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Model for obtaining the daily direct and diffuse solar radiations

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Abstract—**The depletion of the conventional energy resources (fossil, oil and gas), pollution, and climate change require reflection on the need for energy diversification by a fast integration of renewable energies. The most important benefit of renewable energies is the solar energy, which is the main prerequisite of the life on the Earth. It is the direct source for generating heat, light, cold and power. Solar energy can be used in different ways, either in the photovoltaic systems for the electricity production or in thermal systems for the hot water production, field where it knows a considerable development particularly in the housing sector**

In this paper we will determine the empirical model R.sun that will allow us to estimate the daily direct and diffuse radiation on a horizontal plane and compare the diffuse radiation with the results measured at the site of Adrar city of Algeria when four seasons.

The expected results of this comparison are of importance for the investment study of solar systems (solar power plants for electricity production, for example) and also for the design and performance analysis of any system using the solar energy.

Keywords- Solar Radiation, Adrar, R.Sun, Irradiation

NOMENCLATURE

G_{hc}: Global radiation (W/m2)
B_{hc} :Beam radiation (W /m2)
D_{hc}: Diffuse radiation (W/m2)
I_N: Direct normal radiation (W/m2)
h : Solar altitude (degrees)
γ: Elevation above sea level (m)
j': Day angle (rad)
T_{Lk}: Atmospheric turbidity factor
δ_R: Rayleigh optical thickness
T_n: Transmission function
F_d: Diffuse Function

1. INTRODUCTION

The Algeria potential for renewable energy is strongly dominated by solar energy. Algeria considers this source of energy as an opportunity and a lever for economic and social development, particularly through the establishment of wealth and job-creating industries. The potential for wind, biomass, geothermal and hydropower energies is comparatively very small. This does not, however, preclude the launch of several wind farm development projects and the implementation of experimental projects in biomass and geothermal energy **[5].**

Global energy demand is growing rapidly, and natural energy resources such as oil, gas and uranium decrease due to a large dissemination and development of the industry in recent years. To cover the energy needs, research is conducted in renewable energy. A renewable energy that can fulfill the demand of the world until now, solar energy is free and inexhaustible in most parts of the world and has become an economic source.

Knowledge of solar radiation and these components on horizontal and inclined surfaces is necessary and indispensable to any study or design of solar installations. But generally, in the meteorological stations the global solar radiation is measured on horizontal surfaces and on the capital of each region

The monitoring stations are rare across the country. For the estimation of the solar radiation, we use theoretical models **[08-16]**. These models are built in the form of correlation. In order to be applicable to sites considered, they must be confronted with the actual measured values on the site considered over a period covering the deferent seasons.

However, a comparative study was performed on solar illumination on a horizontal plane. Do this several days were selected to compare the values calculated by this model and those given by the radiometric station Adrar, we chose the site of Adrar to the study, the choice of this site was made on the availability of radiometric data sought. Indeed, Adrar is a Saharan town in the middle of the Sahara, this region known by very high daytime temperatures in summer and low temperatures in winter shows Figure 1.

The experimental data of solar radiation used in 2014 came from Research Unit in Renewable Energies in the Saharan Medium in Adrar (*URER-MS*).

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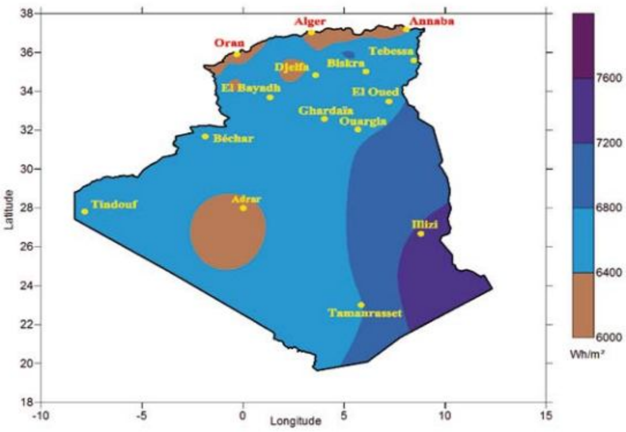

Figure 1: Monthly average of solar irradiation [6]

2. MODEL DESCRIPTION

A modeling of the solar radiation will be presented according to the mathematical R.sun model. This model use specific equation for the determination of the geometrical parameters (solar declination angle, height of the sun, azimuth and angle of incidence, etc.) and atmospheric parameters (optical thickness of the atmosphere and Linke turbidity factor).

The global radiation received is the sum of direct radiation, diffuse and reflected components, Figure 2 shows the components of the solar radiation**[7].**

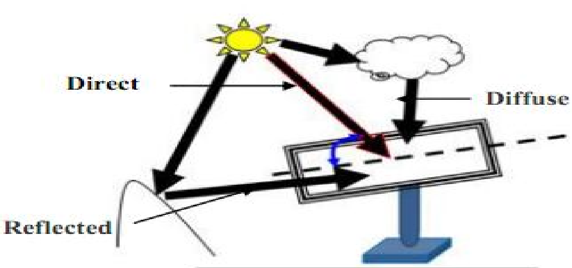

Figure 2: Components of the global radiation

A. R.sun model

The direct normal radiation is expressed as a function of the factor T_L Using the formula:

$$I_N = I_0 \exp(-T_L\, m\, \delta_R) \quad (1)$$

The beam irradiance normal to the solar beam B_{0c} (W/m^2), attenuated by the cloudless atmosphere, is calculated as follows **[1]:**

$$B_{0c} = G_0 \exp\{-0.8662\, T_{LK}\, m\, \delta_R(m)\} \quad (2)$$

The term -0.8662 T_{LK} is the air mass 2 Linke atmospheric turbidity factor [dimensionless] **[2].** The parameter m in equation (1) is the relative optical air mass calculated using the formula **[1]:**

$$m = (p/p_0)/(\sin h^{ref} + 0.50572\,(h^{ref} + 6.07995)^{-1.6364}) \quad (3)$$

where h^{ref} is the corrected solar altitude h (an angle between the sun and horizon) in degrees by the atmospheric refraction component Δh^{ref}:

$$\Delta h^{ref} = 0.061359\,(0.1594+1.123\,h + 0.065656\,h^2)/(1 + 28.9344\,h + 277.3971\,h^2) \quad (4)$$

$$h^{ref} = h + \Delta h^{ref} \quad (5)$$

The p/p_0 component in (3) is correction for given elevation γ (m):

$$p/p0 = \exp(-\gamma/8434.5) \quad (6)$$

The parameter $\delta_R(m)$ in (1) is the Rayleigh optical thickness at air mass m and is calculated according to the improved formula by as follows **[1]:**

for $m \leq 20$:

$$\delta_R(m) = 1/(6.6296 + 1.7513\,m - 0.1202\,m^2 + 0.0065\,m^3 - 0.00013\,m^4) \quad (7)$$

for $m > 20$

$$\delta_R(m) = 1/(10.4 + 0.718\,m) \quad (8)$$

The beam irradiance on a horizontal surface B_{hc} (W/m^2) is then calculated as:

$$B_{hc} = B_{0c} \sin h \quad (9)$$

The beam irradiance on an inclined surface B_{ic} (W/m^2)) is calculated as:

$$B_{ic} = B_{0c} \sin \delta_{exp} \quad (10)$$

Or

$$B_{ic} = B_{hc} \sin \delta_{exp}/\sin h \quad (11)$$

where δ_{exp} is the solar incidence angle measured between the sun and an inclined surface defined in equation (12).

In the R.sun model we have implemented the sun declination δ [rad] defined as **[1]:**

$$\delta = \arcsin(0.3978 \sin(j' - 1.4 + 0.0355 \sin(j' - 0.0489))) \quad (12)$$

As the cloudless sky becomes more turbid, the diffuse irradiance increases, while the beam irradiance decreases. The estimate of the diffuse component on a horizontal surface D_{hc} (W/m^2) is made as a product of the normal extraterrestrial irradiance G_0, a diffuse transmission function

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T_n dependent only on the Linke turbidity factor T_{LK}, and a diffuse solar altitude function F_d dependent only on the solar altitude h **[1,3]:**

$$D_{hc} = G_0\, T_n(T_{LK})\, F_d(h) \quad (13)$$

The estimate of the transmission function $T_n(T_{LK})$ gives a theoretical diffuse irradiance on a horizontal surface with the sun vertically overhead for the air mass 2 Linke turbidity factor. The following second order polynomial expression is used:

$$T_n(T_{LK}) = -0.015843 + 0.030543\, T_{LK} + 0.0003797\, T_{LK}^2 \quad (14)$$

The solar altitude function is evaluated using the expression:

$$F_d(h) = A1 + A_2 \sin h + A_3 \sin^2 h \quad (15)$$

where the values of the coefficients A1, A2 and A3 are only depended on the Linke turbidity factor T_{LK} defined in the following expressions:

$$A_1' = 0.26463 - 0.061581\, T_{LK} + 0.0031408\, T_{LK}^2 \quad (16)$$

$$A1 = 0.0022/Tn(T_{LK}) \quad \text{if } A1'\, Tn(T_{LK}) < 0.0022 \quad (17)$$

$$A1 = A_1' \quad \text{if } A1'\, Tn(T_{LK}) >= 0.0022 \quad (18)$$

$$A2 = 2.04020 + 0.018945\, T_{LK} - 0.011161\, T_{LK}^2 \quad (19)$$

$$A3 = -1.3025 + 0.039231\, T_{LK} + 0.0085079\, T_{LK}^2 \quad (20)$$

The model for estimating the clear-sky diffuse irradiance on an inclined surface D_{ic} (W/m^2) **[4]** distinguishes between sunlit, potentially sunlit and shadowed surfaces. The equations are as follows:
for sunlit surfaces and non-overcast sky (h in radians):

if h>=0.1 (i.e. 5.7^0)

$$D_{ic} = D_{hc} \{F(\gamma_N)(1 - K_b) + K_b \sin \delta\exp/\sin h\} \quad (21)$$

if h < 0.1 (i.e. 5.7°)

$$D_{ic} = D_{hc} \{F(\gamma_N)(1 - K_b) + K_b \sin \gamma_N \cos {}_{ALN}/(0.1 - 0.008\, h)\} \quad (22)$$

Where
A_{LN} is the azimuth of the sun to an inclined surface
F(γN) is a function accounting for the diffuse skyirradiance
The K_b is a measure of the amount of beam irradiance available (proportion between beam irradiance and extraterrestrial solar irradiance on a horizontal surface):

$$K_b = B_{hc}/G_{0h} \quad (23)$$

where G_{0h} (W/m^2) is calculated as:

$$G_{0h} = G_0 \sin h \quad (24)$$

Fig.3: Used meteorological station Neal URER-MS Adrar

3. RESULTS AND INTERPRETATIONS

2.1 Achievements

For a validation of solar radiation, we will confront some values; clear sky, solar radiation provided by the radiometric station Adrar with values on the horizontal plane.
We present the following figures, comparative graphs relating to diffuse and direct dolaire radiation R.Sun model with diffuse experimental data of 2014 the site of Adrar.

2.2 Results achieved

The experimental data on the components of global solar radiation on the horizontal plane, and a clear sky and a winter day on the town of Adrar are presented in figures below as graphs, and by comparing them with data from the model studied.

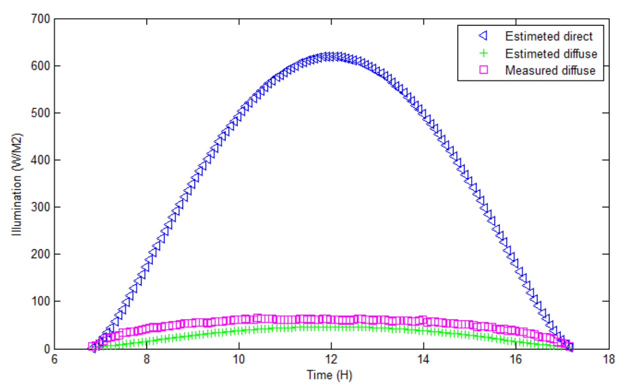

Fig. 4: Solar radiation fluxes for January 15, 2014

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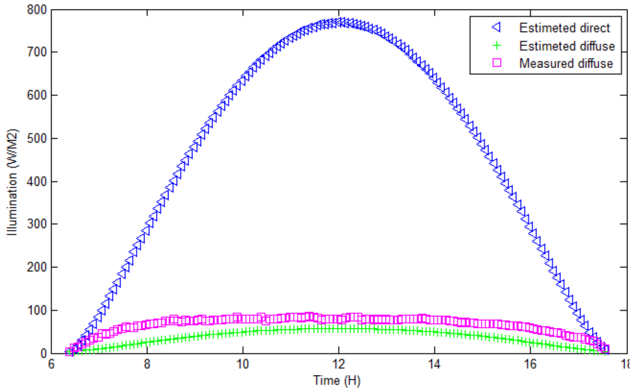

Fig. 5: Solar radiation fluxes for February 24, 2014

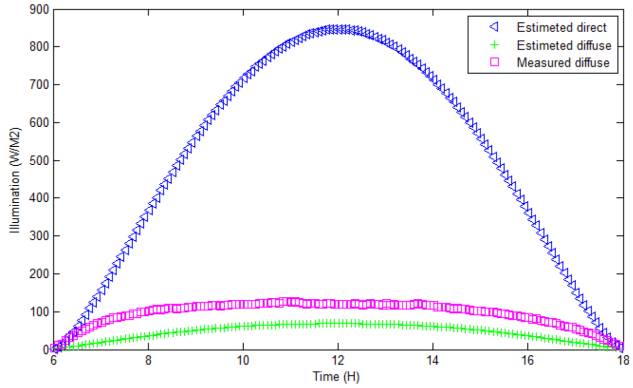

Fig. 6: Solar radiation fluxes for March 22, 2014

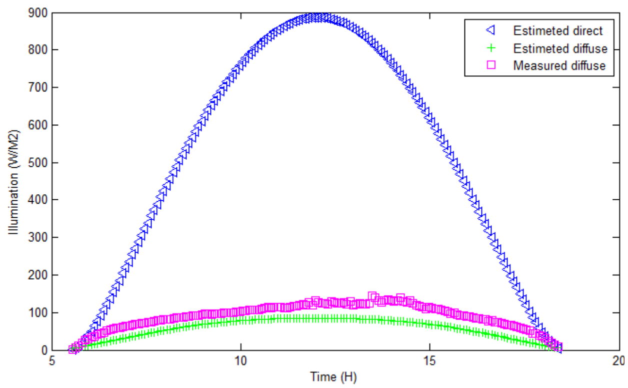

Fig. 7: Solar radiation fluxes for April 25, 2014

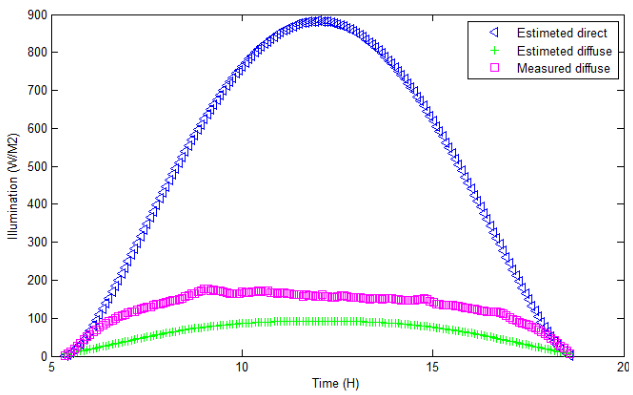

Fig. 8: Solar radiation fluxes for May 12, 2014

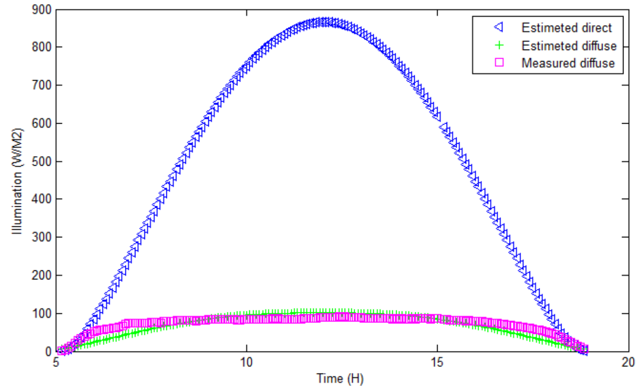

Fig. 9: Solar radiation fluxes for June 03, 2014

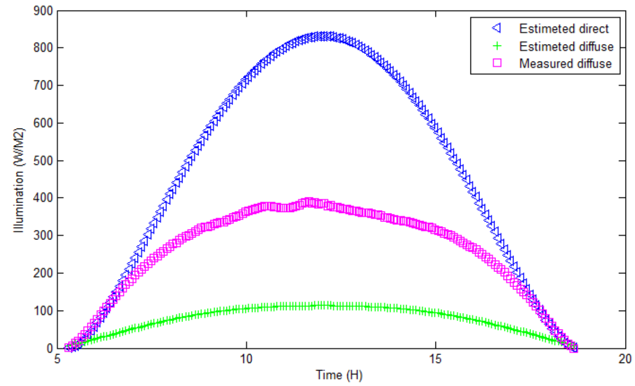

Fig. 10: Solar radiation fluxes for July 29, 2014

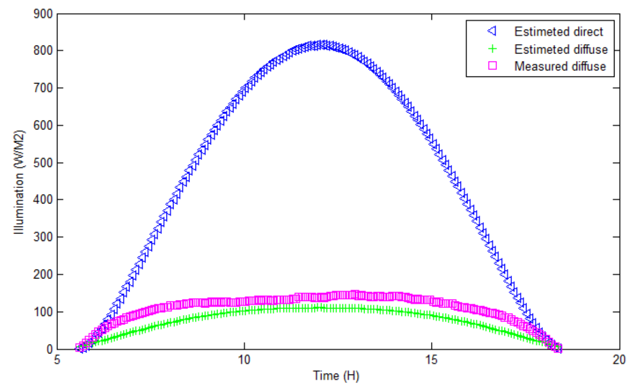

Fig. 11: Solar radiation fluxes for August 23, 2014

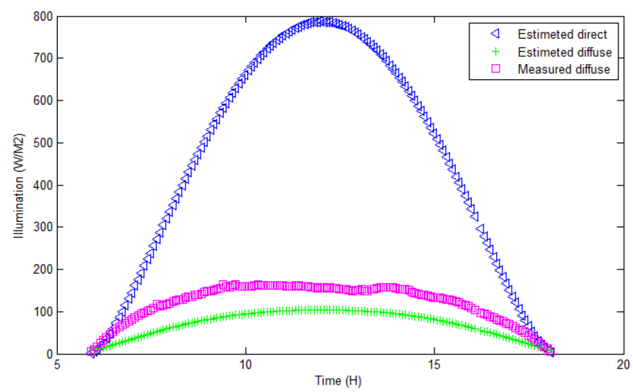

Fig. 12: Solar radiation fluxes for September 13, 2014

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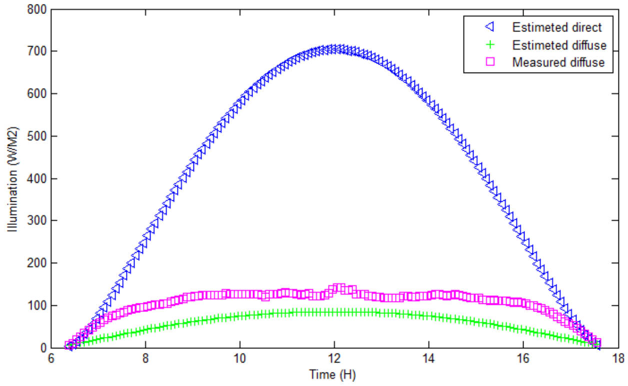

Fig. 13: Solar radiation fluxes for October 17, 2014

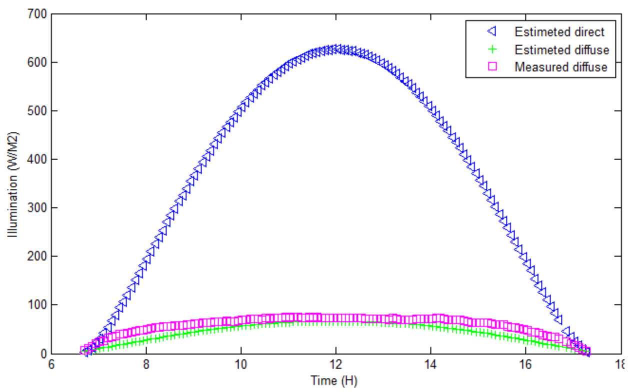

Fig. 14: Solar radiation fluxes for November 13, 2014

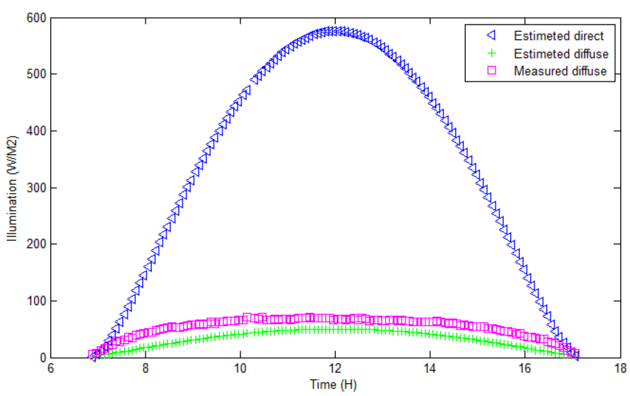

Fig. 15: Solar radiation fluxes for December 16, 2014

2.3 Comparative study and critical analysis

In order to achieve a critical analysis of the results, it was made a comparison of experimental data with those from the model. It was thus also calculated the relative error of diffuse radiation at the site of Adrar.

The results obtained are summarized in Fig. 16 below.

The average relative error is given by the following equation:

$$E_m\,(\%) = \sum_i \frac{E\,(\%)}{i} \qquad (25)$$

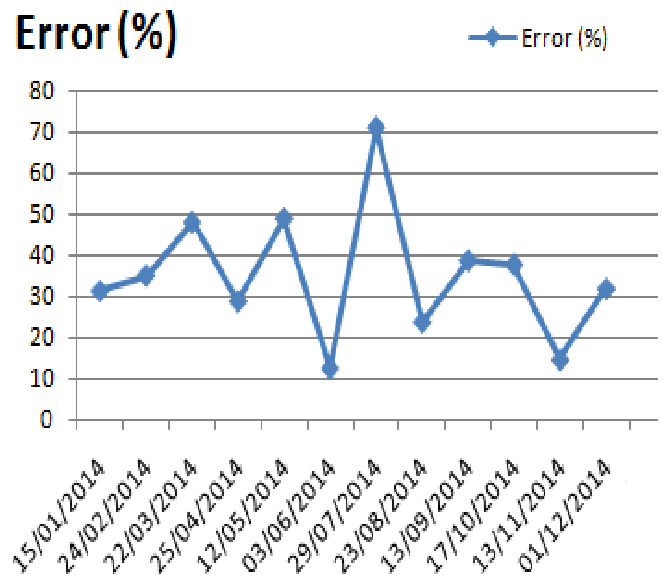

Fig. 16: Error calculation results on the horizontal sunlight for some clear days, on the site.

4. RESULTS AND INTERPRETATION

In analyzing the results shown in Figures (4 to 15) it is deduced that:

- The direct and diffuse solar radiation increases with the growth of time until a maximum value of about 12: 00 and then begins to decrease until it reaches zero (layer of the sun).
- We noticed that the direct solar flux varies between 600 and 900 (W/m^2), the diffuse solar flux varies between 50 and 150 (W/m^2) with an increase in summer, a slight decrease during the months of spring and autumn and a considerable decline in winter. This variation is mainly due to the declination angle and temperature change.
- For this model, note that for most situations, the values of the estimated diffuse component are diverge to the measured values. The average relative error is large. A typical example appears July 29 where the curve simulated by this model are in very disagreement with the measured values curves, so the relative error is very large (the error does exceed 70% for this day).
- We also found this model is disagreeable during most seasons of the year (the error exceed 70%.
- The model R.Sun is generally unfavorable for estimating diffuse solar irradiance on a horizontal sensor especially in the month of July.

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5. CONCLUSION

In this article, modeling of solar radiation by the R.Sun model is presented and performed. Model used to own equations calculated atmospheric parameters (mass, optical thickness of the atmosphere…etc), and calculated the direct illumination, diffuse and global.

This work allowed us to compare the measured values and those estimated by the parameterized model. We found that the R.Sun model gives a bad estimate of diffuse solar radiation; the results obtained for the site diverge with real data.

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