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Air humidity influence on global solar radiation on the surface of a photovoltaic module in Niger: Case of the city of Dosso

Aminou Baare Ali[1-2], Mahamadou Hamidine[3], Harouna Sani Dan Nomao[1-2], Makinta Boukar[1-2], and Saîdou Madougou[1-2]

[1]Department of Physics, Faculty of Science and Techniques Abdou Moumouni University, Niger

[2]Laboratory of Energy, Electronics, Electrical Engineering, Automation and Industrial Computing (L3EA2I), Niger

[3]Department of Physics, Dan Dicko Dankoulodo University of Maradi, Niger

ABSTRACT: The production of a photovoltaic solar system depends on a number of atmospheric parameters, namely the solar radiation received by the surface of the panel and the temperature of the surface of this panel. However, this solar radiation and temperature are also influenced by other meteorological parameters. The objective of our work is on the one hand, to evaluate the solar potential of Dosso city in Niger and on the other hand, to study the influence of air humidity on solar radiation during a month of high heat (May) and a month of high humidity (August) during the year 2021.

KEYWORDS: air, humidity, solar, radiation, photovoltaic, Niger.

1 INTRODUCTION

Nowadays, energy is the key factor in the economic development of any country on earth [1,7]. Photovoltaic solar energy, one of the branches of renewable energies, is the result of the direct transformation of solar radiation into electricity. This solar technology emerged thanks to a physical phenomenon, specific to certain materials, called semiconductors, which when exposed to sunlight, produce electricity [2,8]. The exploitation and optimization of this form of energy requires a control of the distribution of solar irradiation, which depends on several parameters, namely geographical, atmospheric and meteorological [4,14].

2 MATERIALS AND METHODOLOGY

2.1 PRESENTATION OF THE STUDY AREA

Located in the extreme south-west of Niger, DOSSO region covers an area of 31,000 km^2 or 2.45% of the national territory. It is located between 11°50 and 14°50 north latitudes and between 2°30 and 4°40 east longitude. The climate is characterized by a dry season (November to May) and a rainy season (June to October). Two prevailing winds characterize this region: it is the harmattan blowing from November to April and the monsoon blowing from May to October.

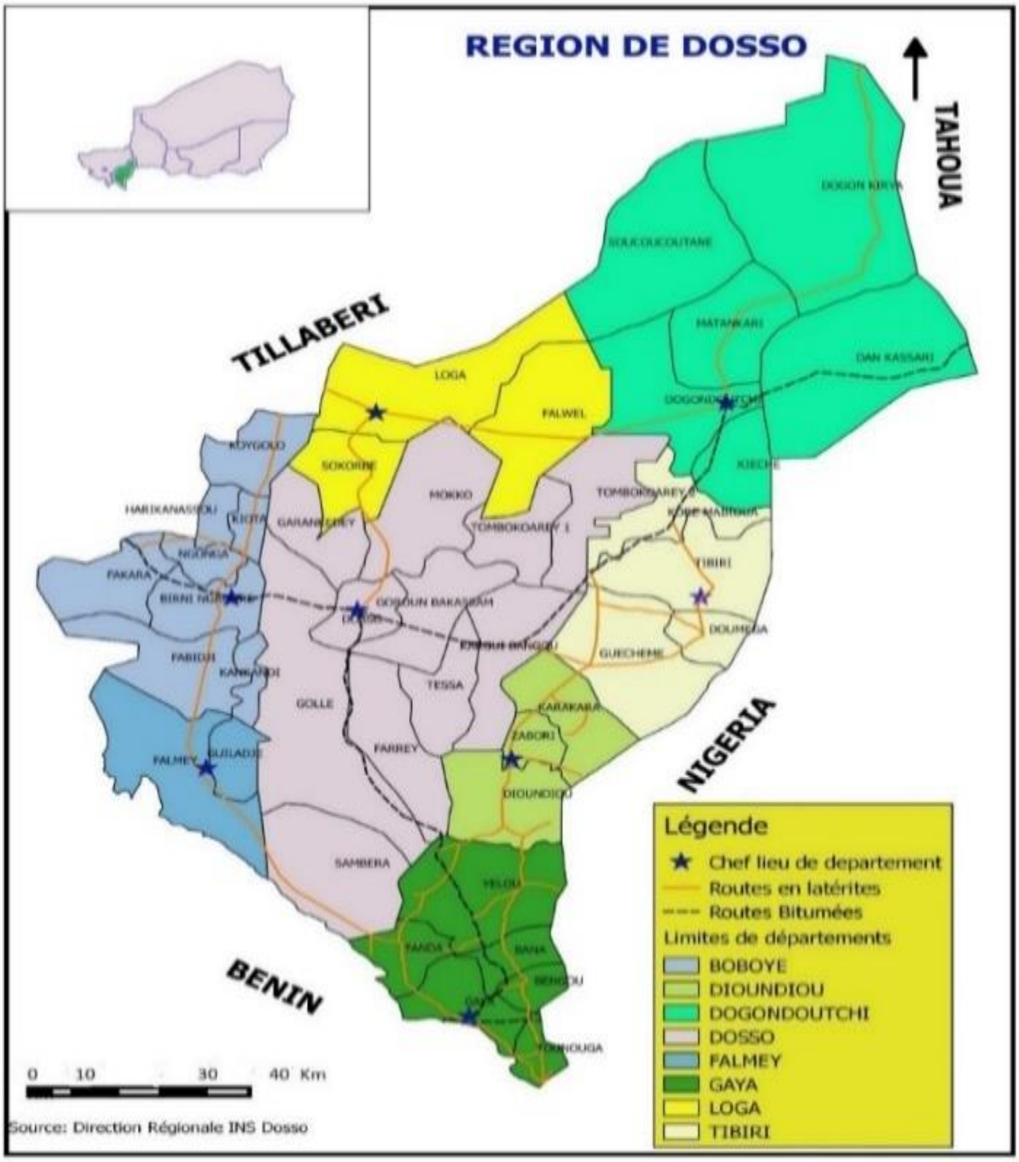


Fig. 1. Map of administrative division and geographical location of the Region of Dosso. (Source: PDR, Dosso, 2016)

The town of DOSSO is identified by the following geographical coordinates: Latitude 13° 02′ 46" North and Longitude 3° 11′ 50" East with average altitudes of about 250 m.

Our measurement site is located by the following geographical coordinates: 13°02’30” North latitude, 3°11’15” East longitude and an average altitude of 217 m. The choice of the city of DOSSO as a study area is motivated by its geographical position which gives it a high level of humidity during the rainy season.

Our data collection was spread over two periods:

- The first period from May 1st, 2021 to June 1st, 2021, which we consider to be a period of high heat
- The second period from August 1, 2021 to September 1, 2021, which we consider to be a period of high humidity

To carry out the data collection, we used a number of mobile and handheld devices which will be described below.

2.2 METEOROLOGICAL PARAMETERS AND MEASURING DEVICES

The parameters measured during our data collection are ambient temperature, and relative air humidity. The device used to perform the measurements is shown in Figure 2.

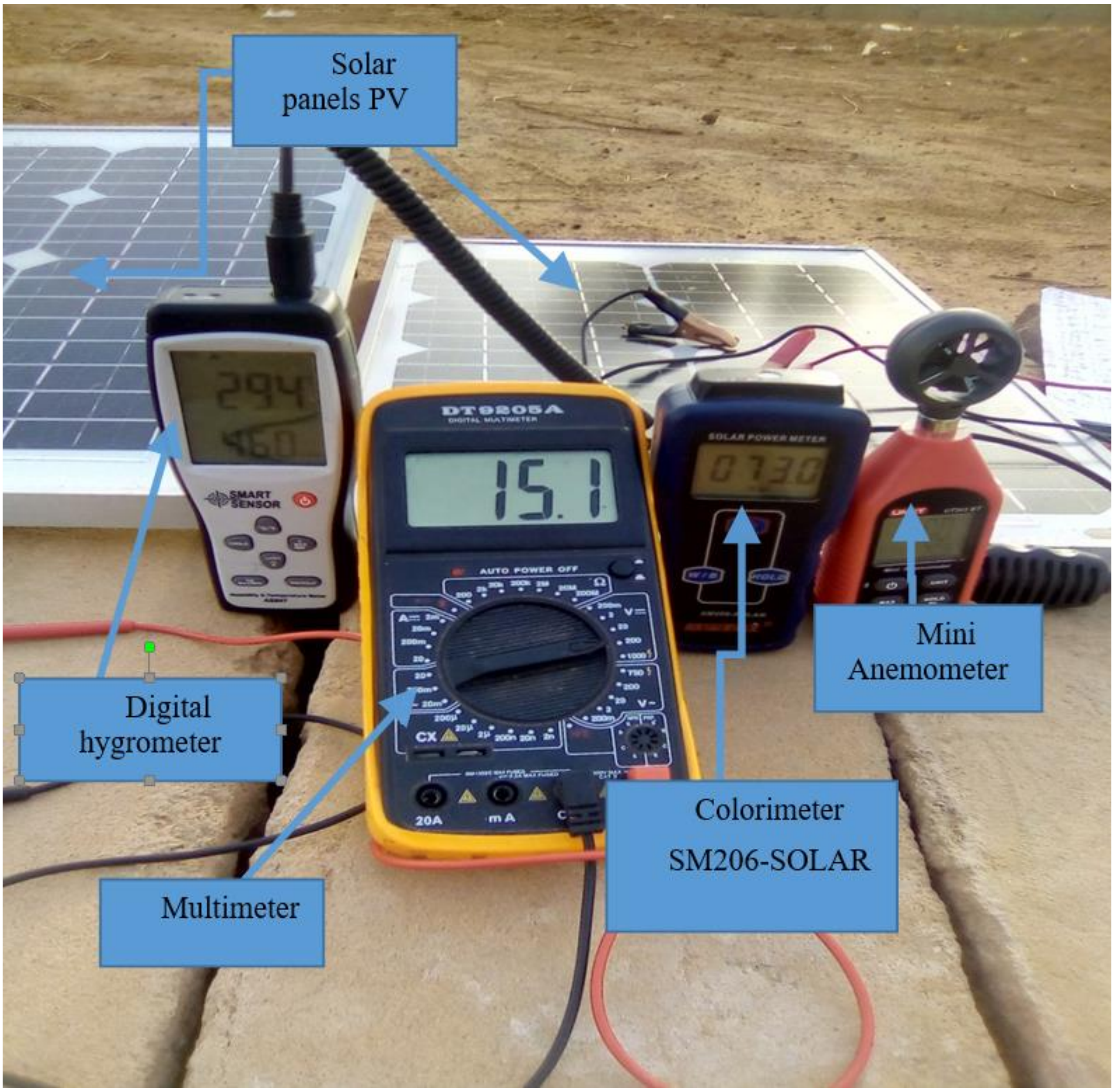


Fig. 2. Experimental equipment

Temperature characterizes the amplitude of heat of a body or an environment.

The relative humidity of the air is defined as the ratio of the pressure exerted by the water vapor contained in the air at a given temperature to the pressure of the saturated water vapor [9, 10].

It is determined on a scale from 0 to 100%. It characterizes the amount of water vapor in the air and the ability of this water vapor to condense.

For our study, we used the SMART-SENSOR type thermometer-hygrometer for humidity and heat measurements (Figure 3). The device has a sensor, a probe and is powered by an electric battery of electromotive force (f.e.m.) of 9 Volts in DC.

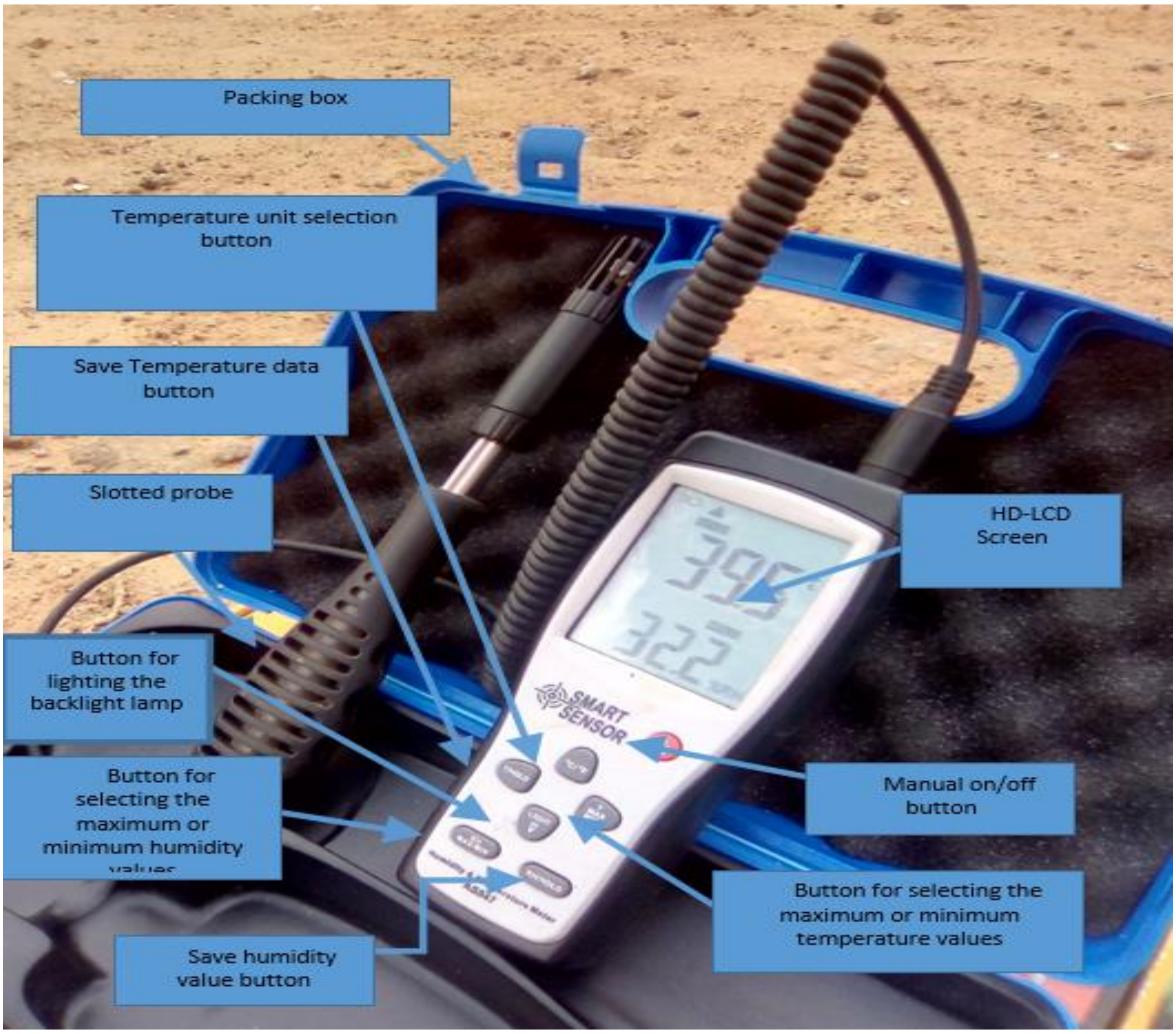


Fig. 3. SMART-SENSOR thermometer-hygrometer with its packaging box

This sensor measures relative humidity of the air as a percentage over a range of 5% to 98%. Uncertainties in measurements are given in Table 1.

Table 1. measures relative humidity

Parameters	Uncertainty
Humidity 5% to 40%	5%
Humidity 41% to 80%	3%
Temperature -20°C to 1000°C	1.5%

The measurements are carried out by placing the device on the place of installation of the solar panels and the data acquisition is carried out manually.

We also note the state of the sky to assess the effects of atmospheric and meteorological parameters on the quality of our measurements. It turns out that there is more atmospheric disturbance in August than in May as shown in Figure 4.

a) View from the sky on 06/05/2021 b) View from the sky on 03/08/2021

Fig. 4. Sky states for 06/05/2021 and 03/08/2021

3 Estimation Of Global Solar Radiation On A Horizontal Plane

We use global radiation, which is the sum of direct radiation and diffuse radiation.

3.1 Calculation Of Direct Solar Radiation On A Horizontal Plane

Direct solar radiation I passing through the atmosphere without modification is obtained by the following formula [1, 13]:

$$\boldsymbol{I}=\boldsymbol{E}_{\mathbf{s}}.\exp.\,(-\mathrm{AM}.\boldsymbol{T}_{\mathrm{L}}.\boldsymbol{E}_{\mathrm{r}}) \qquad (1)$$

I: in [W/m^2]

AM: the relative optical air mass in [kg]

T_L: Linke's disorder factor

E_r: Rayleigh optical thickness in kg-1

E_s: solar radiation received by a surface perpendicular to the solar rays placed at the upper limit of the Earth's atmosphere.

The optical thickness of Rayleigh is given by the following formula [1, 13]:

$$\boldsymbol{E}_{\mathrm{r}}=\frac{1}{0{,}9\mathrm{AM}+9{,}4} \qquad (2)$$

We consider AM = 1.5 kg corresponding to the case where the radiation has passed through 1.5 times the thickness of the atmosphere. This is the reference for ground-based energy calculations. Taking into account AM, we get: Er = $9.3.10^{-2}$ kg^{-1}

The radiation Es, expressed in [w/m^2], is determined by the relation (3) [1, 11, 13]:

$$\boldsymbol{E}_{\mathbf{s}}=\mathbf{E}_{\mathbf{0}}\left[1+0{,}0334\cos\left(\frac{360\,(\mathrm{j}\text{-}2{,}706)}{365{,}5}\right)\right] \qquad (3)$$

With:

E_0: the solar constant (average value of $E_{o,}$ equal to 1370 [W/m^2]);

J: The order number of the day in the year or date (example: 1 for January 1st).

For our case, we will consider four days to determine the daily irradiation (May 1st, June 1st, August 1st and September 1st of the year 2021).

Linke's disorder factor (TL) is given by the following formula [1, 3]:

$$T_L = 2,4 + 14,6b + 0,4\,(1+2b)\,ln\,(Pv) \tag{4}$$

With:

b: the coefficient of atmospheric cloudiness which varies according to the environment;

P_v: vapor pressure in [mmHg];

For our study, the city of Dosso being an urban commune, we will then take b = 0.10 for the calculation of the Linke factor TL.

The expression of vapor pressure is given by the following relation [13]:

$$P_v = HR * P_{vs} \tag{5}$$

HR: the average relative humidity in [%]

P_{vs}: the pressure of the saturated vapor in (mmHg) is determined by the relation (6) [13]:

$$P_{v_s} = 2,165\left(1,098 + \frac{T}{100}\right)^{8,02} \tag{6}$$

T: the air temperature in [°C];

For the HR and T parameters, we used the data measured on our site when collecting data.

Using equation (7), we determine the direct incident radiation [1]:

$$I = 1370\ \exp\left[\frac{-TL}{(0,9 + 9,4\sin\ (h))}\right] \tag{7}$$

Direct irradiation on a horizontal plane is given by equation [1, 3]:

$$I_d = I\sin\ (h) \tag{8}$$

3.2 Calculation Of Diffuse Radiation On A Horizontal Plane

Diffuse irradiation is calculated from equation (9) [1, 3]:

$$I_D = 54,8\sqrt{\sin\ (h)}\left[TL - 0,5 - \sqrt{\sin(h)}\right] \tag{9}$$

3.3 Calculation Of Global Radiation On A Horizontal Plane

Taking into account that the overall irradiation on a horizontal plane is the sum of the direct and diffuse irradiation, it will be given by the relation (10) [1, 3, 5]:

$$I_G = I_d + I_D \tag{10}$$

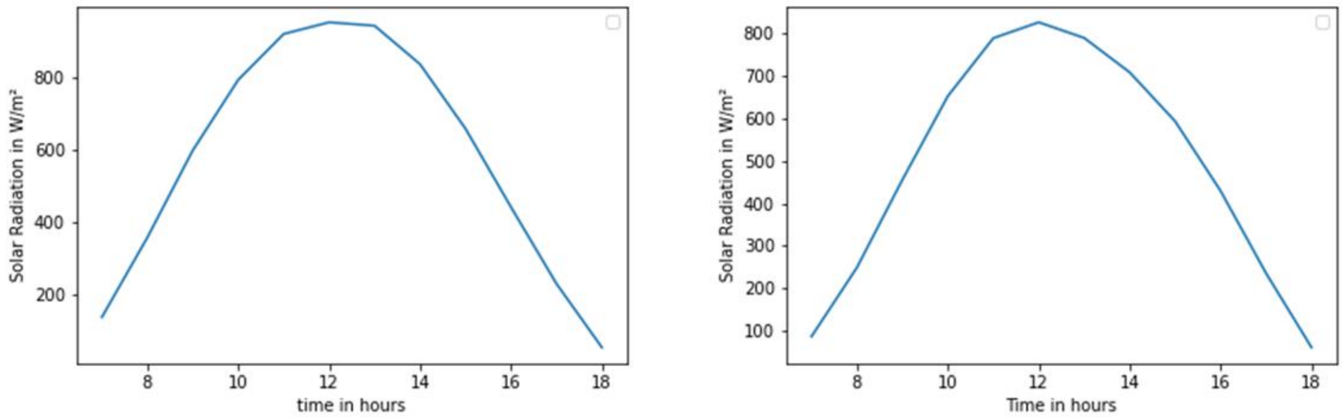
3.4 Solar Radiation Data

For our study, we used data from Helioclim-3. They are obtained from the soda site by integrating the geographical coordinates of our data collection site (city of Dosso) [6]. As the data from these sites are expressed in Universal Time (UT), we give the results of the measurements and those calculated according to Universal Time.

4 Results And Interpretation

In this part, we present the results of the measurements carried out and the discussion.

4.1 Evolution Of Measured Solar Radiation



a) Average solar irradiation in May. b) Average solar irradiation in August.

Fig. 5. The daily averages of global solar radiation on a horizontal plane in Dosso in May and August 2021August of 2021

The data is obtained from the Soda site, integrating the geographical coordinates of our site. We represent the curves (Figure 5) indicating the evolution of the measured global solar radiation [6].

In view of the results obtained from the different measurements, we see that solar energy is available in DOSSO both in the month with high temperature (May) and in the month with high humidity (August), with an uneven daily distribution. The maximum hourly average obtained in May is 951.81W/m^2 recorded at 12: 00 and the minimum average is 55.09W/m^2 recorded at 18: 00.

In August, the maximum average is 827.15W/m^2 at 12: 00 and the minimum average is 61.09W/m^2 at 18: 00.

We notice that solar radiation is higher in May than in August.

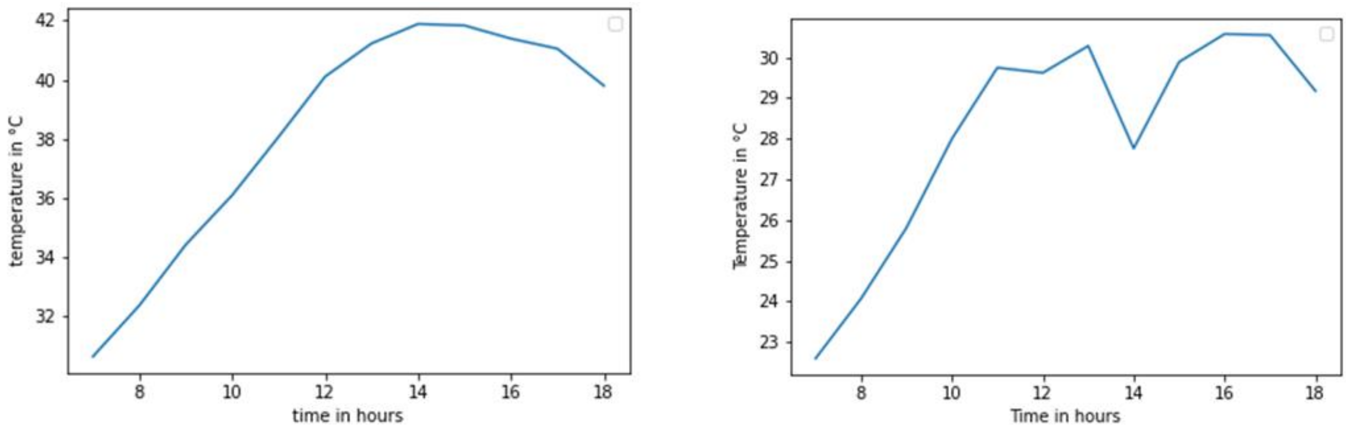
This uneven distribution over time can be explained by seasonal variability. Indeed, during the month of August the radiation is reduced by the combined actions of the effects of clouds, rain and dust.

4.2 Temperature Evolution

The temperature is much higher in May than in August. From the measurements made on our site, during the month of May, the minimum hourly average temperature recorded is 30.6°C at 7: 00 am. The temperature obtained at 18: 00 is 39.8°C. However, the maximum average is recorded at 14: 00 with a value of 41.9°C.

For the month of August, the average minimum temperature is recorded at 7: 00 am and is 22.2°C, at 6: 00 pm the temperature is 29.2°C and the maximum average is recorded at 4: 00 pm with a value of 30.6°C.

Figure 6, presents the temperature evolution during the month of May and August of the year 2021 in DOSSO:



a) Average temperature in May

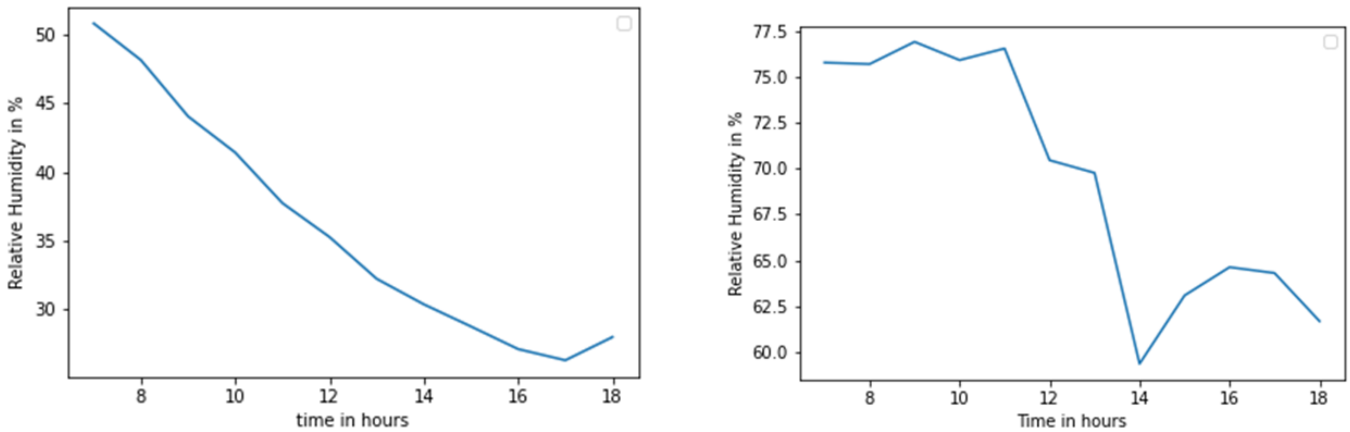
b) Average temperature in August

Fig. 6. Curves of evolution of the average temperature in May and August of the year 2021 in Dosso

We notice a fairly significant drop in temperature in August compared to May and a fluctuation is observable on the values between 11: 00 and 14: 00. This difference is explained by the presence of clouds, which decreases the intensity of the radiation.

Here, we see that the pace of the temperature curves evolves in the same direction as that of solar radiation.

4.3 EVOLUTION OF RELATIVE AIR HUMIDITY



a) Average relative air humidity in May.

b) Average relative air humidity in August.

Fig. 7. Curves of evolution of the average relative air humidity in May and August of 2021 in Dosso

Relative air humidity measurements allowed us to compare the humidity level in May and August of 2021. The curves in Figure 7 show the evolution of relative air humidity as a function of time for the two months

From curve (a) (figure 7) showing the evolution of air humidity during the month of May, we notice a decrease from 7: 00 a.m., where the humidity is maximum with a value of 50.82%, until 17: 00 with a value of 26.3%, then begins a growth phase between 17: 00 and 18: 00 where the curve reaches a value of 28%.

Curve (b) in Figure 7 shows the evolution of air humidity in August. This humidity reaches the maximum value at 9: 00 a.m., which is 76.9% and then decreases to 59.4% at 14: 00. From 14: 00 begins an increase in humidity up to 65% and then a decrease is observed. This slight variation in humidity is due to cloud cover.

From the two curves, we notice that the air humidity is much higher in August than in May.

4.4 COMPARISON OF SOME MEASURED VALUES WITH CALCULATED VALUES

To make this comparison, we plotted on each figure the curve of the measured radiation and that of the theoretical radiation (calculated) for a horizontal plane.

- Day of May 1st, 2021

The day of May 1st, 2021, was characterized by a clear sky until 14: 00 when a presence of cloud cover is observable until sunset. We notice in Figure 8 from 12: 00, the measured values are lower than the theoretical values with a significant drop in both values from 14: 00 until 18: 00.

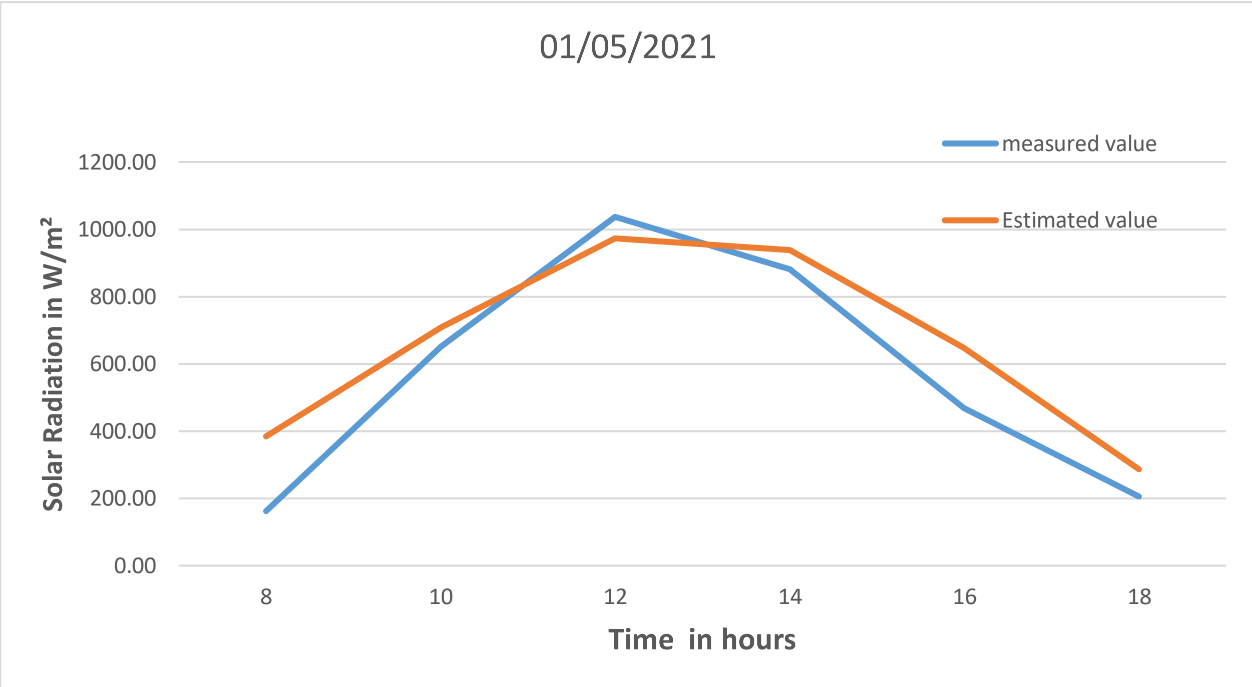


Fig. 8. Comparison curves of global solar irradiation

- Day of June 1st, 2021

The day of June 1st, was marked by clear skies from sunrise to sunset.

Here, we notice in Figure 9 a significant drop in measured and theoretical irradiation from 14: 00 to 18: 00 with a smaller deviation.

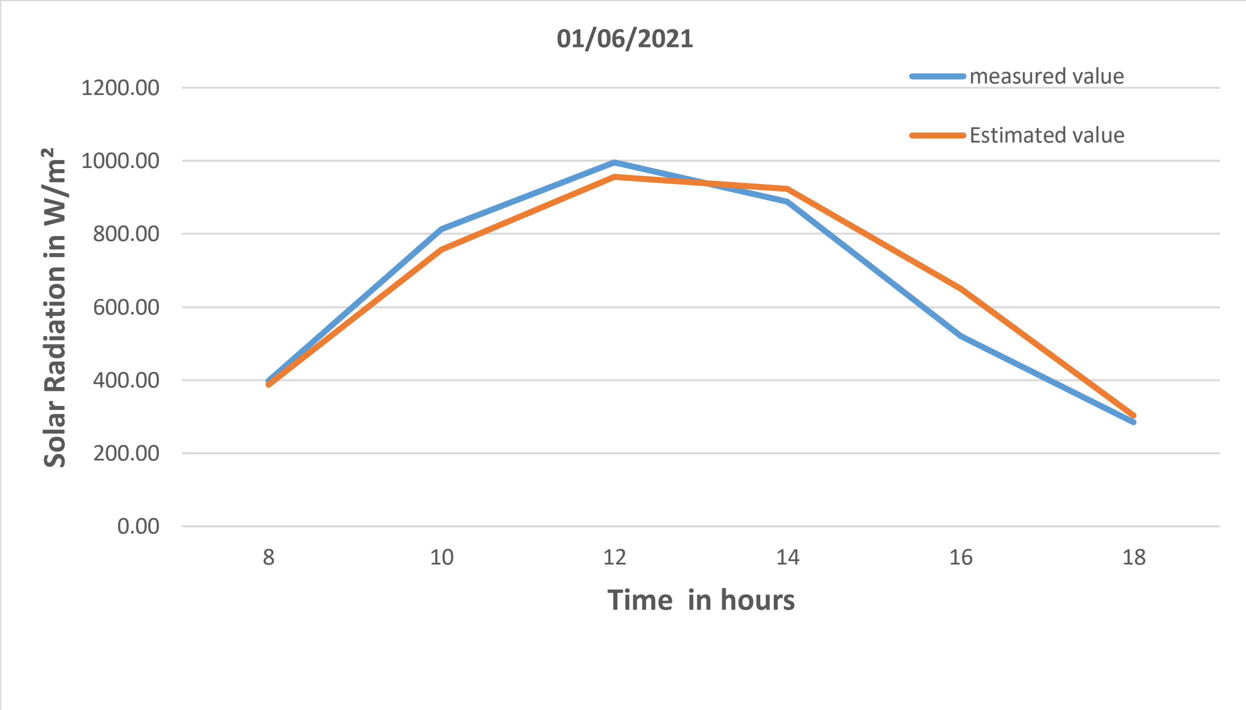


Fig. 9. Comparison curves of global solar irradiation

For the Day of August 1st, 2021: August 1st, was marked by a clear sky from sunrise to 11: 00 am, then a cloudy attenuation of the sky until sunset. We notice in Figure 10, that from 12: 00, the measured value becomes lower than that estimated until 18: 00.

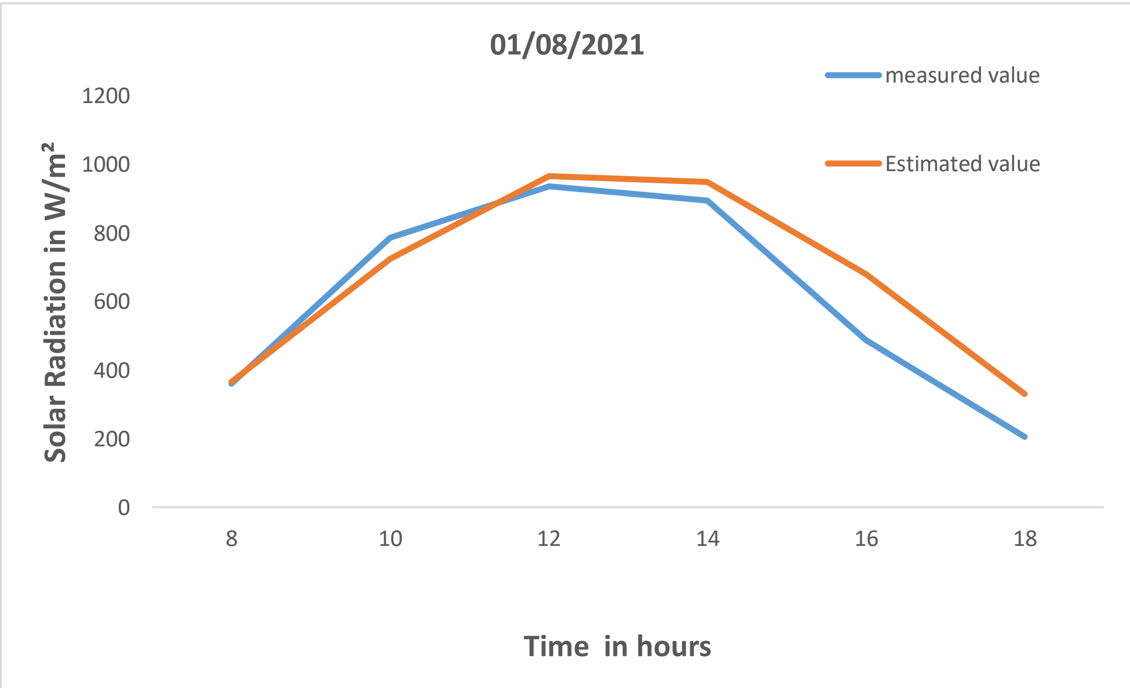


Fig. 10. Comparison curves of global solar irradiation

- For the day of September 1st, 2021:

The day of September 1st, was characterized by a presence of cloud cover until 9: 00 am, then a clear sky (clear sky) for the rest of the day. Here according to Figure 11 the estimated value becomes higher than the value measured from 12: 00 to 18: 00.

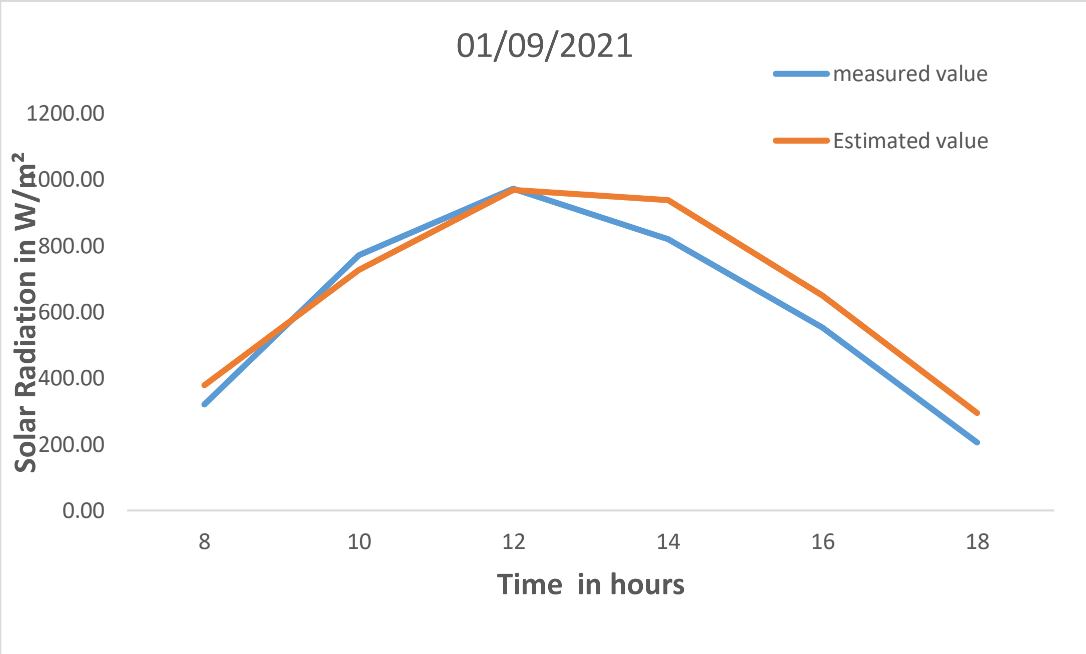
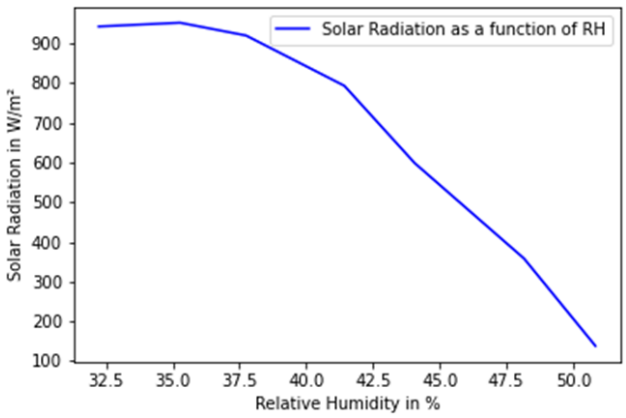


Fig. 11. Comparison curves of global solar irradiation

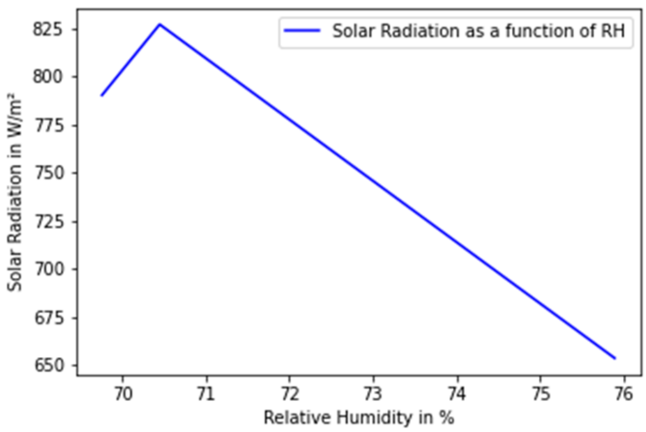
We note for the four days considered that the measured values of the global radiation exceed the estimated values, from sunrise to zenith (about 12: 00), except for the day of September 1st, when between 8: 00 and 9: 00, the theoretical values are slightly higher than the calculated values. This difference is due to the attenuation of the sky by the passage of clouds. However, once the sun reaches zenith, the estimated solar radiation values are higher than the measured values.

4.5 Solar Radiation And Relative Humidity

The data of solar radiation and those of the relative humidity of the air of our site, allowed us to draw curves, presenting the evolution of the radiation as a function of humidity for the months of May and August figure (12).



a) Solar radiation as a function of humidity in May.



b) Solar radiation as a function of humidity in August

Fig. 12. Curves of evolution of global radiation as a function of relative humidity of the air in Dosso in May and August of the year 2021

From these curves we note, in May as in August, a significant drop in solar radiation when the relative humidity of the air increases. The period of minimum humidity corresponds to that of maximum radiation. A significant variation in solar radiation followed by some disturbances is observed in August, which is due to the high humidity recorded during the month of August and other meteorological phenomena (precipitation, wind, pressure), favoring the humidity of the air.

5 Conclusion

The city of DOSSO, has a large solar deposit that will be enough to realize solar thermal or photovoltaic installations. However, meteorological factors such as temperature, wind, dust but especially the relative humidity of the air due to the geographical position of the region (Sudanian zone) considerably reduce the effectiveness of the solar potential on the surface of the earth.

The variation of the relative humidity of the air of a place over the course of a day, a month or a year, causes a great influence on the solar deposit of the place. If it increases, the power of solar radiation weakens.

We made a comparison between the two values of global radiation: for the day of May 1st, a maximum value of 1036W/m^2 was obtained from satellite data against 973W/m^2 for the theoretical value, hence a good agreement between the values. Indeed, the relative error is: 6.08%.

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