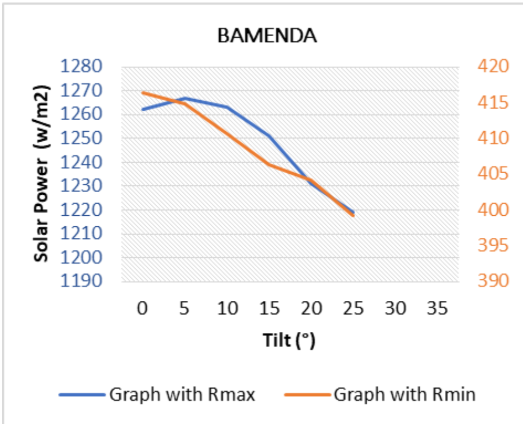

Figure 12: Power attracted by a Solar sensor in Bamenda

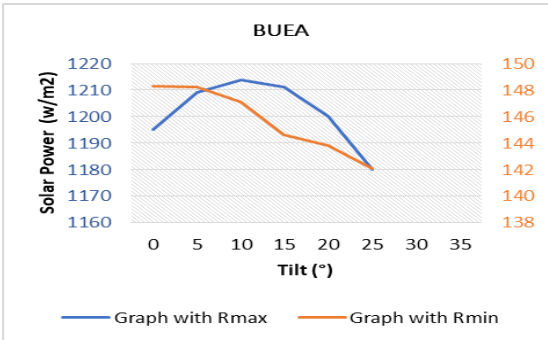

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Figure 13: Power attracted by a Solar sensor in Buea

The analysis of the data contained in table 3 below shows that an optimum tilt angle of 10° in Garoua remain the same in sunniest or least sunny days. In Bamenda and Bertoua, there is no significant difference between the optimum tilt angle in sunniest and least sunny days, so the optimum tilt angle in the least sunny day (5°) is recommended. In the others 7 cities where the difference is significant, a value of the tilt angle corresponding to the intersection between the two graphs should be considered. Table 4 gives the summary of the optimum tilt angle in each town. The values found are not in accordance with the general rule for which the optimum tilt angle must the angular value of the latitude of the installation site.

Table 3: Optimal tilt angle for the sunniest and least sunny in some cities in Cameroon

Town	Latitude (°)	i_{op} (R_{max})	P A (w/m^2)	I_{op} (R_{min})	P A (w/m^2)
Ma	10.6	10°	1478	30°	223,7
Ga	9.30	10°	1372	10°	346,7
Ndere	7.30	5°	1345	10°	310,2
Be	4.60	5°	1256	0°	266,3
Yde	3.90	10°	1086	20°	420,4
Dla	4.10	10°	1214	0°	148,3
Ebwa	2.93	10°	1063	20°	348,3
Bsam	5.48	20°	1288	0°	415,9
Bda	6.00	5°	1267	0°	416,3
Buea	4.15	10°	1214	0°	148,3

Tableau 4: Optimum tilt angle for solar sensor in some cities in Cameroun

Town	l (°)	i_{op}(°)
Ma	10.6	15
Ga	5.48	10
Ndere	6.0	10
Be	9.3	5
Yde	2.93	15
Dla	7.3	5
Ebwa	4.15	10
Bsam	4.6	10
Bda	3.9	5
Buea	4.1	5

CONCLUSION

This research, for a better installation of solar sensor in Cameroon, has provided interesting results on the optimization of the installation of solar devices in Cameroon. The analysis of solar radiation and temperature data over 10 reference years made it possible to determine the sunniest and hottest months for each of the 10 regions of the country. The daily solar radiation varies between 4,43 KWh/m^2 and 5,88 KWh/m^2 according to areas in Cameroon with an average temperature between 21.07°C and 27.8°C. The simulations then showed that the optimal tilt angle of the solar collectors varies between 5 and 15 degrees depending on the region. this study will provide valuable guidelines to designers and installers of solar thermal and photovoltaic systems in Cameroon, allowing them to maximize the energy efficiency of these installations according to the specific weather conditions of each locality.

APPENDIX

Nomenclature

a	Azimut (°)
Bda	Bamenda
Be	Bertoua
Bsam	Bafoussam
CM	Coolest Month
*D**	Diffuse Solar radiation on horizontal surface (W/m^2)
D (i, γ)*	Diffuse solar radiation on the sensor area (w/m^2)
Dla	Douala
Ebowa	Ebolowa
ESMAP	Energy Sector Management Assistance Program
*G**	Hourly global solar radiation on horizontal surface (W/m^2)
G(i, γ)*	Hourly global solar radiation (w/m^2)
Ga	Garoua
h	Height of the sun (°)
HM	Hottest Month
i	Sensor tilt angle (°)
i_{op}	Optimum tilt angle of the solar sensor (°)
LSM	Least Sunny Month
Ma	Maroua
MP	Maximum Power (W/m^2)
Ndere	Ngaoundéré
PA	Power Attracted
R(i, γ)*	Reflected solar radiation on the sensor area (w/m^2)
Rmax	Daily maximum solar radiation

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	(Kwh/m^2)
Rmin	Daily minimum solar radiation Kwh/m^2)
*S**	Direct solar radiation on horizontal surface (W/m^2)
S(i, γ)*	Direct solar radiation on the sensor area (w/m^2)
SM	Sunniest Month
TD	Temperature Deviation
Ydé	Yaoundé
γ	Sensor orientation angle (°)
Ρ	Albedo (-)

ACKNOWLEDGEMENTS

Authors appreciate Mr Sambero Ngaroua Céleste, Mr Matakon Ngaroua Modeste and Dr Hiswé Fatamou who provided insight and expertise that assisted the research.

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