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Study of the Solar Potential and Five Meteorological Parameters (Climates) of the Nigerien City of Zinder: Case Study, Niger

Aboubacar ALI[1], Makinta BOUKAR[1], Ibrah SEIDOU SANDA[2], and Saïdou MADOUGOU[1]

[1]Laboratoire d'Energétique, d'Electronique, d'Electrotechnique, d'Automatique, et d'Informatique Industrielle (LAERT-LA2EI), Niger

[2]Centre Régional AGRHYMET, Niger

ABSTRACT: This article proposes a study of the solar field and five climatic parameters of the Nigerien city of Zinder (Zinder city extends between the parallels 12° 48' and 17° 30' North and in longitude between 7° 20' and 12° 0' East. They are among the sunniest areas of Niger) from 1961 to 2010 based on experimental data. Most of the researchers work in this area uses few measured values to evaluate solar radiation. In this study we use fifty years (50 years) of experimental data. We will use two models most frequently used in the literature by researchers that are well adapted to the Niger region. After deep analysis of the evolution of global solar radiation, wind speed, temperature, duration of insolation, and precipitation during this period in this city located in the eastern part of the country, it is clear that : all solar energy applications require a rigorous, detailed and complete knowledge of solar radiation and climatic parameters of the site.

KEYWORDS: Irradiation models, diffuse, temperatures, wind speed, rain and duration of sunshine.

1 INTRODUCTION

Niger, due to its geographical location, is one of the sunniest countries in the world. It benefits from more than 3000 hours of sunshine per year, or approximately 2,300 kWh / m^2 / year [1]. The region of Zinder, located in the south-eastern part of Niger, extends between 12 ° 48 'and 17 ° 30' North and in longitude between 7 ° 20 'and 12 ° 0' East. It is one of the sunniest areas in Niger. The duration of sunshine in Niger varies very little in space during the year and is about 9 hours on average, but it is higher in the dry season than in the rainy season.

All applications of solar energy, namely domestic hot water production [2], [3], space heating [4], [5], solar air conditioning [6], drying of agro-food products [7], [8], [9], solar water [10], solar photovoltaic [11], [12] and thermodynamic solar [13] require a thorough and detailed knowledge of sunlight, maximum and minimum temperature, and the thermo-anemometer. Measurements of global radiation, maximum and minimum temperatures and wind speed for the Nigerien town of Zinder over the period 1961 to 2010 (50 years) were obtained from the Nigerien National Meteorological Service in Niamey.

2 METHODOLOGY

2.1 COLLECTION OF EXPERIMENTAL DATA

The collection of global solar radiation from Zinder is done at the National Center for Solar Energy (CNES), other parameters such as temperature, wind speed, rainfall and duration of Zinder city sunshine are collected at the national center for Meteorology.

2.2 SOLAR RADIATION

Experimental knowledge and even the forecast of solar radiation are of paramount importance for the reliable dimensioning of solar energy systems. Several studies have been conducted as part of the Solar Energy Potential assessment.

Ground-based experimental data on global solar radiation are not however always available in most places [14], [15], [16], [17], [18]. It is in that sense that Samuel Chukwujindu Nwokolo et al. conducted a study to classify and review the empirical models used to estimate global solar radiation in West Africa. They classified the empirical models used into six main categories and presented them according to the input parameters used. They also classified them into several subgroups and were finally presented according to their year of development. A total of 356 empirical models and 68 functional forms are presented in the literature for estimating solar radiation in West Africa [19].

The solar radiation comprises the following components [20]: Direct radiation (S_b) which is the radiation that goes through the atmosphere without being modified; the diffuse radiation (D_d) which is the part of the solar radiation diffused by the solid or liquid particles suspended in the atmosphere (air, cloudiness, aerosols, etc.) and the total solar radiation which is the sum of the direct radiation and comprises the total of the radiation scattered in the atmosphere as well as some of the radiation reflected from the ground.

$$G_g = S_b + D_d \quad (1)$$

Where:

G_g stands for global radiation

S_b stands for direct radiation

D_d stands for diffuse radiation

The earth reflects some of the direct sunlight. This quantity is called the albedo stream. Albedo is generally defined as the ratio of solar energy reflected on a surface to direct solar energy [19].

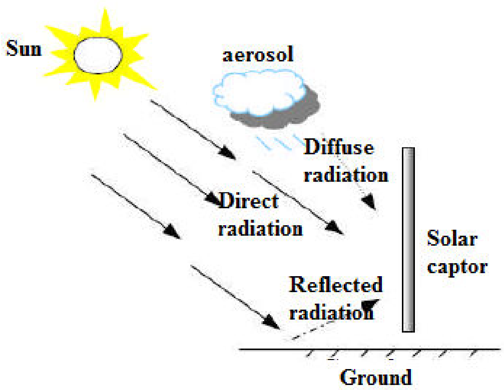

Fig. 1. Different forms of solar radiation [29]

2.3 MODELING OF TEMPERATURE AND SOLAR RADIATION INCIDENT

Several models for the approximation of solar radiation [22] are based on several variables such as water vapor determined by the condensable water depth and the atmospheric cloud factor defined by the ANGSTRÖM coefficient. Many researchers have been interested in the theoretical study of this solar radiation.

The works carried out by C. ZIDANI et al. [22] on a simulation of the apparent position of the sun at any time of the day and year, followed by a simulation of the instantaneous, Orientation. A. BAIG et al [24] conducted studies to establish a model based on the Gaussian distribution function to estimate daily global illumination. H. AROUDAM et al. [25] developed a model of the correlations between clarity index, cloud number and sunshine fraction. A physical model based on the general equation of radiative transfer of solar radiation in the soil-atmosphere system was used by A. MECHAQRANE et al [26] to estimate the global hourly and daily irradiations on a horizontal ground surface from the satellite sat-2 satellite measurements. A. Moummi et al. [27] proposed a comparison study between two empirical approaches to calculate the solar field.

In this article we are going to use the two semi-empirical approaches of PERRIN DE BRICHAMBAUT and LIU JORDAN to evaluate the city of Zinder solar field. For the determination of the ambient temperature (minimum and maximum), we are using three models: the theoretical model, the corrected theoretical model and the IDLIMAN model.

The different components of solar radiation vary according to the height of the sun, the angle of incidence, the weather and the visibility of the atmosphere. Perrin BRICHAMBAUT presented an empirical method to estimate the energy received by any orientation sensor [28].

For a clear sky, the illuminations of the diffuse radiation D_d and of the direct radiation S_b, received by a sensor are given by the following relations:

$D_d = (\frac{1+\cos(\theta)}{2})\, D_H + (\frac{1-\cos(\theta)}{2})\, \mu * G_H$ **(2)**

$S_b = A_1 + \cos(i)\ \exp.(-\frac{1}{A_{3.}\sin(h+2)})$ **(3)**

$D_H = A_2\ (\sin(h))^{0,4}$ **(4)**

$G_H = A_2\ (\sin(h))^{8}$ **(5)**

Where D_H: Diffused illumination received by a horizontal surface.

G_H: Overall illumination received by a horizontal surface.

θ : Angle of inclination of the plane with respect to the horizontal in degree (°)

The global radiation Gg is deduced from the following formula: $G_g = S_b + D_d$ **(6)**

$$\mu = \begin{cases} 0.9 \text{ to } 0.8 \text{ Snow} \\ 0.8 \text{ to } 0.4 \text{ light floor} \\ 0.4 \text{ to } 0.2 \text{ Greenery} \end{cases}$$ **(7)**

μ : Albedo of the ground

$A_1 A_2$ and A_3: Are constants that depend on the state of the atmosphere.

Table 1. Parameters describing the state of the atmosphere [22]

State of the atmosphere	A_1	A_3	A_2
Dark blue sky	1300	6	87
Light blue sky	1230	4	125
Milky blue sky	1200	2.5	187

In most cases, it is more appropriate to estimate the overall illumination on a plane inclined by the generalized LIU JORDAN relation in the form [22]:

$E_c = E_0[1+0.033\cos(\frac{360}{365})\ N]$ **(8)**

$T_b = a_1 + a_2 \exp(\frac{-k}{\mathrm{Sinh}})$ **(9)**

$a_1 = R_0[0.4237-0.00821\ (6-Z)^2]$ **(10)**

$A_2 = R_1\ [0.5055-0.00595\ (6.5-Z)^2]$ **(11)**

$K = R_k[0.2711-0.1858\ (2.5-Z)^2]$ **(12)**

$\sin(h) = \sin(L).\sin(d) + \cos(L).\cos(d).\cos(\emptyset)$ **(13)**

$\emptyset = 15(STT-12)$ **(14)**

Where STT is Solar Time True

$d = 23.45\sin[0.986(N+284)]$

L stands for Latitude of the place in degrees (°)

d stands for declination of the sun in degrees (°) **(15)**

N stands for the Number of the day from January 1st

Ø stands for the Solar angle in degree (°)

Z stands for the altitude of the location expressed in km and R_0, R_1, R_k, k are dimensionless correction constants.

Table 2. Dimensionless correction constants [22]

Type of Time	R_0	R_1	R_k
Tropical	0.95	0.98	1.02
Summer (average altitude)	0.97	0.99	1.02

The direct radiation on a horizontal plane is given by the relation:

$S_b = I_c.\tau_b.(\sin(h))$ **(16)**

The diffuse radiation by a clear sky on a horizontal plane is given by the relation

$D_d = I_c(0.2710\text{-}0.2939.\tau_b).(\sin(h))$

I_c stands for constant solar

τ_b stands for correction constant **(17)**

The global radiation is given by

$G_g= S_b + D_d$ **(18)**

In most cases, the ambient temperature is taken as the mean value of the two extreme temperatures. Its evolution from sunrise to sunset is marked by minimum values at sunrise and sunset and a maximum value in the middle of the day. These are the only values given by meteorological stations. The modeling of air temperature generally used as heat transfer fluid in the solar collectors is of key importance.

The minimum and maximum temperature values given by meteorological stations are not sufficient to monitor its development over the course of a day because many heat transfer phenomena are linked to it. The variation of temperature is closely related to the radiant temperature of the celestial vault (temperature of the sky). Indeed, for sites in altitude, thermal losses must be taken into account. The equivalent ambient air temperature can be calculated from the following expression [29]:

$T_{eq} = \frac{T_a\,.h_{cve}+\ T_{ciel}.h_{rve}}{h_{ve}}$ **(19)**

Where: Ta is the ambient temperature of the air

h_{cve} : Is the coefficient of thermal losses by convection between the front face of the sensor and the external environment.

h_{rve} : Is the coefficient of the thermal losses by radiation between the face of the sensor and the external environment

$T_{sky}= [\ T_a^4\ \text{-}\frac{R}{S}]^{0.25}$ **(20)**

T_a stands for ambient temperature

In this relation, R represents the net flux of radiation exchanged by the coolant for the low wavelengths, often measured by meteorological stations (sometimes called R4), and depends substantially on the altitude. If the R value cannot be determined, the temperature of the sky (Tsky) can be calculated by Swimbank's law:

$T_{sky} = 0{,}0552.\ T_a^{1.5}$ **(21)**

The theoretical evolution of the ambient temperature can be modeled by the equation (22):

$T_e(t) = \frac{T_{max}+T_{min}}{2} + (\frac{T_{max}-T_{min}}{2}) \cos (\frac{2\pi t}{\Delta t})$ **(22)**

Tmax, Tmin and Δt are respectively maximum temperature, minimum temperature and duration of the solar day.

In this model, the maximum temperature is reached at midday solar true time at which the density of the heat flux is at maximum. This model does not correspond to the reality because it is considered that the maximum temperature is reached only at the solar thermal noon which corresponds to the instant of the true solar noon plus 1/8 of the duration of the solar day (Δt) [29]. This is mainly due to the thermal inertia of the soil, the thermal equilibrium between the environment and the soil.

The theoretical model is modified to take into account the notion of the "solar thermal noon" at which the instant maximum ambient temperature is obtained. The ambient temperature is considered as the average temperature. The ambient temperature can be modeled by the following relation [29]:

$$T_e(t) = \frac{T_{max} + T_{min}}{2} + \left(\frac{T_{max} - T_{min}}{2}\right) \cos\left(\frac{2\pi\left(t - 12 - \frac{\Delta t}{8}\right)}{\Delta t}\right) \quad (23)$$

According to this D'IDLIMAN model,, the ambient temperature is evaluated according to the following expression:

$$T_e(t) = T_1 + T_2 \cos\left[(14 - STT)\frac{\pi}{12}\right] \quad (24)$$

With :

$$T_1 = (T_{max} + T_{min})/2 \quad (25)$$

$$T_2 = (T_{max} - T_{min})/2 \quad (26)$$

T_{max} and T_{min} Represent the maximum and minimum ambient temperatures during a day.

3 RESULTS AND DISCUSSIONS

We selected for our study the monthly averages of the minimum and maximum temperatures, wind speed and global radiation of 11 years of the study period. Indeed, the reason for choosing these years is to avoid the curves congestion.

Fig 2 below gives the average duration of sunshine. The months of February, July, August and September record the shortest duration of sunshine. The longest duration of sunshine, 10.13 hours a day is recorded by the months of March and November and the shortest is recorded by the month of July (7.74 hours per day). The entire city is illuminated by the sun about 9 hours on average per day.

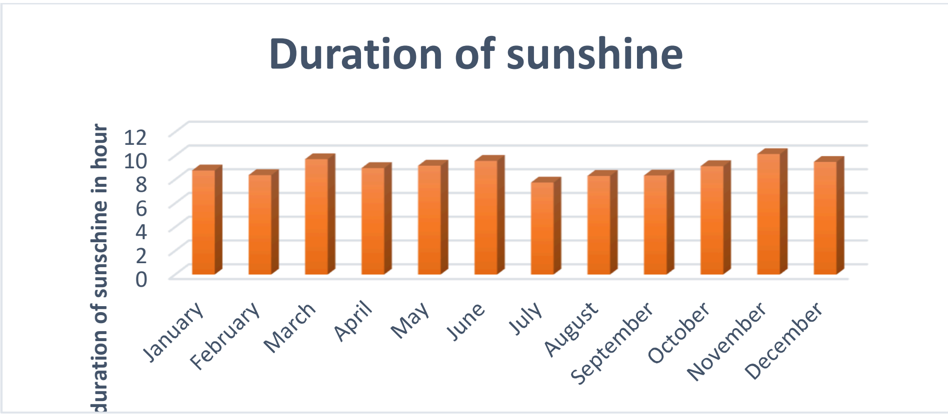

Fig. 2. The average monthly insolation duration

Figure 3 below shows the average rainfall (rainfall) measured from the Zinder station during the period. We note that it reaches its peak in July which corresponds to the period of the greatest rainfall in Niger. May, June, September and October have the lowest rainfall. The months of January, February, March, April, November and December correspond to periods without rain (dry and hot seasons).

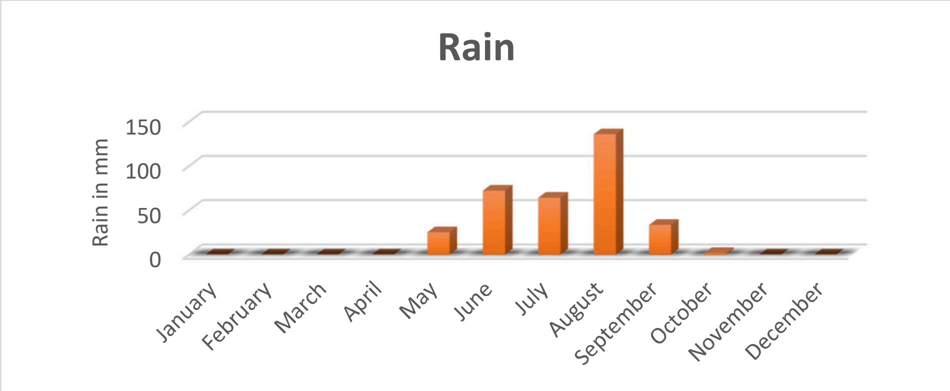

Fig. 3. Average monthly rain

The variations of these quantities are represented by FIGS. 2, 3, 4 and 5 below

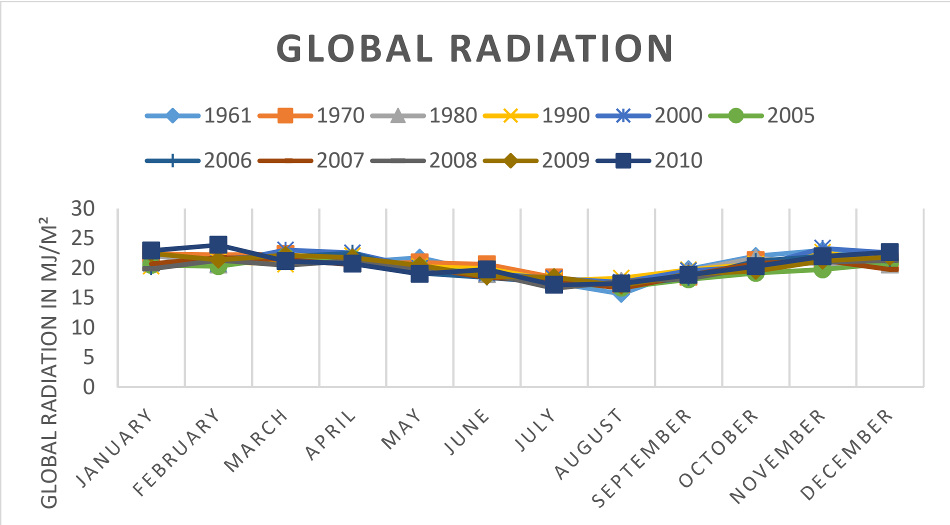

Fig. 4. The average monthly minimum temperature

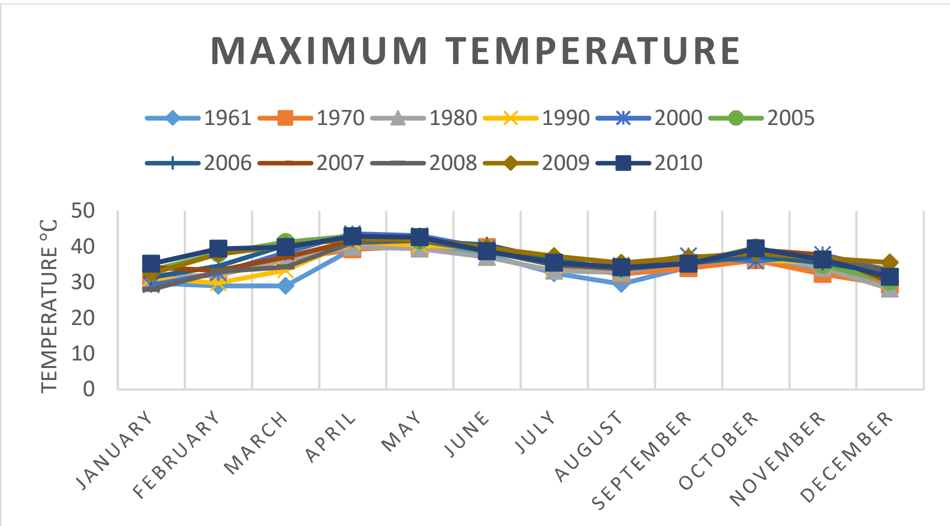

Fig. 5. The average monthly maximum temperature

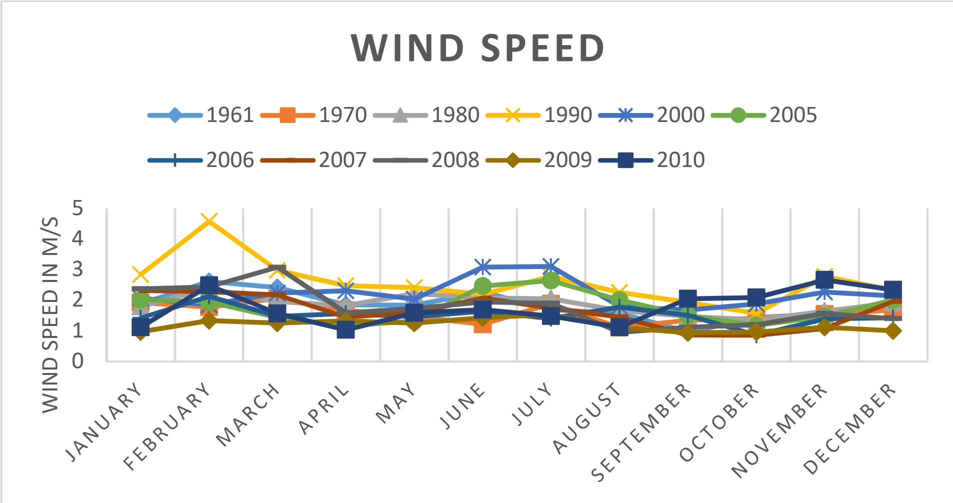

Fig. 6. Average monthly wind speed

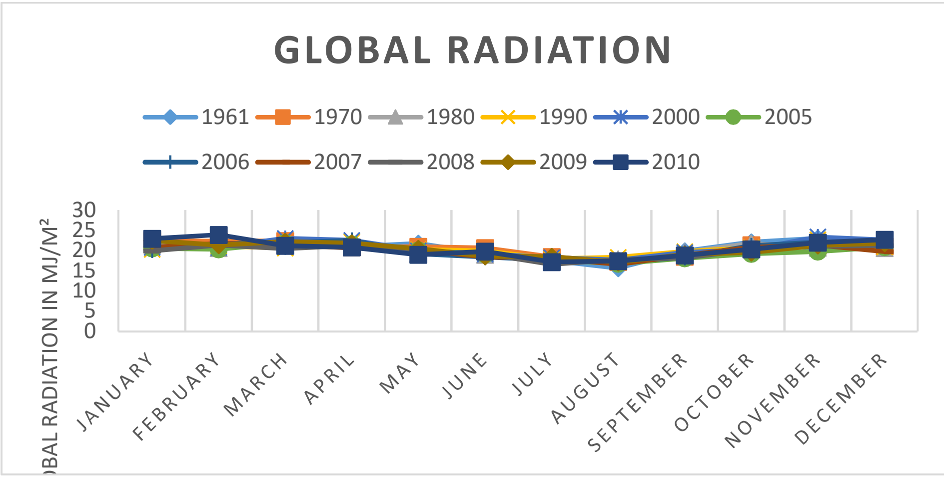

Fig. 7. The average monthly total write-off

We notice that in Figures 2 and 3, monthly averages of minimum temperatures vary from 15 °C to 28 °C, monthly averages of maximum temperatures range from 30 °C to 42 °C. The month of January records the lowest temperature that corresponds to the period of coolness and the month of May records the highest temperature which corresponds to the period of heat. In conclusion, the minimal and maximum temperatures obtained from this city make it possible to make a good dimensioning of a photo-thermal energy system.

Fig 4 shows the evolution of the mean wind speed measured from the Zinder station during the 1961 to 2010 period. This average speed is almost less than 3 m / s. We note that it reaches its peak in February which corresponds to the period of the harmattan wind and for the rest of the period its value is around 2 m / s. For a photo-thermal system, the wind is a cooling factor, so for the month of February, this cooling will have an important effect because it is one of the warmest m878vf b l months and records the highest wind speed. For the other months that have low average speeds, the wind has no great influence.

The analysis of FIG. 5 shows that the lowest values of the average global radiation are obtained during the months of August, July and September. These months correspond to the periods when rainfall is high. The decrease in global radiation is explained by the fact that aerosols (especially clouds) cover the sun's rays. By comparing the annual mean value over the period 1961-2010 (50 years) of the total irradiation of the town of Zinder 20,35 MJ / m².day and that obtained from the city of Ouagadougou for example 17,45 MJ / M².day over the period 1992-2006 (14 years) [4] ; we can say that the town of Zinder is sunnier than that of Ouagadougou.

The simulations of the different models are done under the environment of R version 2.2.3 software on February 28, 2010 where the number of the day N corresponds to 59 from January 1st. The choice of February 28 is not peculiar; it corresponds to the day of the simulations.

FIGS. 6, 7, 8, 9, 10 and 11 represent the evolvement of the diffuse, direct and overall radiation of the two models during the day of 28 February, which corresponds to the day when we made the simulations. FIGS. 12 and 13 show the evolution respectively of the solar constant corrected according to the numbers of the days and the ambient temperatures. The analysis of Figures 6, 7, 8, 9, 10 and 11 shows that the models give a good estimate of solar radiation. The model of Perrin BRICHAMBAUT gives a good estimate more than that of LIU JORDAN contrary to the conclusions of A. MOUMMI [21].

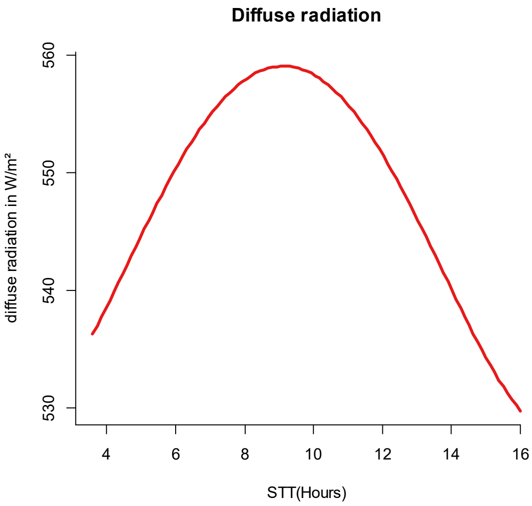

Fig. 8. Diffuse radiation of the model LIU JORDAN model

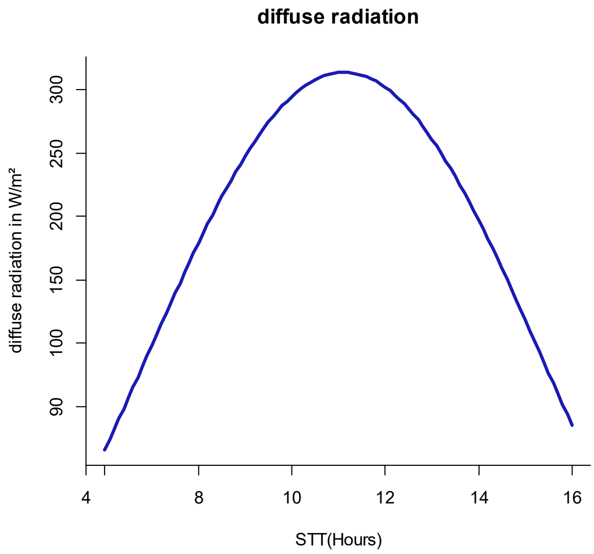

Fig. 9. Diffuse radiation of the model Perrin BRICHAMBAUT model

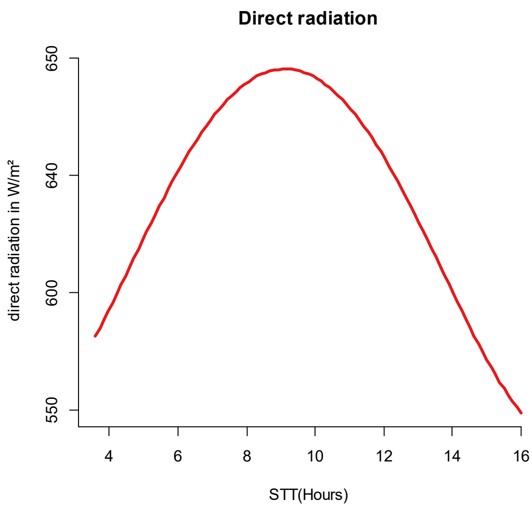

Fig. 10. direct radiation of the model LIU JORDAN model

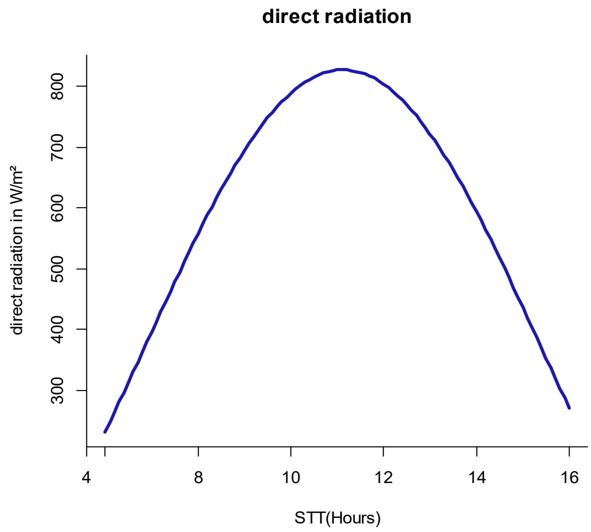

Fig. 11. direct radiation of the model Perrin BRICHAMBAUT model

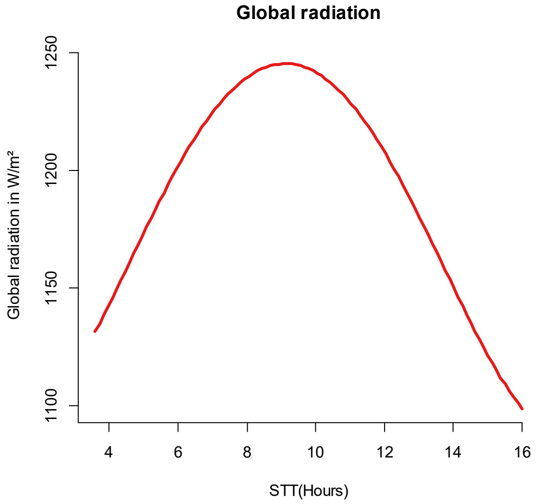

Fig. 12. Global radiation of the LIU JORDAN model

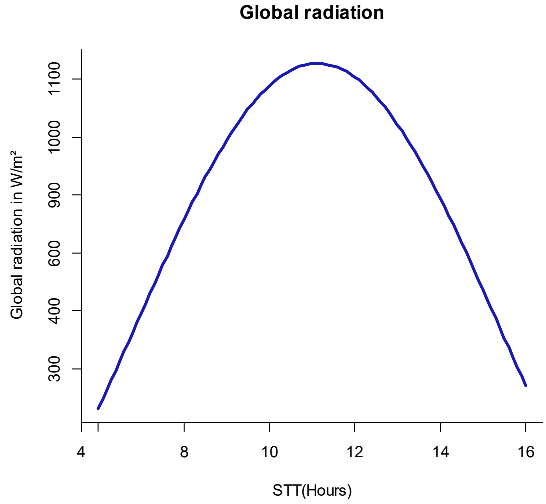

Fig. 13. Global radiation of the Perrin BRICHAMBAUT model

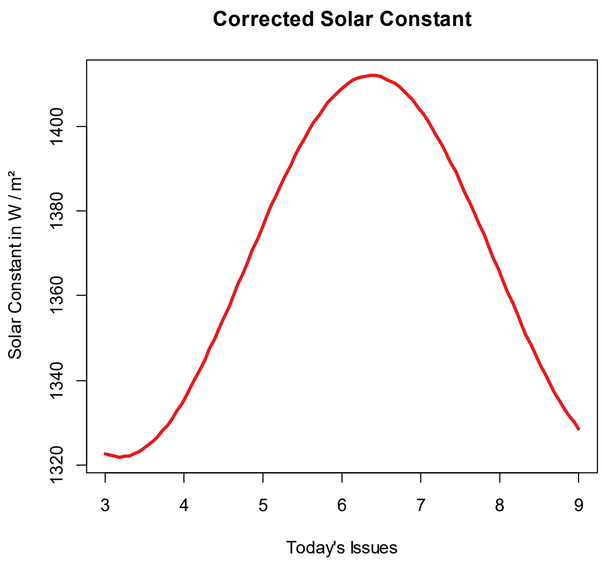

Fig. 14. The corrected solar constant

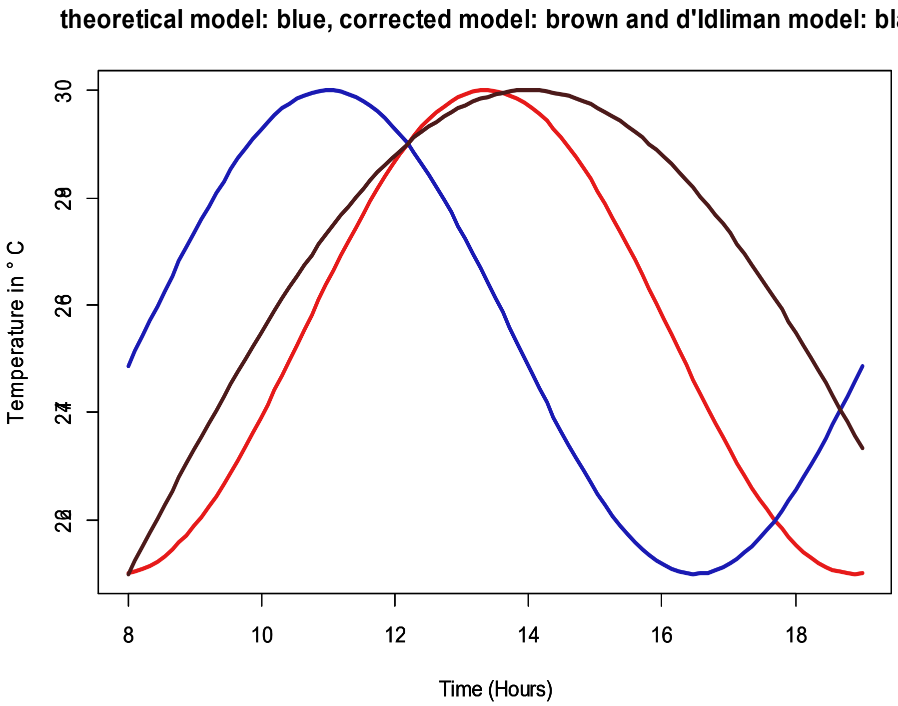

Fig. 15. Temperature profile for According to the number of the day models theoretical, corrected and IDLIMAN

The maximum diffuse sunlight is 340W / m2 (Fig 7), the direct is 850 W / m2 (Fig 9) and the global is 1200W / m2 (Fig 11) for the Perrin BRICHAMBAUT model at 1 pm Solar Time True (TSV). For the LIU JORDAN model, the maximum diffuse radiation (FIG. 6), direct (FIG. 8) and global FIG. 10) are respectively 575 W / m2, 750 W / m2 and 1255 W / m2 at 13:00 TSV. The maximum ambient temperature is 33 °C at 13:00 for the theoretical model which does not correspond to the reality because it does not take into account the thermal inertia of the earth. The maximum ambient temperature is 33 °C at 14:30 (Fig 13) for the theoretical model corrected and that of IDLIMAN which take into account the thermal inertia of the soil. There is a time difference between the global radiation and the maximum temperature. This is explained by the thermal inertia of the soil. The corrected solar constant is simulated by varying the integer N from 1 January to 10 January.

4 Conclusion

In this study, deep analyzes of solar irradiation and climatic parameters have been presented on one hand and models of solar irradiation and temperature by semi-empirical approaches are presented, simulated and analyzed on the other hand. These analyzes allowed us to study the theoretical and experimental evolution of the global radiation and these parameters during the period.

After comparing the measured values with those estimated by the different models studied, we can say that the two models of Perrin BRICHAMBAUT and LIU JORDAN give a good estimate of the solar radiation as we met in the literature. The corrected and IDLIMAN models give a correct estimate for ambient temperature compared to the theoretical model.

This study can allow the development of a solar atlas for the city of Zinder according to the different months of the year. The atlas will indicate the values of the quantities to be used for reliable dimensioning of solar energy systems (photovoltaic and photothermal).

This study may be extended to other cities in Niger provided that the measured temperatures and wind velocities are obtained.

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