Université Mohamed Khider de Biskra
Faculté des Sciences et de la Technologie
Département de Génie Mécanique

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Présenté et soutenu par :
Mr. Aymen BEN AICHI

Le : Saturday 26 June 2021

Influence du rayonnement solaire global selon les conditions climatiques et le type de ciel.

Jury:

Dr.	Noureddine MOUMI	Pr	Université de Biskra	Président
Dr.	Foued CHABANE	MCA	Université de Biskra	Rapporteur
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Faculty of Science and Technology
Department of Mechanical Engineering

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Presented and sustained by :

Mr. Aymen Ben Aichi

On: Saturday June 26, 2021

Influence of global solar radiation according to climate condition and type of sky.

Jury:

Mr.	Noureddine MOUMI	Pr	University of Biskra	President
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University year: 2020-2021


بسم الله الرحمن الرحيم

Dedication

I dedicate my work to those who gave me life:

My father and my mother.

All my brothers: Saber, sohair, Ali and karim

All my family.

All my relatives.

All my friends and acquaintances without exception.

Everyone who helped and encouraged me.

I am pleased to dedicate this modest work to my university,

Mohammed khaidar University,

represented by all its staff and cadre, the distinct beacon of scientific knowledge in our beloved nation. I also extend my dedication to all those who believe in science as a base for evolution of nations.

Aymen Ben Aichi

Acknowledgement

I thank God the Almighty for giving us the health and the will to begin and complete this memoir.

First of all, this work would not be as rich and would not have been possible without the help and supervision of Mr. FOUED CHABANE, I thank him for the quality of his exceptional supervision, for his patience, its rigor and its availability during my preparation of this thesis.

my thanks also go to all our teachers for their generosity and the great patience they have shown despite their academic and professional responsibilities.

my heartfelt thanks also go to all the people who have helped and supported us from near or far.

Aymen Ben Aichi

Summary

Chapter IV: Results and Discussion

Nomenclature	Unit
$G_{propose}$: the global irradiation for several days of tests for an inclined plane (45°)	(W/m²)
G : Daily global solar radiation.	(W/m²)
G_h : the global radiation received by a horizontal surface.	(W/m²)
G_{h0} : extraterrestrial irradiation.	(W/m²)
I_{sc} : is the extraterrestrial solar constant evaluated by.	(W/m²)
I_0 : the average solar constant equal to1367 $W.m^{-2}$.	(W/m²)
I_n : Direct solar irradiation of normal incidence.	(W/m²)
I_h : the direct radiation received by a horizontal surface.	(W/m²)
n j: the number of the day in the year.	(-)
θ_z : is the zenith angle.	(°)
h : is the height of the sun, given in appendix A.	(°)
U_0: the thickness of the ozone layer.	(cm)
m_r : is the relative optical air mass.	(kg)
m_a : the corrected air mass.	(kg)
m : Air mass.	(kg)
l: represents the quantity of ozone vertically above the location.	(cm)
α_w : represents the absorption coefficient of direct radiation by water vapor.	(-)
X_w : is the condensable water thickness.	(cm)
U_w : is the thickness of condensable water vertically from the location.	(cm)
P: is atmospheric pressure.	(mbar)
P_0 : is the atmospheric pressure at sea level (P_0 = 1013 mb).	(mbar)
ωs : is the hour angle of sunrise in degrees.	(°)
Z: the altitude of the site, relative to sea level.	(m)
Φ: in degrees.	(°)
L : longitude,	(°)
φ : latitude .	(°)
T: ambiant temperature (K) .	(°C)
T_{max} : the maximum temperature.	(°C)
Ta : room temperature.	(°C)

T_a : ambient temperature.	(^oC)
H_R: relative humidity.	(%)
H_a : absolute humidity .	(%)
D_h: diffuse radiation from the sky, received by a horizontal surface.	(W/m²)
DI: the duration of insolation.	(hour)
TL: Linke turbidity factor.	(-)
Tm: the astronomical duration of the day.	(hour)
N : this is the number of days of the year.	(-)
K_T: the clarity index.	(-)
K_D : the overall irradiation.	(-)
β: the new pollution parameters.	(μmol.mol^{-1})
β_0: Reference constant for total contaminated elements equal to 40 (μmol.mol^{-1}).	(μmol.mol^{-1})
TC: Time Correction Factor.	(hour)
LST: Local Solar Time.	(hour)
LSTM: Local Standard Time Meridian.	(hour)
UTC: Coordinated Universal Tim.	(hour)
TST: True solar time.	(hour)
MST: Mean solar time.	(hour)
S: Direct radiation.	(W/m²)
D: Diffuse radiation.	(W/m²)
ρ : Albedo from the neighboring soil.	(-)
PM: Particulates matter.	(μg/m^3)

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General Introduction

General Introduction:

Solar radiation incident at the Earth's surface is the ultimate energy source for life on the planet, and it influences the climatic conditions of our habitats significantly. The amount of solar energy that reaches the surface is a major component of the surface energy balance and governs a wide range of surface processes, including evaporation and associated hydrological components, snow and glacier melt, plant photosynthesis and related terrestrial carbon uptake, and the diurnal and seasonal course of surface temperatures.

It also has significant practical implications, such as for solar energy technologies and agricultural productivity. Changes in the amount of solar energy reaching the Earth's surface can have far-reaching environmental, societal, and economic consequences. There is mounting evidence that the amount of solar radiation incident at the Earth's surface has not remained stable over time.

Traditionally, the amount of solar radiation (sunlight) incident on the Earth's surface has been assumed to be constant over time for the purposes of planning and assessing solar energy systems. However, as the climate and levels of air pollution change, solar resources may no longer be stable over time and undergo significant decadal changes. Observational data spanning decades confirms long-term changes in this quantity.

Solar radiation reaching the Earth's surface is becoming an increasingly appealing resource for meeting the world's rapidly growing energy demands on a renewable, carbon- and nuclear-free basis.

PV system energy yields are first and foremost determined by the amount of solar resources available (i.e., the amount of solar radiation reaching the Earth's surface). Furthermore, changes in ambient temperatures must be considered, as rising ambient temperatures reduce PV power output. and other meteorological factors that influence PV system energy yields, such as wind, snow, or dust deposition on PV panels.

Surface solar radiation is frequently assumed to be constant in time. However, long-term observational radiation records show that surface solar radiation has significant multidecadal variations, which should be considered in solar resource assessments. Often in accordance with patterns of anthropogenic air pollution. This suggests that anthropogenic air pollution and the associated aerosol accumulation in the atmosphere may have played a significant role in the decadal variations in surface solar radiation.

So far, only a few studies have used climate model projections to estimate multidecadal changes in solar resources as a result of climate change and to assess the impact on solar energy applications.

To this end, we have dedicated this study to the use of a global solar radiation calculation model at the Biskra site.

This study is divided into four chapters:

The first chapter covers fundamental astronomical concepts that are extremely useful for understanding the solar field.

The second chapter includes Solar radiation models (global, direct and diffuse radiation on an inclined and horizontal plane).

The third chapter is based on an experimental and theoretical study of global solar radiation on a horizontal plane. This study is used to validate models that predict global solar radiation variations.

The final chapter will present the data and discuss the experimental results obtained with our experimental data.

CHAPTER I

GENERAL INFORMATION ON ENERGY AND SOLAR RADIATION

I.1. Introduction

Solar irradiation data is needed at all levels of solar power development, from initial government planning through to large-scale project development or the calculations needed to size smaller systems.

In this chapter we present a bibliographical synthesis on solar radiation and solar energy as renewable energy, namely its advantages, disadvantages and applications.

I.2.Solar energy:

Solar energy is the energy force that sustains life on Earth for all plants, animals, and people. The source of solar energy is the nuclear interactions at the core of the Sun, where the energy comes from the conversion of hydrogen into helium. Sunlight is readily available, secure from geopolitical tensions, and poses no threat to our environment and our global climate systems from pollution emissions.[1]

Solar energy is primarily transmitted to the Earth by electromagnetic waves, which can also be represented by particles (photons). The Earth is essentially a huge solar energy collector receiving large quantities of solar energy that manifest in various forms, such as direct sunlight used for plant photosynthesis, heated air masses causing wind, and evaporation of the oceans resulting as rain, which forms rivers and provides hydropower.

I.3.The solar resource:

The solar resource is enormous. Just 18 days of sunshine on Earth contains the same amount of energy as is stored in all of the planet's reserves of coal, oil, and natural gas.

Outside the atmosphere, the sun's energy contains about 1,300 watts per square meter. Once it reaches the atmosphere, about one-third of this light is reflected back into space, while the rest continues toward Earth’s surface.

Averaged over the entire surface of the planet, a square meter collects 4.2 kilowatt-hours of energy every day, or the approximate energy equivalent of nearly a barrel of oil per year.

Deserts, with very dry air and little cloud cover, receive the most sun—more than 6 kilowatt-hours per day per square meter on average over the course of the year.[2]

I.4.The solar field in Algeria:

The solar field is a set of data describing the evolution of solar radiation available over a given period. It is used to simulate the operation of a solar energy system and to make the most exact sizing possible given the demand to be satisfied.

Due to its geographical location, Algeria owns one of the highest solar energy irradiation potential in the world (Fig. 1), one would consider that it is really urgent and essential to take advantage of this energy source abundance through the development of solar energy applications among which solar water heating is the simplest technique and the most affordable.[3]

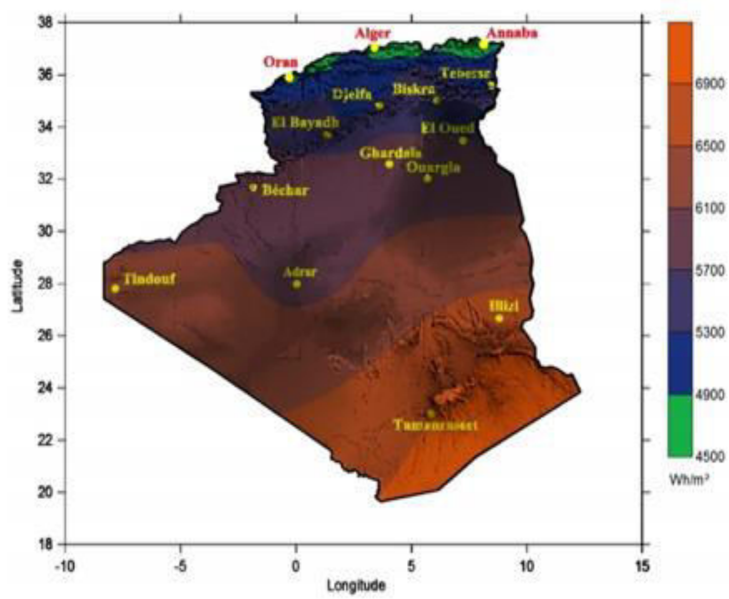

Figure.I.1: Typical Algerian daily irradiation chart.

Algeria represents the greatest solar potential of the entire Mediterranean basin, i.e. 169,000 TWh /year for thermal solar, 13.9 TWh /year for solar photovoltaic. As assessed by the German Space Agency (ASA). Algeria's solar potential is the equivalent of 10 large fields of natural gas that would have been discovered in Hassi R'Mel. The distribution of solar potential by climatic region at the level of Algerian territory is shown in Table I.1 according to the amount of sunshine received annually. The duration of sunshine in the Algerian Sahara is of the order of 3500h / year is the longest in the world, it is always greater than 8h/d and can reach up to 12h/d during the summer with the exception from the extreme south where it drops to 6h/d in summer.

Regions	Coastal region	High plateaus	Sahara
Area (%)	4	10	86
Average sunshine duration (h /year)	2650	3000	3500
Average energy received(KWh/m2/year)	1700	1900	2650

Table I.1: Sunshine received in Algeria by climatic regions.

I.5.The difference between solar power and solar energy:

Solar energy is broadly defined as the total amount of energy emitted by the sun via visible light and other unseen electromagnetic waves. Any technology that converts the sun's energy into another form of energy, such as heat or electricity, is referred to as a solar energy system. Passive solar systems, solar thermal systems for water or space heating, and solar power are all examples of solar energy.

Solar power is a subset of solar energy, which is a more specific term that usually refers to the conversion of the sun's rays to electricity. Photovoltaic (PV) systems, which directly convert sunlight to electricity using a semiconductor material, and concentrated solar power (CSP) systems, which first convert sunlight to heat before using the heat to generate electricity, are the two main types of solar power systems.[4]

I.6.Solar energy technologies:

Solar energy technologies are broadly classified as being either passive or active according the way they capture, convert and distribute sunlight. Among their applications are space heating and cooling through solar architecture, providing potable water by distillation and disinfection, lighting, hot water generation, heat for cooking, and heat for industrial processes. Active solar techniques include the use of photovoltaic panels, or solar thermal collectors, which use either electrical or mechanical equipment, to convert sunlight into useful power outputs. Passive solar techniques include orienting the construction of a building toward the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that circulate air naturally. Active solar technologies increase the amount of energy produced and are considered supply side technologies, while passive solar technologies reduce the need for alternative energy sources and are generally considered demand side technologies9 . Methods that specifically generate electricity (using either photovoltaic cells or thermal solar methods which use the Sun's energy to effectively boil water and drive a steam turbine) are normally described as solar power technologies.[5]

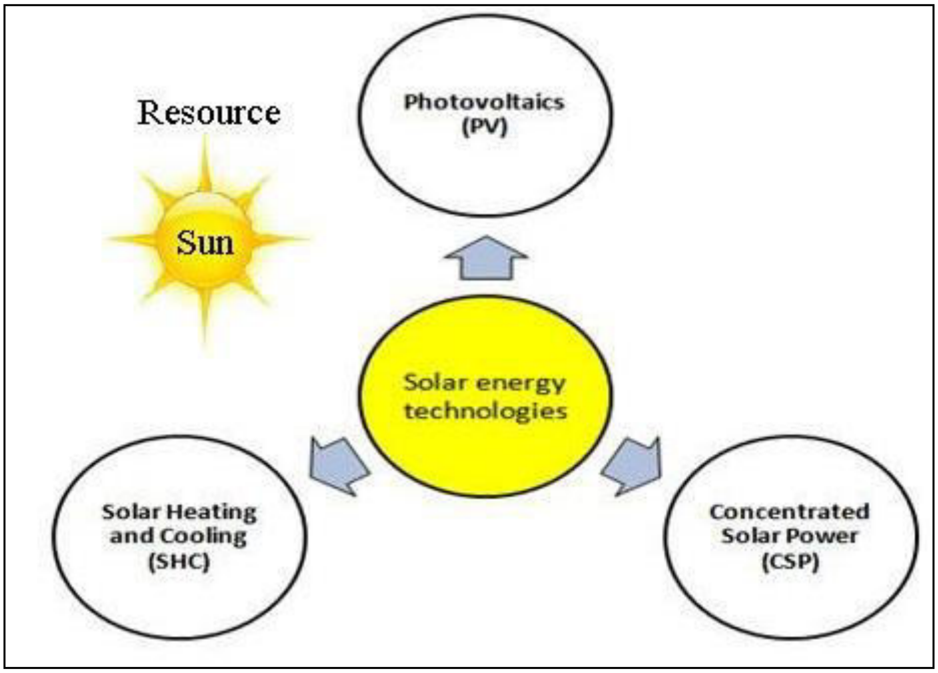

Figure.I.2: Basic solar energy technologies.

I.7.Advantages of solar energy [6]:

- **No Monthly Bills:** Once you have a solar power system installed, it will run for years, and according to statistics, the system will not require any prior maintenance for the next 25-30 years.
- **Inexhaustibility of Fuel Supply:** The sun is the fuel in this case, and it is limitless. This is in contrast to other energy sources such as coal, natural gas, uranium, and so on.
- **Low Maintenance Cost:** Solar power system needs very little maintenance and the major part of that is to clean the dirt and rubble that may be found on it. You don't have to do this every day or every month, but just a few times in a year.

- **No Negative Environment Impact:** Solar power system does not produce pollution be it air or noise. Thereby reducing the rate at which our ozone layer is depleted, while it generates power.
- **No Wasting of Space:** with solar panels put on the rooftops of the house, you get to generate the needed energy without loss of land. This available space could be used to do other things that you have in mind.
- **Improving Technology:** Solar system technology advances on a daily basis. Solar energy has a highly competitive market; this competition increases the effectiveness of solar panel designs while also lowering costs.
- **Improves the Economy and availability of Jobs:** The use of solar panel system in a country helps reduce the rate at which the fuel is imported from other countries. Everyone knows that imports are subtracted from a country's GDP not added, and to reduce this one has to develop his own country to stand on its own. Solar power system is very important in helping the country's economy. As statistics have shown that the solar power generating section of the country employs more staffs than any other power generating section. As this section improves, it shall continue to bring about more employment opportunities.

I.8.disadvantages of solar energy [6]:

- Solar panels can be expensive to install resulting in a time-lag of many years for savings on energy bills to match initial investments.
- Electricity generation depends entirely on a countries exposure to sunlight; this could be limited by a countries climate.
- Solar power stations do not match the power output of similar sized conventional power stations; they can also be very expensive to build.

Solar power is used to charge batteries so that solar powered devices can be used at night. The batteries can often be large and heavy, taking up space and needing to be replaced from time to time.

I.9.The sun:

The sun is a hot sphere of gas with internal temperatures exceeding 20 million Kelvin as a result of nuclear fusion reactions at its core that convert hydrogen to helium. Because it is strongly absorbed by a layer of hydrogen atoms closer to the sun's surface, radiation from the inner core is not visible. Convection transports heat through this layer.[7]

The surface of the sun, called the photosphere, is at a temperature of about 6000K and closely approximates a blackbody. For simplicity, the 6000 K spectrum is commonly used in detailed balance calculations but temperatures of 5762 ± 50 K and 5730 ± 90 K have also been proposed as a more accurate fit to the sun's spectrum. Astronomers use 5778 K when classifying the sun as a star. For consistency in this site we use the approximation of 5800 K.[8]

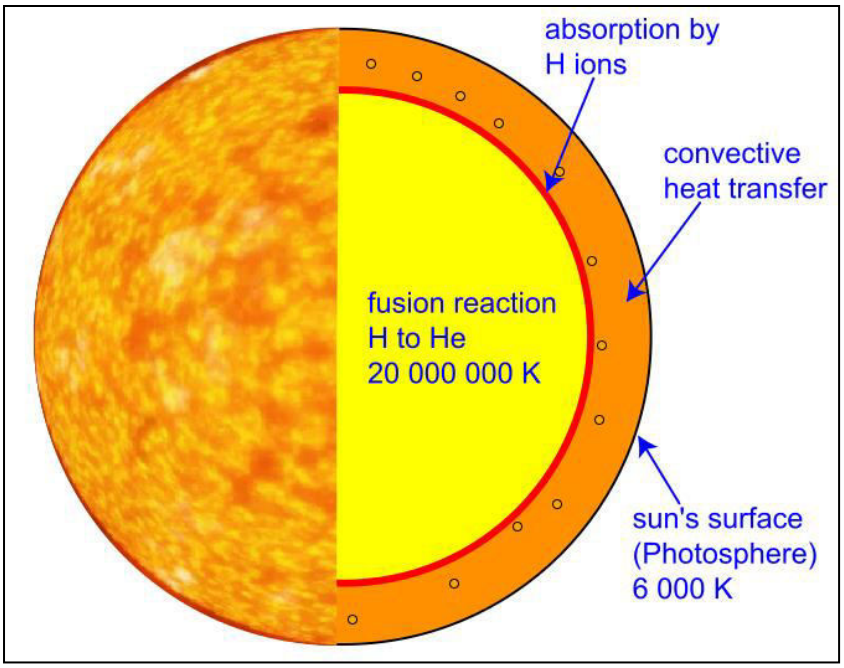

Figure.I.3 : Anatomy of Sun.

I.9.1.Sun–Earth Geometric Relationship:

The amount and intensity of solar radiation reaching the Earth's surface is determined by the Earth's geometric relationship to the Sun. This geometric relationship and its effects for different seasons in both hemispheres are depicted in (Figure.4). The position of the Sun at any time and in any location on Earth can be estimated using two methods: first, simple equations with inputs of the day of the year, time, latitude, and longitude, and second, complex algorithms with inputs of the exact position of the Sun. Mostly, such algorithms are valid for a limited period varying from 15 to 100 years; the best uncertainties achieved are greater than ±0.01 (Blanco-Muriel et al. 2001; Michal sky 1988). Ibrahim and Afshin (2004) summarized a step-by step procedure for implementing an algorithm developed by Meeus (1998) to calculate the solar angles in the period from the years 2000 B.C. to 6000 A.D. for which uncertainties of ±0.0003 were accomplished.

I.9.2.Earth-Sun Distance:

The Earth has a diameter of 12.7 × 103 km, which is approximately 110 times less than the Sun's. The Earth orbits approximately once around the Sun every 365 days. The eccentricity of the Earth's orbit is very small, about 0.0167, causing the elliptical path to be nearly circular. The Earth's elliptical path varies from 14.7 107 km in early January—the closest distance to the Sun, known as perihelion—to 15.2 107 km in early July—the farthest distance, known as aphelion. The astronomical unit (AU), which is used to calculate distances within the solar system, is defined as the average Earth–Sun distance of 14.9 107 km. However, the Earth is about 4% closer to the Sun at the perihelion than the aphelion. The Sun subtends an angle of 32′ on the Earth at a 1 AU distance.[9]

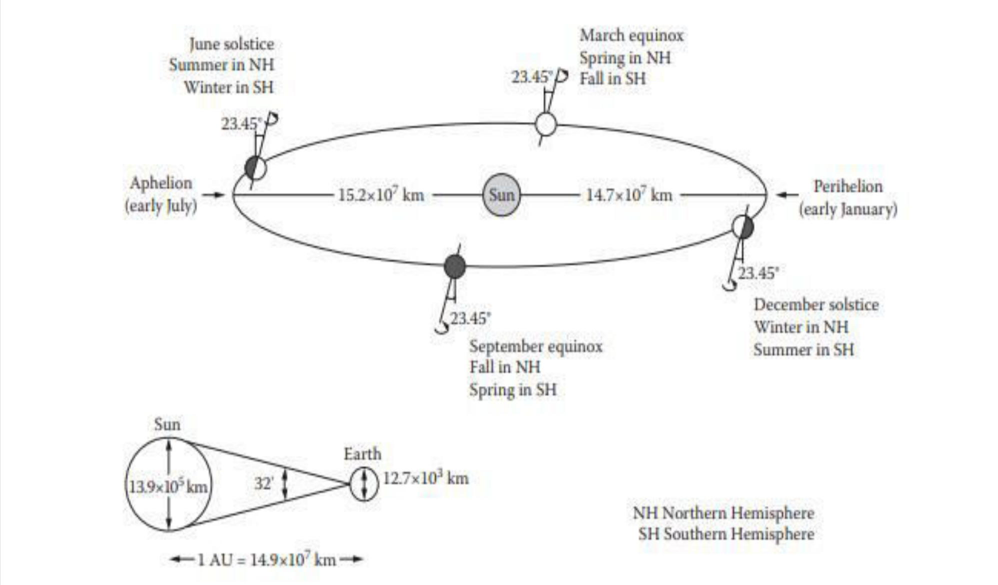

Figure.I.4: Earth–Sun geometric relationships.

I.10.Solar radiation:

Solar radiation is radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy. The spectrum of solar radiation is close to that of a black body with a temperature of about 5800 K. About half of the radiation is in the visible short-wave part of the electromagnetic spectrum. The other half is mostly in the near-infrared part, with some in the ultraviolet part of the spectrum.[10]

I.10.a.Solar Irradiance:

The intensity with which radiation enters the Earth's atmosphere is referred to as solar irradiance. Consider the difference between a 20-watt and a 100-watt light bulb as a relatable example of solar irradiance. Both emit visible light at the same wavelengths, but the brightness and intensity are drastically different. The intensity, or irradiance, of the 100-watt bulb is greater. The amount of radiant flux on a given area is measured in watts per meter squared (W/m2).[11]

I.10.b.Solar constant:

The irradiance of the sun on the outer atmosphere when the sun and earth are spaced at 1 AU - the mean earth/sun distance of 149,597,890 km - is called the solar constant. Currently accepted values are about 1360 W m^{-2} (the NASA value given in ASTM E 490-73a is 1353 ±21 W m^{-2}). The World Metrological Organization (WMO) promotes a value of 1367 W m^{-2}. The solar constant is the total integrated irradiance over the entire spectrum (the area under the curve in Figure 1 plus the 3.7% at shorter and longer wavelengths.[12]

The variation in the earth/sun distance causes a 6.6 % change in the irradiance falling on the earth's atmosphere over a year. Variations in solar activity cause irradiance to change by up to 1%. It is easier to describe the irradiance of a Solar Simulator in terms of "suns." One "sun" is equal to one solar constant's irradiance.

I.10.c.Composition of solar radiation:

Solar radiation is the sun's radiant (electromagnetic) energy. It gives the Earth light and heat, as well as energy for photosynthesis [13]. UV, visible (PAR), and infrared are the three relevant bands or ranges along the solar radiation spectrum. Infrared radiation accounts for 49.4 % of the light that reaches the Earth's surface, while visible light accounts for 42.3 %. Ultraviolet radiation accounts for slightly more than 8% of total solar radiation. Each of these bands has a distinct environmental impact.

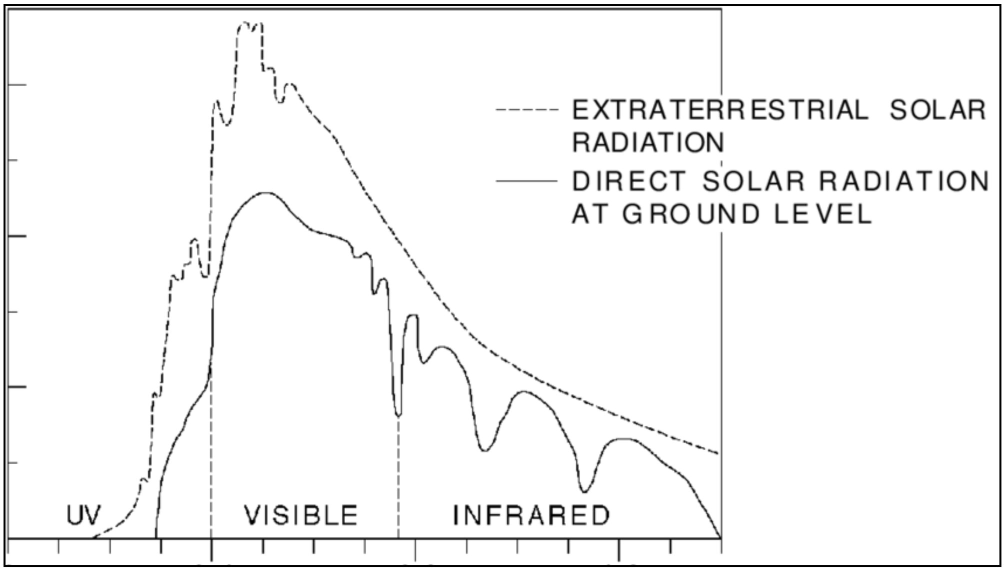

Figure.I.5: composition of solar radiation extraterrestrial and at ground level.

I.10.d.Standard Spectra:

The amount of solar radiation that reaches the earth's surface varies greatly depending on location, atmospheric conditions such as cloud cover, aerosol content, and ozone layer condition, time of day, earth/sun distance, solar rotation, and activity. Because the solar spectra are affected by so many variables, standard spectra have been developed to serve as a foundation for theoretical evaluation of the effects of solar radiation as well as a foundation for simulator design. These standard spectra begin with a simplified (i.e. lower resolution) version of the measured extraterrestrial spectra and use sophisticated models for atmospheric effects to calculate terrestrial spectra.[14]

The most widely used standard spectra are those published by The Committee International d'Eclaraige (CIE), the world authority on radiometric and photometric nomenclature and standards. The American Society for Testing and Materials (ASTM) publishes three spectra for a 37° tilted surface: AM 0, AM 1.5 Direct, and AM 1.5 Global. ASTM chose the conditions for the AM 1.5 spectra "because they are representative of average conditions in the 48 contiguous states of the United States." Figure 5 depicts typical differences between direct and global spectra. These curves are based on ASTM Standards E 891 and E 892 data for AM 1.5, turbidity of 0.27, a tilt of 37° facing the sun, and a ground Albedo of 0.2.

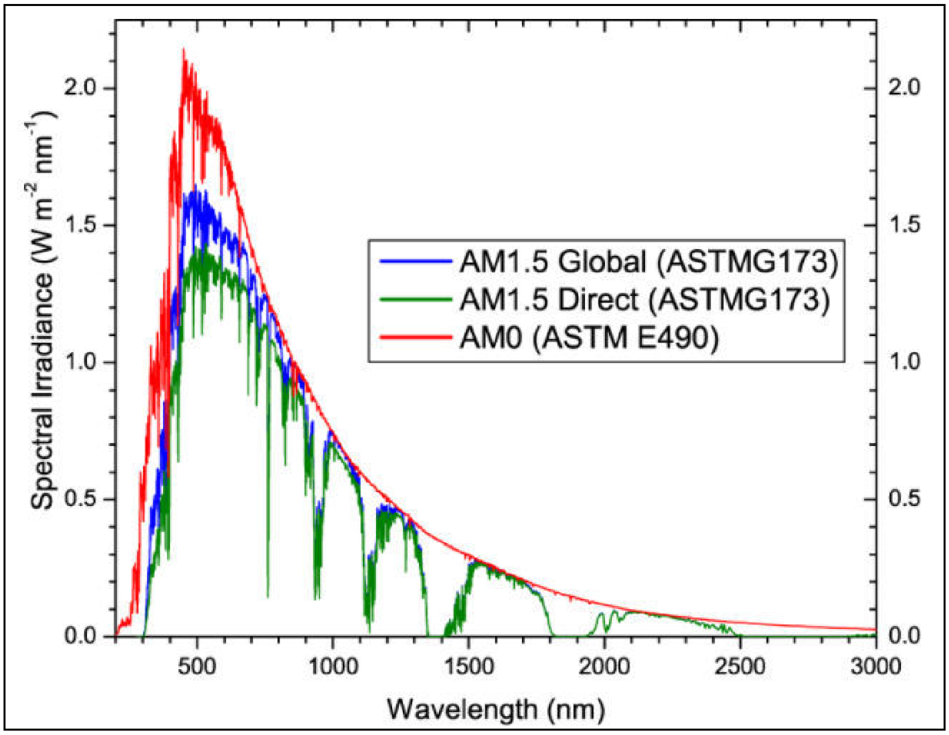

Figure.I.6: Standard Solar Spectra for space and terrestrial use.

I.10.e.The different types of radiation[14]:

- **Broadband radiation :**Photons in a wide electromagnetic spectral wavelength range, typically several hundred nanometers (nm) wide.
- **Diffuse hemispherical radiation:** Photons scattered in the atmosphere, excluding those from the solar disk, arriving on a horizontal surface originating from the 2p steradian hemisphere of the sky dome.
- **Direct normal radiation:** Nearly parallel rays of photons arriving on a surface perpendicular to the line from the observer to the center of the solar disk originating from within the 0.5 solid angle centered on the solar disk. Experimentally, this also includes additional sky radiation within 2.5–3 of the center of the solar disk.

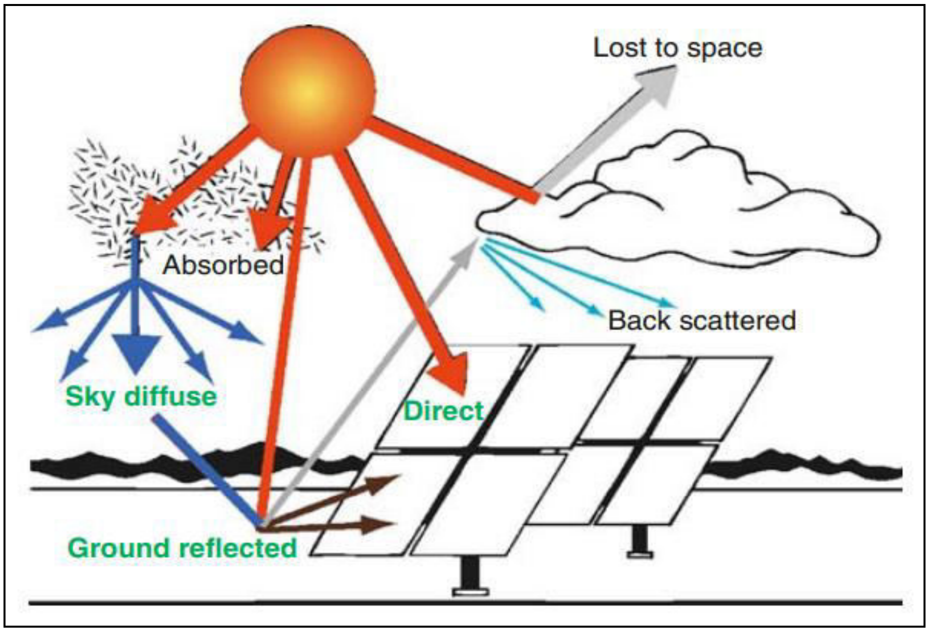

Figure.I.7: Types of solar radiation

I.11.Conclusion:

In this chapter we have given an overview of solar energy, explaining the basic characteristics of solar radiation and some basic notions about our star (the sun), its dimensions, its layers, the origin of the energy it radiates, the nature of this energy and its distribution at the outer limit of the earth's atmosphere.

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CHAPTER II

Bibliographic Search

II.1.Introduction

in this chapter our work consists of a bibliographic study which allows us to bring together some theoretical models established in other sites around the world. These models are in the form of empirical relationships that relate the components of solar radiation to major meteorological parameters, such as ambient temperature, relative humidity, sunshine duration, and astronomical parameters, such as maximum day length, declination of sunlight. sun, the variation in the distance between the earth and the sun and the solar irradiation at the limit of the atmosphere.

II.2. Solar radiation models:

II.2.1.Model of CHABANE [1]:

The model established was based on nonlinear regressions as a function of the height of the sun and the relative humidity written as a function of the global irradiation for several days of tests for an inclined plane (45 °) of south orientation:

$$G_{proposè} = 696.42 \times \left(\frac{h}{1.124}\right)^{1.124} + 1.751 \times \left(\frac{H_r}{1.24}\right) 1.24 \qquad \text{(II.1)}$$

II.2.2.Model of Lacis & Hansen [2]:

The general formula proposed by Lacis & Hansen for the calculation of global solar radiation on a horizontal plane:

$$G = I_{SC} \times COS\theta_Z \left[\frac{(0.647 - \rho_S - \alpha_\omega)}{(1 - 0.0685\rho)}\right] + 0.353 - \alpha_\omega \qquad \text{(II.2)}$$

I_{sc} is the extraterrestrial solar constant evaluated by:

$$I_{SC} = I_0 \times \left[1 + 0.033 \times \cos\left(\frac{360}{365}(n_j - 3)\right)\right] \qquad \text{(II.3)}$$

With I_0 : the average solar constant equal to1367 $W.m^{-2}$ and n j: the number of the day in the year (n j = 1 for January 1 and n j = 365 for December 31)

θ_z is the zenith angle, $\theta_z = 90° - h$ where h is the height of the sun, given in appendix A.

The coefficient α0 corresponding to the absorption of direct solar radiation by the ozone layer is calculated by the relationship:

$$\alpha_0 = \frac{0.02118 U_0}{1 + 0.042 U_0 + 3.23.10^{-4} U_0^2} + \frac{1.082 U_0}{(1 + 138.6 U_0)^{0.805}} + \frac{0.0658 U_0}{1 + (103.6 U_0)^3} \quad \text{(II.4)}$$

Where, U_0, the thickness of the ozone layer corrected by the optical path of solar radiation through this layer and defined by:

$$U_0 = I \times m_r \quad \text{(II.5)}$$

Where, m_r is the relative optical air mass given the equation:

$$m_r = \left[\cos\theta_z + 0.15(93.885 - \theta_z)^{-1.253}\right]^{-1} \quad \text{(II.6)}$$

And, l represents the quantity of ozone vertically above the location (thickness of the ozone layer)

$$l = \left\{235 + \left[150 + 40\sin\left(0.9856(n_j - 30)\right) + 20\sin(3L)\right]\left[\sin^2(1.28\varphi)\right]\right\}/1000 \quad \text{(II.7)}$$

L and φ are respectively the longitude and latitude of the place.

α_w represents the absorption coefficient of direct radiation by water vapor. given by the equation:

$$\alpha_W = \frac{2.9 X_W}{(1 + 141.5 X_W)^{0.635} + 5.925 X_W} \quad \text{(II.8)}$$

X_w is the condensable water thickness corrected by the optical path of the radiation through this layer, given by:

$$X_W = m_a \times U_W \quad \text{(II.9)}$$

U_w is the thickness of condensable water vertically from the location (cm). It is given by the equation:

$$U_W = \frac{0.493}{T} HR \times \exp\left(26.23 - \frac{5416}{T}\right) \quad \text{(II.10)}$$

With, ma the corrected air mass expressed by:

$$m_a = m_r \left(\frac{P}{1013}\right)^{0.75} \times \left(\frac{273}{T}\right)^{0.5} \quad \text{(II.11)}$$

P is atmospheric pressure (mbar). It can be calculated from:

$$P = P_0 \exp(-0.0001184 \times Z) \quad \text{(II.12)}$$

P_0 is the atmospheric pressure at sea level (P_0 = 1013 mb); z , the altitude of the site (m), relative to sea level; T, ambient temperature (K) and RH, relative humidity (%).

II.2.3. Model of L. Imane [3]:

The established model is based on nonlinear regressions as a function of the relative humidity and height of the sun written as a function of the global irradiation for several days of tests for a horizontal plane. the proposed model in the form:

$$G_{proposè} = A \times \left| \left(\frac{h + H_r}{100} \right) - X_c \right| + Y_0 \quad (II.13)$$

II.2.4. Model of Perrin-Brichambaut [4]:

The global radiation on a horizontal plane is the sum of the direct and diffuse radiation given by:

$$G_h = I_h . \sin(h) + D_h \quad (II.14)$$

Where

I_h : the direct radiation received by a horizontal surface.

D_h: diffuse radiation from the sky, received by a horizontal surface.

G_h : the global radiation received by a horizontal surface.

II.2.5. Model of K. Zina [5]:

The established model is based on nonlinear regressions as a function of the ambient temperature and height of the sun written as a function of the global irradiation for a horizontal plane. This gives us the proposed model in the form:

$$G_{proposè} = A \times \left| \left(h + \frac{T_a}{320} \right) - X_c \right|^P \quad (II.15)$$

II.2.6. Model of CHABANE [6]:

The model was based on the development of this correlation using data from solar and global radiation over the course of a year on the Ghardaïa meteorological station.

Two predictions of the distribution of solar radiation: direct and scattered light over a horizontal area models, are examined to predict hourly irradiation of Ghardaia using approach such as regression models. Comparisons between model predictions and measured values.

This model makes it possible to calculate the diffuse and direct radiation given by the following relation:

$$\begin{cases} D = a_1 + b_1 \times h + c_1 \times h^2 \\ I = a_2 + b_2 \times h + c_2 \times h^2 \end{cases} \qquad \text{(II.16)}$$

II.2.7. Model of Kasten (1996) [7]:

The most recent estimation model is that presented by Kasten. It expresses TL link disorder from direct irradiation received on a normal plane on a clear sky day as follows:

$$T_L = \frac{1}{\delta_R \times m} \log\left(\frac{I_0}{I_n}\right) \qquad \text{(II.17)}$$

$$\delta_R = \left(6.6293 + 1.7513m - 0.1202m^2 + 0.0065m^3 - 0.00013m^4\right)^{-1} \qquad \text{(II.18)}$$

I_n : Direct solar irradiation of normal incidence

I_0 : Solar constant

m : Air mass.

II.2.8. Model of S.Kaplanis et E.Kaplani [8]:

They proposed a model in the form of a sine equation of the form:

$$G = a + b\cos\left(\frac{2\pi n}{364}\right) \qquad \text{(II.19)}$$

With :

G : Daily global solar radiation ;

N : this is the number of days of the year;

a, b and c are the constants of this model.

II.2.9. Model of Al-Salaymeh [9]:

The model written in exponential form and given with the following relation:

$$G = a_0.\exp\left[-0.5 \times \left(\frac{x - a_1}{a_2}\right)^2\right] \qquad \text{(II.20)}$$

a_0 is the amplitude, a_1 the center and a_2 the width.

II.2.10.Model of Sayigh [10] :

The model of Sayigh. Developed using data relating to several Indian sites, where the latitude is between 8 ° North and 28.6 ° North and the longitude between 72 ° East and 88 ° East. This relationship takes into account geographic parameters, such as latitude and longitude. It also takes into account some astronomical parameters, namely, the theoretical day length, extraterrestrial irradiation calculated on a horizontal plane. The meteorological parameters relating to the site, and which are used in this model, are: the duration of insolation DI, relative humidity RH and the maximum temperature T_{max}.

In this model, Sayigh et al. characterized climatic zones by a factor Ψi, j. Thus according to the monthly average per day of relative humidity and according to the month considered, they define three climatic zones respectively characterized by the ranges of relative humidity, RH ≤ 65%, RH ≥ 70% and 65% <RH <7,0%. Thus knowing the value of HR from the graph connecting the HR parameters and the number of the month considered, the corresponding value of Ψi, j is determined. However, the model of Sayigh et al. Have given by the following relation:

$$G_H = 11.6KN\, exp\left(\varphi\left(\frac{DI}{T_m}\right) - \left(\frac{HR}{15}\right) - \left(\frac{1}{T_{max}}\right)\right) \quad \text{(II.21)}$$

$$N = 1.7 - 0.458\,\varphi \quad \text{(II.22)}$$

φ being the latitude of the site expressed in radians.

Statistical validation of models for reconstituting monthly averages per day...

$$K = 100\left(nT_m + \Psi_{\text{ij}} cos(\varphi)\right) \quad \text{(II.23)}$$

$$n = \frac{1}{(1+0.1\varphi)} \quad \text{(II.24)}$$

↓ I	J →	1	2	3	4	5	6	7	8	9	10	11	12
	1	1.28	1.38	1.54	1.77	2.05	2.30	2.48	2.41	2.36	1.73	1.38	1.17
	2	1.46	1.77	2.05	2.15	2.05	2.05	2.10	2.17	2.14	1.96	1.60	1.43
	3	1.60	1.81	2.00	2.17	2.25	2.26	2.24	2.20	2.10	1.92	1.74	1.60

Table.II.1: Value of Ψi, j according to the number of the month (J) and the climatic zone (I)

II.2.11.Model of Reddy [11, 12] :

This relationship has also been established for several Indian sites. The same parameters used in the model of Sayigh. were renewed in this model, but in addition Reddy took into account the number of rainy days in the month. Thus the proposed model is described by the following relation :

$$G_h = K\left[1 + 0.8\left(\frac{DI}{T_m}\right)\right]\frac{(1-0.2t)}{\sqrt{HR}} \quad \text{(II.25)}$$

$$K = 100\left(nt + \Psi_{ij}\cos(\varphi)\right) \quad (II.26)$$

With:

$$n = \frac{1}{(1+0.1\varphi)} \quad (II.27)$$

φ in degrees.

II.2.12.Model of Swartman [13] :

Likewise, using relative data from 14 Indian stations, two relationships were established by Swartman. These relationships make it possible to estimate the overall irradiation on a horizontal plane from the duration of insolation and relative humidity. In this model, as the astronomical length of the day, the author assumes that the latter is equal to 12 hours per day for each month of the year. These two relationships are given as follows:

$$G_{h1} = 11.6 * 490\left(\frac{DI}{12}\right)(0.35HR)^{-0.262} \quad (II.28)$$

$$G_{h2} = 11.6 * 460 \exp 0.607\left(\frac{DI}{12} - HR\right) \quad (II.29)$$

II.2.13.Model of Garg [14] :

From the air saturation curve, Garg et al., Using the least squares method, developed a multilinear relationship relating absolute humidity H_a to relative humidity RH, at room temperature Ta. From this correlation and the fraction of insolation defined by the ratio: duration of insolation DI to the astronomical duration of the day Tm and from extraterrestrial irradiation Gh0 calculated on a horizontal plane, Garg et al. Developed the following relation:

$$G_h = G_{h0}\left(0.14 - 0.4\left(\frac{DI}{T_m}\right) - 0.0055H_a\right) \quad (II.30)$$

With H_a is absolute humidity.

$$H_a = HR(4.7923 + 0.3647T_{a^1} + 0.0055T_{a^2} + 0.0003T_{a^3}) \quad (II.31)$$

T_m : astronomical duration of the day and T_a : ambient temperature.

In these relations, G_h is expressed in Wh/m^2.

II.2.14.Model of Sabbagh [15] :

Based on data from several Gulf countries, in particular, the Saudi Arabian sites, Sabbagh et al. have developed two empirical relationships linking the different meteorological parameters which affect the attenuation of solar radiation, namely: the duration of insolation DI, the relative humidity RH, the maximum temperature T_{max}, the altitude Z, the geographical location (longitude L, latitude φ and its location with respect to the sea and a water lake characterized by the characteristic area factor, which are given by the following relations:

$$G_h = 18.1Kexp\left[\varphi\left(\frac{DI}{12}\right) - \left(\frac{HR}{100}\right)^{1/3} - \left(\frac{1}{T_{max}}\right)\right] \quad \text{(II.32)}$$

$$G_h = 18.4(419.391DI - 292.73HR + 330.571) \quad \text{(II.33)}$$

DI, HR , and T_{max} are respectively the monthly averages per day of the insolation duration, relative humidity and maximum average temperature for the month in question.

II.2.15.Model of Hussain [16] :

Hussain's model is based on the model of Garg et al. Thus, this expression makes it possible to estimate the overall irradiation as a function of the monthly averages per day of the absolute humidity and the duration of insolation. This expression is given as follows:

$$G_h = G_{h0}\left(0.394 + 0.364\left(\frac{DI}{T_m}\right) - 0.0035H_a\right) \quad \text{(II.34)}$$

II.2.16.Model of A.S Sambo [13] :

A period of 60 months of measuring the duration of insolation, maximum and minimum temperatures, average temperature and specific humidity, was used to develop 12 different correlations with which the monthly average per day of irradiation Global can be calculated for the Kano site in northern Nigeria.

The correlations obtained were combined to arrive at a simplified form of Angström standard equation, this correlation is given as follows:

$$K_T = 0.62 - 0.294\frac{DI}{T_m} + 0.178\left(\frac{DI}{T_m} - HR - \frac{T_{\min}}{T_{\max}}\right) + 0.491\left(\frac{DI}{T_m} * \frac{T_{\min}}{T_{\max}}\right) \quad \text{(II.35)}$$

II.2.17.Model of W.E. Alnaser [17] :

For reconstructing the monthly average per day of global irradiation on a horizontal plane, Alnaser has developed a new model for Bahrayn. In this model, it uses six parameters (astronomical and meteorological). So he tried to demonstrate the effect of the choice of the number of parameters on the accuracy of this model. Thus, he proposes:

$$G_h = 1066.167 + 0.5133 G_{h0} - 8.924 HR + 2647.32 \frac{DI}{T_m} - 34.604 T_a + 31.202 T_{sol} \quad \text{(II.36)}$$

II.2.18.Modeling of the diffuse radiation of F.Chabane [1] :

In this study, proposed models based on nonlinear regressions as a function of the height of the sun and the hour angle, written according to the diffuse irradiation for several days of tests for an inclined plane (45 °) d 'south orientation:

The diffuse radiation as a function of the height of the sun and the hour angle can be written as :

- **Model 1 :**

$$D = a^h \times \sin(b \times h)^b + c \times \exp(d \times \omega) \quad \text{(II.37)}$$

Where the constants a, b, c, d, e and f are such that:

$a = 83.545,\ b = 1.996,\ c = 82.275,\ d = -0.0193,\ R^2 = 0.799$

- **Model 2 :**

$$D = a^h \times \sin(b \times h)^c + d \times \cos(e \times \omega)^f \quad \text{(II.38)}$$

Where the constants a, b, c, d, e and f are calculated from the least squares method such that :

$a = 8.049,\ b = 0.323,\ c - 0.65,\ d = 148.606,\ e = 1.122,\ f = 0.751,\ R^2 = 0.849$

Modeling of direct radiation:

The models established were based on nonlinear regressions as a function of the height of the sun and the hour angle written as a function of direct irradiation for several days of tests for an inclined plane (45 °) with a south orientation:

The direct radiation as a function of the height of the sun and the hour angle can be written as :

- **Model 1 :**

$$I = a \times \sin(b \times h) + c \times \cos(d \times \omega) + e \times \cos(h) \times \sin(\omega) \quad \text{(II.39)}$$

Where the constants a, b, c, d, e and f are calculated from the least squares method such that :

$a = 503.825,\ b = 1.217,\ c = 189.54,\ d = 1.697,\ e = -66.456,\ R^2 = 0.874$

- **Model 2 :**

$$I = a \times h^b \times \sin(c \times h) \times \cos(d \times \omega) \quad \text{(II.40)}$$

Where the constants a, b, c, d, e and f are calculated from the least squares method such that :

$a = 764.617,\ b = -0.268,\ c = 1.027,\ d = 0.799,\ R^2 = 0.86$

II.2.19.Model of Liu & Jordan [18] :

A first relationship has been established by Liu & Jordan which expresses the fraction of diffuse irradiation compared to the overall irradiation KD as a function of the clarity index KT. The data used relate to the site of Blue Hill Massachusetts (USA), this correlation is given as follows:

$$K_D = 1.39 - 4.027K_T + 5.531K_{T^2} - 3.108K_{T^3} \tag{II.41}$$

For $0.30 < K_T < 0.70$

II.2.20.Model of Collares-Pereira & Rabl [19] :

Collares-Pereira & Rabl, using relative data from five sites in the United States, proposed a polynomial correlation of order 4, given as follows :

$$K_D = 1.188 - 2.272K_T + 9.473K_{T^2} - 21.856K_{T^3} + 14.648K_{T^4} \tag{II.42}$$

For $0.17 < K_T \leq 0.80$

KD=0.99 For KT ≤ 0.17

Another relationship has been developed by Collares-Pereira & Rabl which will depend, this time, on the hour angle of sunrise ωs, a parameter characterizing the season considered. This relation is given as follows :

$$K_T = 0.775 + 0.347\left(\frac{\pi}{180}\right)(\omega_s - 90) - \left[0.505 + 0.261\left(\frac{\pi}{180}\right)(\omega_s - 90)\right]\cos[2(K_T - 0.9)] \tag{II.43}$$

ωs is the hour angle of sunrise in degrees; ωs ≈ 90 ° for the months of February, March, April, August, September and October, ωs ≈ 100 ° for the months of May, June and July and ωs ≈ 80 ° for the months of November, December and January.

II.2.21.Model of Erbs, Klein and Duffie [20]:

Erbs et al. Used hourly-scale measurements from four US stations, global and diffuse irradiations to develop a season-dependent model linking the two quantities shown. So they proposed the following relations :

$$K_D = 1.391 - 3.560K_T + 4.189K_{T^2} - 2.137K_{T^3} \tag{II.44}$$

For $\omega_S \leq 80° et 0.30 \leq K_T \leq 0.80$

$$K_D = 1.311 - 3.022 K_T + 3.427 K_{T^2} - 1.821 K_{T^3} \quad \text{(II.45)}$$

For $\omega_s > 80° et 0.30 \leq K_T \leq 0.80$

II.2.22.Model of Hussain [16]:

Likewise, for the reconstruction of diffuse irradiation, Hussain proposed the same type of relationship as that established for the estimation of global irradiation. This relationship is a function of the duration of insolation, ambient temperature, humidity and the monthly average per day of extraterrestrial irradiation calculated on a horizontal plane. It is given by :

$$D_h = G_{h0}\left(0.306 - 0.165\left(\frac{DI}{T_m}\right) - 0.0025 H_a\right) \quad \text{(II.46)}$$

II.2.23.Model of Chabane according to air quality index and turbidity factor [21]:

This is a mathematical model that contributes to providing all points of change for solar radiation according to variation in the angle of solar elevation. where 'Chabane' proposed in this work a model sufficient to predict the solar radiation on a horizontal area in different contexts and added air pollution such as CO, CO2, and CH4 linked with parameters such as η beam, κ beam, κ diffuse, β, and TL, which represent a new pollution factor that defines the mathematical model according to two components, direct and diffuse radiation. We know that the effect of pollution on light is achieved by absorbing solar radiation, which obscures part of it, and the rest of the radiation crosses the Earth's atmosphere at a limited rate.

$$Beam = A_2 + \frac{(A_1 - A_2)}{1 + exp\left(\frac{h - \left(\frac{T_L}{10} + \eta_{beam}\right)}{\beta - \kappa_{beam}}\right)} \quad \text{(II.47)}$$

The values of β and TL estimate the new pollution parameters and Linke turbidity factor, respectively, which is scripted by the relationship as follows:

$$T_L = 8.055 \times O_3^{0.0104} \times WV^{0.128} \times BE^{0.295} \quad R^2=0.986 \quad \text{(II.48)}$$

$$\beta = 0.1 \times \frac{M_{CO} + M_{CO_2} + M_{CH_4}}{10^3} - \beta_0 \quad R^2=0.9996 \quad \text{(II.49)}$$

β_0: Reference constant for total contaminated elements equal to 40 ($\mu mol.mol^{-1}$).

M_{CO}: Nano mole of the carbon monoxide per mole of dry air ($nmol.mol^{-1}$).
M_{CO2}: Nano mole of the carbon dioxide per mole of dry air ($nmol.mol^{-1}$).
M_{CH4}: Nano mole of the methane per mole of dry air ($nmol.mol^{-1}$).

η_{beam} ($\mu mol.mol^{-1}$) and κ_{beam} ($\mu mol.mol^{-1}$) represent the new coefficients of the pollution corresponding to beam solar radiation, according to β and TL, respectively, written according to the relationship as follows:

$$\eta_{beam} = \eta_0 \times T_L^{5.25} \times \beta^{-0.1388} \qquad R^2=0.9222 \qquad \text{(II.50)}$$

η_0 constant of the coefficient of η_{beam} related to the beam solar radiation, and equal to 0.0000429 $(\mu mol.mol^{-1})^{1.4}$.

$$\kappa_{beam} = \kappa_0 \times T_L^{0.702} \times \beta^{1.678} \qquad R^2=0.984 \qquad \text{(II.51)}$$

κ_0 constant of the coefficient of κ_{beam} related to the beam solar radiation equal to 2.396 $(\mu mol.mol^{-1})^{0.8}$.

The global solar radiation obtained by beam and diffuse solar radiation and the diffuse solar radiation were estimated as follows:

$$Diffuse = A_2 + \frac{\left(\left(\frac{T_L}{10} + \kappa_{diffuse}\right) - A_2\right)}{1 + exp\left(\frac{h - x_0}{\alpha}\right)} \qquad \text{(II.52)}$$

$$\kappa_{diffuse} = \kappa_1 \times T_L^{6.868} \times \beta^{-0.184} \qquad R^2=0.893 \qquad \text{(II.53)}$$

κ_1 constant of the coefficient of $\kappa_{diffuse}$ relates to diffuse solar radiation equal to −0.0000545 $(\mu mol.mol^{-1})^{1.2}$.

II.2.24.Model of Chabane Using Linke Turbidity Factor and Tilt Angle[22]:

This model aims to focus on the sunlight coming to the earth and the different intensity that has a strong relationship with the number of days in the year, for example, some atmospheric compounds and also the angle of inclination that receives sunlight knowing that the total sunlight is composed of two direct and diffuse compounds. this mathematical model focuses on include all the effects of atmospheric compounds, which are CO2 and O3.

$$(Dir, Dif)_\beta = a \times exp\left(-exp\big(k \times (h - h_c)\big)\right) \qquad \text{(II.54)}$$

This model is used to calculate coefficients depending on tilt angle corresponding to models of diffuse and direct radiation, as follows:

		Direct	Diffuse	R^2
a	a_1	6.26846	5.22654	0.87429
	b_1	0.01063	0.00561	
	c_1	−1.80E−04	−7.93E−05	
h_c	y_1	0.33892	0.28172	0.92918
	A_1	−0.02811	−0.15021	
	t_1	53.18931	116.93018	
k	y_2	0.05487	T_L	0.94525
	A_2	T_L	−0.01084	
	t_2	−285.17767	−46.05131	
R^2		0.97739	0.98785	

Table.II.2: The constants fixed according to coefficients a, h_c and k which are dependent on tilt angle.

II.3.Conclusion

In this chapter we have given an overview works related to the modeling of the solar radiation it is clear that there is a diversity of the models. There are those that are based on experimental data specific to the sites studied and then those based on the simulation. Knowledge of the geometric parameters (declination, hour angle and height) and geographic coordinates (latitude, longitude). very important for a study to determine the position of the sun.

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CHAPTER III

Theoretical and experimental study

III.1.Introduction:

To understand the different modes of conversion of the radiation of our star, theoretical bases are essential. We acquire them starting from the resource, namely the energy coming from our star and received on the surface of the earth, several studies have been carried out to model this key parameter.

The aim of the study to propose a model to estimate solar radiation based on influence the following measured parameters: particulate matters, ambient temperature, temperature dew point, WBTtemperature, Wind speed and relative humidity.

III.2.Part oneTheoretical study:

III.2.1.Modeling of global horizontal radiation:

Biskra is considered an ideal region for the exploitation of solar energy, as it is a desert region with a sunny climate, and despite the ease of use of equipment, the investments are low compared to the energy reserves that can be provided. However, the possibility of exploiting it is directly related to the climatic conditions. (Air quality is a very important factor affecting solar radiation).

In this context, we will mention global radiation modeling based on data of particulate matter, ambient temperature, dew point temperature, WBT temperature, wind speed and relative humidity.

III.2.2.Methodology and site presentation:

The measurements were carried out in the Technology Hall of the Department of Mechanical Engineering at the University of Biskra (in 2021).

III.2.3.Terrestrial Solar Radiation:

While the solar radiation incident on the Earth's atmosphere is relatively constant, the radiation at the Earth's surface varies widely due to:

- atmospheric effects, including absorption and scattering;
- local variations in the atmosphere, such as water vapor, clouds, and pollution;
- latitude of the location;
- the season of the year and the time of day.

III.2.3.a.Declination of the sun δ[1]:

the Sun declination angle, δ, is defined to be that angle made between a ray of the Sun, when extended to the center of the earth, O, and the equatorial plane. We take δ to be positively oriented whenever the Sun's rays reach O by passing through the Northern hemisphere.Its expression is given by:

$$\delta = 23{,}45 \sin [0{,}980(j + 284)] \quad \text{(III.1)}$$

$$\text{or } \sin \delta = 0.39795 \cdot \cos [0.98563 \cdot (N - 173)] \quad \text{(III.2)}$$

where the argument of the cosine here is in degrees and N denotes the number of days since January 1.

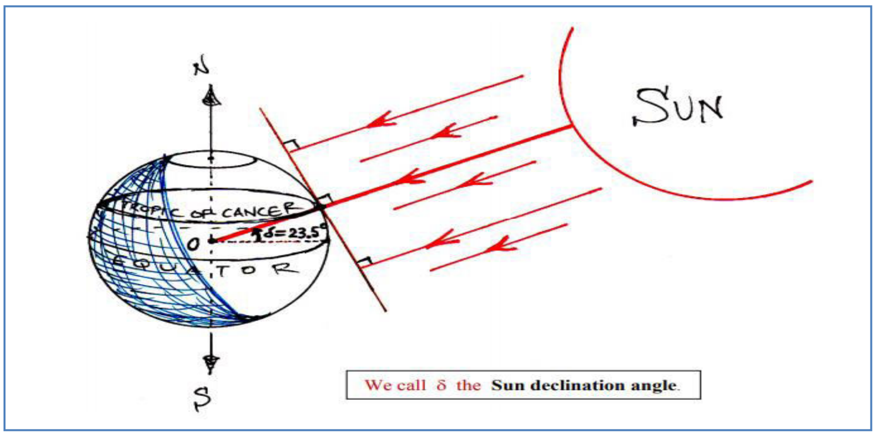

Figure.III.1:the Sun declination angle.

III.2.3.b.Hour angle ω[2]:

hour angle is defined as the angular distance on the celestial sphere measured westward along the celestial equator from the meridian to the hour circle passing through a point. It may be given in degrees, time, or rotations depending on the application.

$$\omega = arc\cos[-tg(\varphi).tg(\delta)] \quad \text{(III.3)}$$

III.2.3.c.Latitude φ and LongitudeL:

The latitude is the angle formed by a line going from the center of the earth to the equator at the point on the equator that is closed to the point of interest and another line that goes from the center of the earth to the parallel that goes through the point of interest.

The longitude is the angle formed by a line that goes through the center of the earth and the equator where the longitude=0 and another line that goes through the center of the earth and a line through the equator and the meridian that goes through the point of interest.

III.2.3.d.The height of the sun[3]:

The height of the sun is the angle (h) formed by the horizontal plane at the place of observation and the direction of the sun. It is given by the relation:

$$\mathbf{Sin(h) = \cos(\varphi)\cos(\delta)\cos(\omega) + \sin(\varphi)\sin(\delta)} \quad (III.4)$$

With:**φ**: longitude of place

δ: The Sun declination angle

ω: hour angle

III.2.4.Solar time:

III.2.4.a.Equation of Time (ET):

The equation of time (ET) (in minutes) is an empirical equation that corrects for the eccentricity of the Earth's orbit and the Earth's axial tilt. An approximation accurate to within ½ minute is**[14]:**

$$\mathbf{ET = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B)} \quad (III.5)$$

Where: $B = \frac{360}{365}(\mathrm{d} - 81)$

III.2.4.b.Time Correction Factor (TC):

The net Time Correction Factor (in minutes) accounts for the variation of the Local Solar Time (LST) within a given time zone due to the longitude variations within the time zone and also incorporates the EoT above.**[4]**

$$\mathbf{TC = 4(Longitude - LSTM) + ET} \quad (III.6)$$

III.2.4.c.Local Solar Time (LST):

The Local Solar Time (LST) can be found by using the previous two corrections to adjust the local time (LT).

III.2.4.d.Local Standard Time Meridian (LSTM):

Local standard time is the clock time for the time zone in which the observing site is situated, but which does not include any shift in time due to the implementation of daylight saving time. There is a fixed relationship between local standard time and Coordinated Universal Time based on the longitude that represents the local time zone.

III.2.4.e.Coordinated Universal Time:

Coordinated Universal Tim (UTC) is the primary world standard for time, with time zones around the world being expressed as positive or negative offsets from it. It is essentially the mean solar time (see below) for any location on the Greenwich meridian. The Greenwich meridian is also called the prime meridian.

$$\mathbf{UTC=TU+1/15} \tag{III.7}$$

III.2.4.f.True solar time (TST):

True solar time is determined by the difference between the Greenwich Hour Angle of a location (which is fixed) and that of the sun, which changes by approximately15° an hour as it traverses the sky. The reference time for true solar time is solar noon (12:00:00 TST), which is defined as the time at which the sun's GHA is equal to the location's GHA. Solar noon is commonly referred to as being when the sun's direction is true north and its position is highest in the sky.

$$\mathbf{TST = 12+ \omega /15} \tag{III.8}$$

III.2.4.g.Mean solar time (MST):

Mean solar time is the solar time which would apply if there was no day to day variation in the Coordinated Universal Time of solar noon at a location. It is determined by the local standard time and the difference between the GHA of the location and the GHA equivalent to the local time zone. The difference between true solar time and mean solar time can range between + 16 and – 16 minutes throughout a year (see below for an explanation).

$$\mathbf{MST =TST-ET} \tag{III.9}$$

III.2.5.Solar Radiation Components:

The total (hemispherical), also known as global horizontal irradiance, is the sum of direct-beam and diffuse radiation on a horizontal surface. The sun moves through a range of elevation angles on a daily basis, from 0^o at sunrise to a maximum at solar noon and back to 0^o at sunset. As a result, the direct beam for a horizontal surface is usually not perpendicular to the horizontal surface., the direct beam is usually not perpendicular to the horizontal surface, but incident at some angle i. The angle i is referred to as the zenith angle, Z (the angle between the local vertical and the center of the solar disk) for a horizontal surface. The direct-beam flux density multiplied by the cosine of the incidence or zenith angle produces the flux density on a surface (Lambert's cosine law).[5]

The total irradiance on a horizontal surface, G, is equal to the (direct beam, B)×cos(Z) plus the diffuse irradiance (F) from the rest of the sky impinging on the horizontal surface.

$$\boldsymbol{G = B \times \cos(Z) + F} \qquad \text{(III.10)}$$

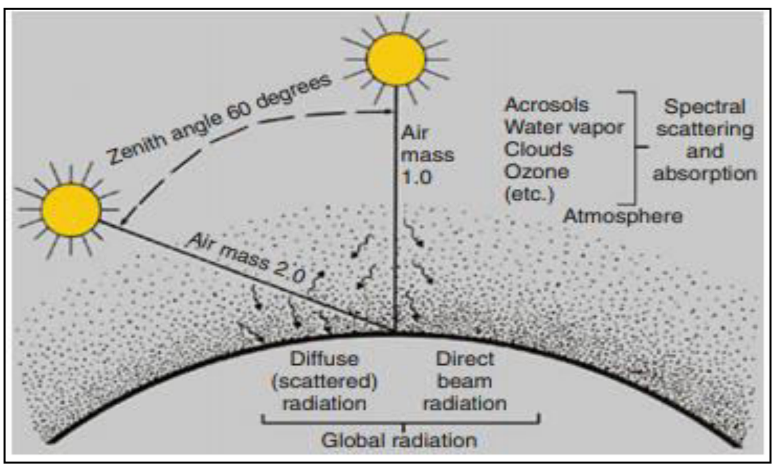

Figure.III.2 : Scattering of the direct-beam photons from the sun by the atmosphere produces diffuse sky irradiance.

III.2.5.a.Direct radiation (S):

Is also sometimes called "beam radiation" or "direct beam radiation". It is used to describe solar radiation traveling on a straight line from the sun down to the surface of the earth.

$$S(i,\gamma) = I[\cosh.\sin i.\cos(\alpha - \gamma) + \sinh .\cos i] \qquad \text{(III.11)}$$

III.2.5.b.Diffuse radiation (D):

It is the radiation diffused by atmospheric components from the entire sky with the exception of the solar disk, so that the vertical component of the diffuse radiation reaching the ground is equal to half the vertical component of the direct radiation Disseminated.

On the other hand, describes the sunlight that has been scattered by molecules and particles in the atmosphere, but that has still made it down to the surface of the earth.[6]
The empirical expressions used to estimate the component of the scattered solar radiation are:

- Part of the sky

On an horizontal surface by clear sky:

$$\mathbf{D = 125\,(\sin h)^{0.4}} \qquad \text{(III.12)}$$

We multiply D by 4/3 by polluted sky and by 3/4 by very pure sky.

-Part of the soil: given by the following formula:

$$\mathbf{D_S\,(i) = \left(\frac{1+\cos(i)}{2}\right).D_H + \left(\frac{1-\cos(i)}{2}\right).\rho\, G_H} \qquad \text{(III.13.a)}$$

With: $G_H = D_H + S_H$ AND $S_H = I \sin(h)$

$$\Rightarrow \mathbf{D_H = G_H - I \sin(h)} \qquad \text{(III.13.b)}$$

D_H: diffuse radiation received by a horizontal surface.

G_H: the total radiation received by the same surface

ρ : Albedo from the neighboring soil

III.2.6.Moindre carréemultiple:

We are trying to model the relationship between the solar radiation RYM and the sum of particulate matter PMS, the sum of Temperature, TS, the sum of the relative humidity, ambient temperature, with velocity wind HTV, and elevation angle of the sun. We put:

- RYM =Solar radiation (W/m²),
- PMS =sum of particulate matter PMS (µg/cm^3),
- TS = the sum of Temperature(°C),

- HTV = the sum of Temperature, TS, the sum of the relative humidity, ambient temperature, with velocity wind

We suppose that this relation is linear of the form:

$$RAYM = a \times MPS^{b} \times TS^{c} \times HTV^{d} \times \sin(h)^{e} \quad \text{(III.14)}$$

The equation is not yet linear, so we try to put in the two members of the equation the (Ln), the prediction equation come to:

$$\ln(RAYM) = \ln\left[a \times MPS^{b} \times TS^{c} \times HTV^{d} \times \sin(h)^{e}\right] \quad \text{(III.15)}$$

$$\ln(RAYM) = \ln(a) + b \times \ln(MPS) + c \times \ln(TS) + d \times \ln(HTV) + d \times \ln(\sin(h)) \quad \text{(III.16)}$$

$$\ln(Y) = A + b \times X_{1} + c \times X_{2} + d \times X_{3} + d \times X_{4} \quad \text{(III.17)}$$

- We want to estimate this relation with a multiple regression model.

The model

We try to model the relationship between more than 2 quantitative variables.

A multiple linear regression model looks like this:

$$Y = A_{0} + \sum_{j=1}^{p} A_{j} \times X_{j} + \varepsilon \quad \text{(III.18)}$$

where:

- y is the variable to be explained (with values in R);
- X_1,…,X, p is the explanatory variables (with values in R);
- ε is the random error term of the model;
- A_0, A_1,…,A_p are the parameters to be estimated.

For n observations , we can write the multiple linear regression model in the form:

$$Y = A_{0} + \sum_{j=1}^{p} A_{j} \times X_{i,j} + \varepsilon_{i} \quad for\ i = 1,...,n$$

In this chapter, we assume that:

- ε_i is a random , unobserved variable ,

- $X_{i,j}$ is observed and not random , - Y_i is observed and random .

We made three additional hypotheses following:

(A1) E [ε_i] = 0 ; ∀ i = 1,….., n ,

or equivalently:

$$E\ [Y_i] = A_0 + \sum_{j=1}^{p} A_j \times X_{i,j} \quad for\ i = 1,...,n$$

Comment on a hypothesis (A1): it indicates that the errors are centered

(A2) V (ε_i) = σ^2, ∀ i = 1,…, n,

or equivalent:

V (Y_i) = σ^2; ∀ i = 1,…, n,

Comments on hypothesis (A2) :

- We speak of homoscedasticity hypothesis (≈homogeneity of variances). - This variance σ 2 is a parameter of the model that must be estimated .

(A3) Cov (ε_i;ε_i') = 0, $\forall\ i \neq i'$

or equivalently:

Cov (Y_i , Y_i') = 0 ; $\forall\ i \neq i'$.

Comment on the assumption (A3) :

- under this assumption, the terms error " i are uncorrelated .

Can be written in matrix model (III-18) as follows: Y = X A +ε

$$Y = \begin{pmatrix} Y_1 \\ Y_2 \\ . \\ . \\ . \\ Y_n \end{pmatrix}, \quad X = \begin{pmatrix} 1 & X_{11} & ... & X_{1p} \\ 1 & X_{21} & ... & X_{2p} \\ . & . & & . \\ . & . & & . \\ . & . & & . \\ 1 & X_{n1} & ... & X_{pp} \end{pmatrix}, \quad A = \begin{pmatrix} A_0 \\ A_1 \\ . \\ . \\ . \\ A_p \end{pmatrix}, \quad and \quad \varepsilon = \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ . \\ . \\ . \\ \varepsilon_n \end{pmatrix}$$

- Y designates the vector to be explained of size n,
- X the explanatory matrix of size n × (p + 1),
- ε the error vector of size n.

The established model is based on nonlinear regressions as a function of global solar radiation in terms of particulate matter, relative humidity, temperature (Ambient, dew point, WBT), wind speed, and sun height. For several days of tests for a horizontal plane, according to condition of climate and the type of sky. The global solar radiation can be written in the form of the experimental measurements, we calculate according to the shape of the chosen model:

$$RAYM = a \times PMS^{b} \times TS^{c} \times HTV^{d} \times sin(h)^{e}$$

$$PMS = PM1 + PM2.5 + PM10$$

$$TS = Tam + TDew + TWBT$$

$$HTV = HUM + Tam + V$$

RAYM : Model of the solar radiation.

PM: Particulates matter.

Tam, TWBT, TDew : Temperature.

HUM: Relative humidity.

V: Speed wind.

a,b,c,d and e: the coefficients of the proposed model.

After that, we took into account the average data values obtained for the three types of climate and sky conditions for the days when the test was performed, such as:

Type of sky	a	b	c	d	e	R^2
Clear	292650,2	-0,433	0,352	-1,429	1,165	0,9504
Cloudy	1074,103	-0,0637	0,2074	-0,266	1,352	0,9546
Partial	0,6319	-0,3091	1,302	0,8117	1,985	0,9394

Table III.1: The values of the coefficients a, b, c, d, e of the model proposed according to the type of days.

In this step, we will develop the data that we measured over a period of the month of March and April 2021.

We made a choice of day according to the type of day (clear, partial, cloudy).

Clear day:

TIMES (h)	PMS ($\mu g/m^3$)	TS (C^o)	HTV	h (^{o})	RAY_{exp} (w/m^2)	RAY_{model} (w/m^2)
08:00	30	40,51	59	0,56427	280	351,231
08:30	25	36,54	59	0,66605	390	433,685
09:00	31	41,5	66,4	0,76358	474	397,938
09:30	15	41,29	62,4	0,85478	585	657,904
10:00	19	41,23	60,2	0,93659	656	674,424
10:30	18	42,36	61,8	1,0047	781	708,841
11:00	13	38,11	62	1,05344	835	809,884
11:30	13	48,2	61,8	1,07694	886	897,258
12:00	12	43,82	60	1,07157	927	933,845
13:00	15	43,49	55	0,98166	934	898,67
13:30	13	45,46	54,5	0,90796	900	924,638
14:00	13	44,53	54	0,82231	831	854,225
14:30	14	43,74	54,5	0,72855	724	725,628
15:00	13	45,18	53	0,62932	678	683,241
15:30	14	43,5	50,4	0,52646	600	583,472
16:00	11	43,39	50,5	0,42124	555	507,554

Table III.2: The parameters of PMS, h, TS, HTV, RAYexp and RAYmodel according toApril 06, 2021.

Partial Day:

TIMES (h)	PMS ($\mu g/m^3$)	TS (C^o)	HTV	h (^{o})	RAY_{exp} (w/m^2)	RAY_{model} (w/m^2)
08:00	30	42,45	57,7	0,71487	352	337,744
08:30	31	46,92	59,96	0,81477	426	483,291
09:00	28	43,68	57,99	0,90902	519	519,281
09:30	26	43,18	57,16	0,99447	574	583,827
10:00	26	46,37	54,31	1,06633	653	669,467
10:30	31	43,21	57,98	1,11783	683	643,146
11:00	22	43,77	56,19	1,14142	711	724,724
11:30	15	43,21	55,12	1,13252	735	783,379
12:00	20	46,44	55,12	1,09296	764	757,349
13:00	16	45,89	55,11	1,02952	773	744,532
13:30	19	45,21	56,75	0,94962	695	638,907
14:00	17	45,34	55,47	0,90147	622	606,319

14:30	16	45,22	55,22	0,85738	572	570,544
15:00	17	44,79	55,24	0,80678	511	504,831
15:30	18	44,81	54,89	0,76758	462	456,885
16:00	16	44,53	54,74	0,71574	420	419,102

Table III.3: The parameters of PMS, h, TS, HTV, RAYexp and RAYmodel according toApril 16, 2021.

Cloudy Day:

TIMES (h)	PMS ($\mu g/m^3$)	TS (C^o)	HTV	h (^{o})	RAY_{exp} (w/m^2)	RAY_{model} (w/m^2)
08:00	43	42,9	74,46	0,59784	246	268,024
08:30	32	44,22	74	0,70085	319	330,852
09:00	25	44,62	74,27	0,80006	382	388,521
09:30	39	44,6	73,14	0,89340	435	424,007
10:00	28	50,41	57,42	0,97775	478	515,360
10:30	25	52,52	65,58	1,04842	512	536,325
11:00	41	47,3	69,82	1,09902	535	519,040
11:30	25	49,4	66,01	1,12255	549	557,348
12:00	24	49,94	65,41	1,11473	553	558,548
13:00	27	49,57	69,01	1,07708	548	531,572
13:30	24	49,31	59,36	1,01571	532	530,830
14:00	29	50,07	62,43	0,93764	507	483,362
14:30	25	49,88	61,29	0,84843	471	444,600
15:00	20	50,5	58,69	0,75195	426	402,901

Table III.4: The parameters of PMS, h, TS, HTV, RAYexp and RAYmodel according toApril 13, 2021.

III.2.7.Solar Radiation Error:

We often find errors in the experimental field, which is due to several of the causes, so there are ways to achieve the best model of global solar radiation. In this context, we will use comparative statistical methods.

III.2.7.a.The root mean square error (RMSE):

Is a verification measure whose value is always positive and equal to zero in the ideal state. It also provides information on the short-term performance of relationships by building on each term by comparing the corresponding elements of forecasts and observations. The smaller the value, the better the model, given in the following relation:

$$RMSE = \left[\frac{\sum \left(X_{mod} - X_{exp} \right)^2}{n-1} \right]^{0.5} \tag{III.19}$$

With:

n :Number of data on global solar radiation or number of hours of the day.

X_{mod} : the global solar radiation of the proposed model.

X_{exp} : global solar radiation measured.

III.2.7.b.Sum of squared errors (SSE):

Represents a measurement of distribution or deviation it is calculated by the square difference between the expected data and the observation in one or more categories, it is given in the following relation:

$$SSE = \frac{1}{N} \sum_{i=1}^{N} \left(M_{exp,i} - M_{mod,i} \right)^2 \tag{III.20}$$

III.2.7.c.Chi-square tests (X^2):

Is to test any statistical hypothesis to calculate the probability that the given theoretical or mathematical distribution is appropriate for the measured data, it is given in the following relation:

$$\chi^2 = \left[\frac{\sum \left(M_{mod} - M_{exp} \right)^2}{n-1} \right] \tag{III.21}$$

III.2.7.d.Mean Relative Error (ERM):

Is defined as the absolute value of the absolute error on the real value, it is given in the following relation:

$$ERM = \left[\frac{\left| X_{mod} - X_{exp} \right|}{X_{mod}} \right] \times 100 \tag{III.22}$$

We translate these errors by day type in the following table :

	χ^2	RMSE	R²	Itération
Clear day	11	26.58	0.950	691
Partial day	6	32.99	0.939	241
Cloudy day	9	19.28	0.954	418

Table III.5: Global solar radiation errors between the proposed model and measured (2021) as a function of days (clear, partial, cloudy).

III.2.8.Main organization:

The organization chart shows the process of the global solar radiation ratio interpolation according to climatic parameters such as air quality, ambient temperature, temperature, dew point ,WBT temperature,Wind speed and relative humidityaccording to the following steps:

1-We will enter the measured data of global solar irradiance during the day of the month of April in 2021.

2-Then we will enter the climatic data respectively.

3-We also enter the data (day, φ, Z).

4-After all, we calculate the proportions (PMS), (TS), (HTV) end (sin(h)).

5-We translate the values calculated in 'Origin lab': y=RAY, x_1=PMS, x_2=TS, x_3=HTV, x_4=sin(h).

6-And then we interpolate the data, to obtain the constants of the interpolation a, b, c, d and e according to the best R².

III.3.Part two: Experimental study:

III.3.1.The climatic characteristics of the city of Biskra:

The city of Biskra is characterized by its desert climate. The geographic features of the city are 34 ° 48`n North latitude, 5 ° 44`East longitude and an elevation of 87 meters above sea level.

Also characterized the maximum temperature in summer, which in July at 42 degrees Celsius and the minimum temperature in winter up to 7 degrees Celsius during the month of January. The average annual temperature is 21.5 ° C.

- **Air Quality:**

Air pollution is a huge problem in most urban areas and can often bemeasured at concentrations higher than regulatory levels in industrial areas. The most common air pollutants include; particulate matter (PM10, PM2.5, PM1) which is emitted from vehicular traffic (petrol and diesel vehicles), fixed combustion processed with solid or liquid fuel, industrial emissions and natural environmental conditions.

Airborne particulate matter (PM) particles vary largely in their frequency, spatial and temporal properties, as well as their chemical configuration. PM10 particles refer to particulates which are <10 µm in size, PM2.5 are particle size less than 2.5 µm) and PM1 (particle size less than 1 µm).

Numerous studies have been conducted to better understand and forecast the concentrations of PM(10, 2.5 and 1) levels in the atmosphere using machine learning techniques to improve health and air quality. Understanding the dynamics of these atmospheric constituents in combination with meteorological parameters provides a holistic description of the available solar radiation for a specific region.

- **Temperature :**

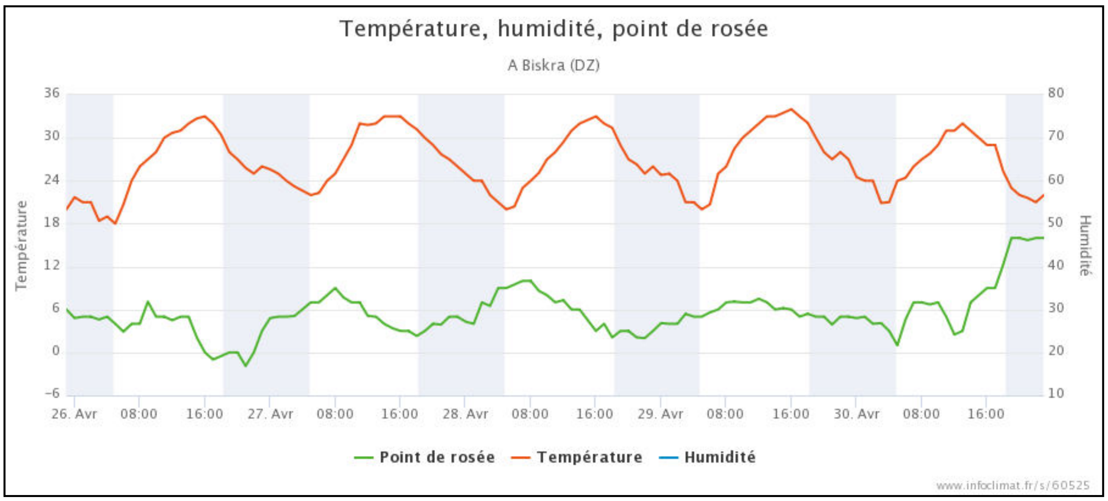

Figure.III.3: Ambient temperature corresponds to the Biskra weather station[7].

We have taken only a sample of the forecast data for the temperature of the city of Biskra 2021, we notice in figures (3) takes a more sinusoidal shape.

Where the maximum temperature is 26-30 in April afternoon in clear day, but the minimum temperature is almost at 6 or 5 in the morning every day.

- **Relative humidity :**

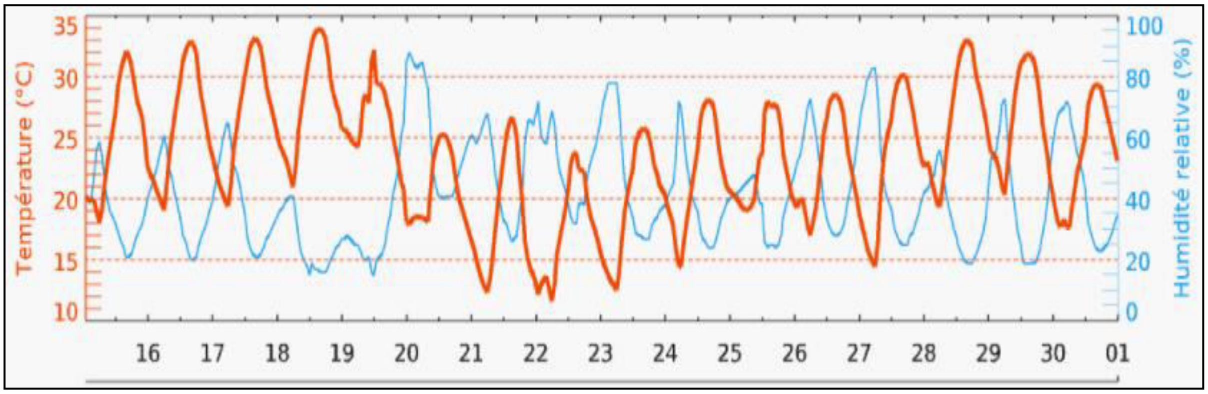

Figure.III.4: Relative humidity at Biskra[7].

The figure.4 represents the humidity in the second half of April 2021 for the region of Biskra, over the days while maintaining the sinusoidal shape we also notice that they are inversely proportional to the temperature. self a maximum at midnight (70% -80%) of each day and at noon it is minimal.

- **Wind speed:**

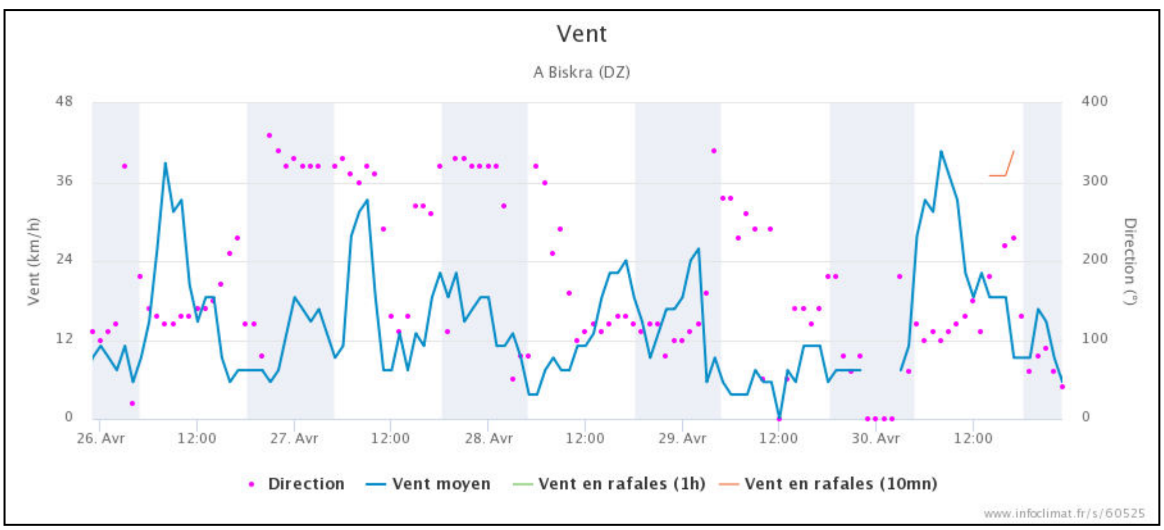

Figure.III.5: Wind speed[7].

We notice from the data of the predicted that the law of variation represented in figure (5) takes a more sinusoidal month form.

Wind intensity peaked on April 26, 27 and 31, with no change in direction Which is still volatile.

III.3.2.Measuring instruments:

- **Industrial Hygrometer PCE-555:**Portable pocket-sized hygrometer for measuring ambient humidity, ambient temperature, dew point and wet ball temperature.

Figure.III.6: Hygrometer PCE-555.

- **Handheld Pyranometer:**This type of sensor is cheaper and measurement changes is fast compared to thermopile sensor. Since it is using same technology (crystalline silicon) as Solar PV System, its measurement is more suitable and closely related to actual Solar PV System production. Temperature might have minor deviation effect on the reading which is not more than 3% in practical.

Figure.III.7:handheld pyranometer 4890.20.

- **Digital Wind Speed Anemometer:**Simultaneously measures & displays airspeed and temperature of the moving air.

Figure.III.8 : DigitalWind Speed Industries Anemometer HT- 9819.

- **Handheld Air Quality detector:**Handheld air quality detector Particulate Matter PM(2.5,10,1) Test Indoor Volatile Organic Compound Gas Formaldehyde Detector.

  The portable particulate monitor will output particulate matter (PM) measurements for PM10, PM1 and PM2.5 in real-time.

  The monitor can also be used to measure gaseous pollutants such as humidity relative and ambient temperature.

Figure.III.9 : Handheld Air Quality detector monitor.

III.3.3.Site Definition infoclimat: Is a global, professional and free site that contains a database of weather events since 1870 around the world. It is considered to be one of the most sensitive websites to weather conditions (semi-permanent observation of weather forecasts), It also has a climate / pluvial base is made up of a network of amateur or non-amateur stations , who communicate their statements monthly. They are all equipped with stations and rain gauges carefully installed and verified to be able to have the most reliable reports possible.

III.4.Conclusion:

This chapter is concerned with the experimental and theoretical study, to obtain a mathematical model that predict the solar radiation ratio values according to climatic parameters (Air quality, temperature, wind and relative humidity). A theoretical study can only be judged on its validity if it is coupled with the experimental aspect. The experimental based on measuring instruments which used as reference tools to obtain exact values.

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CHAPTER IV

Results and Discussion

IV.1.Introduction :

In this chapter, we translate and discuss the results obtained from established models as well as those obtained experimentally.

As well, analyzing the global solar radiation data for the city of Biskra, obtained experimentally, as well as from the applicable model, and a comparison between them.

IV.2.Variation of global solar radiation as a function of time depending on the type of sky:

IV.2.1.Comparison of the experimental data obtained with the proposed model of clear sky:

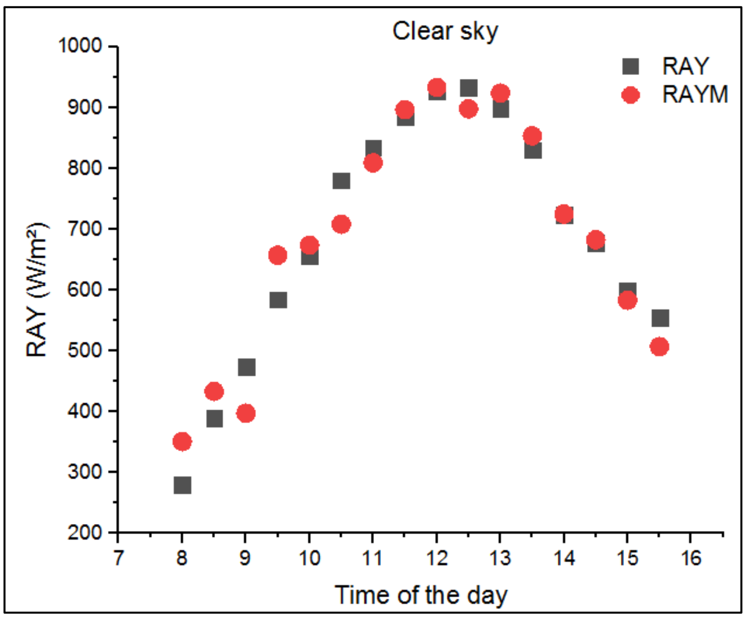

Figure.IV.1 : Global solar radiation according to the model established by against experimental data (Clear sky).

Figure.1 shows the comparison between the established model and the measured data of global solar radiation on the horizontal plane as a function of true solar time according to clear sky condition. We observe that the global solar radiation takes a maximum value at the solar noon by another hand at the sunrise and sunset. We can seen the approximation between the measured data and the established model curves is very well.

IV.2.2.Comparison of the experimental data obtained with the proposed model of partial sky:

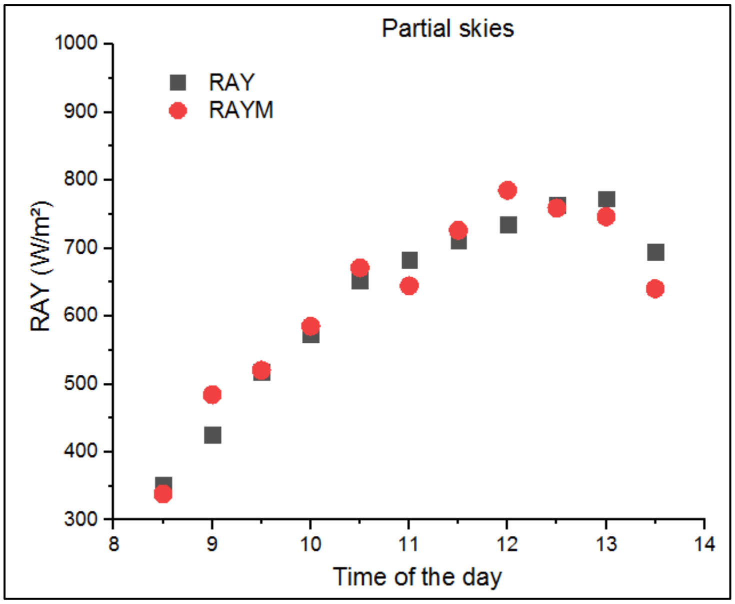

Figure.IV.2 : Global solar radiation according to the model established by against experimental data (Partial sky).

Figure 2 shows the change in the ratio of global solar radiation as a function of real solar time corresponding to the state of the partial sky, shows the change in the ratio of global solar radiation on the horizontal plane. We observe that the solar radiation ratio value is approaching and parallel between the data and the model throughout the day, such that takes maximum value at noon which is equal to 800 W/m^2.

IV.2.3.Comparison of the experimental data obtained with the proposed model of cloudy sky:

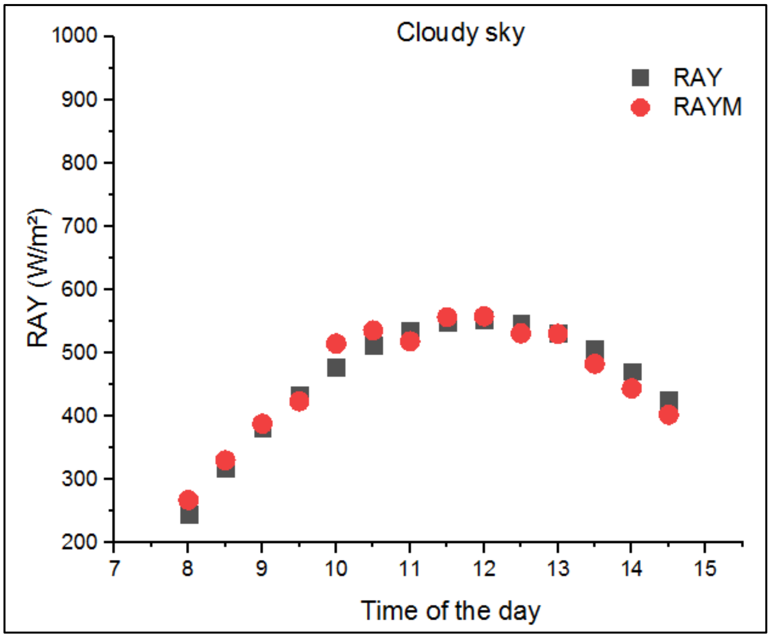

Figure.IV.3 : Global solar radiation according to the model established by against experimental data (Cloudy sky).

Figure 3 show the variation of the ratio of global solar radiation as a function of true solar time over the whole day, correspond to the state of the cloudy sky, according to the measured experimental data and the established model. solar radiation takes maximum value at noon which expects value 560-600. We conclude that the difference between the model and the measured data shows a good approach.

IV.3.Variation of particulate matter PMS as a function according the global solar radiation depending on the type of sky :

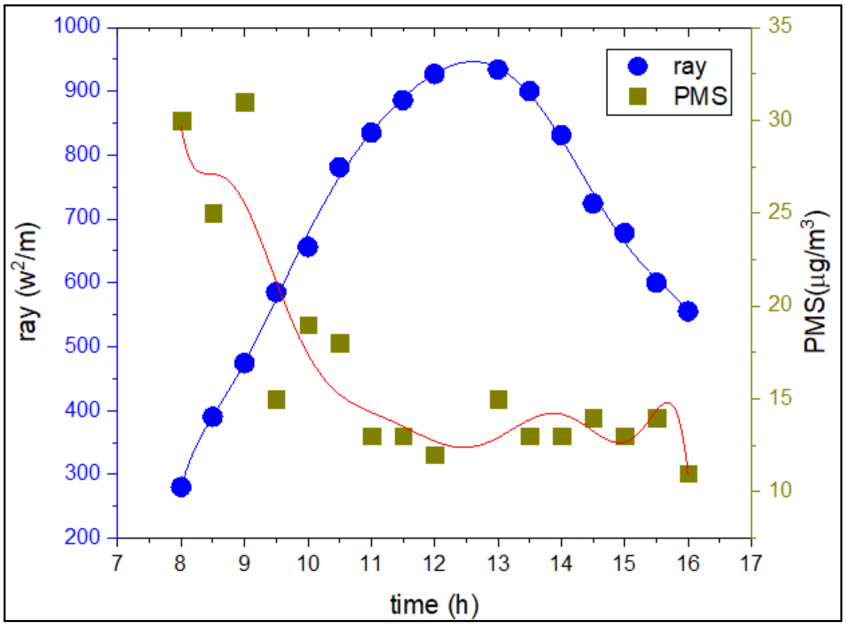

Figure.IV.4 : variation of particulate matters in synchrony with changes in solar radiation over time (Clear 06-04-2021).

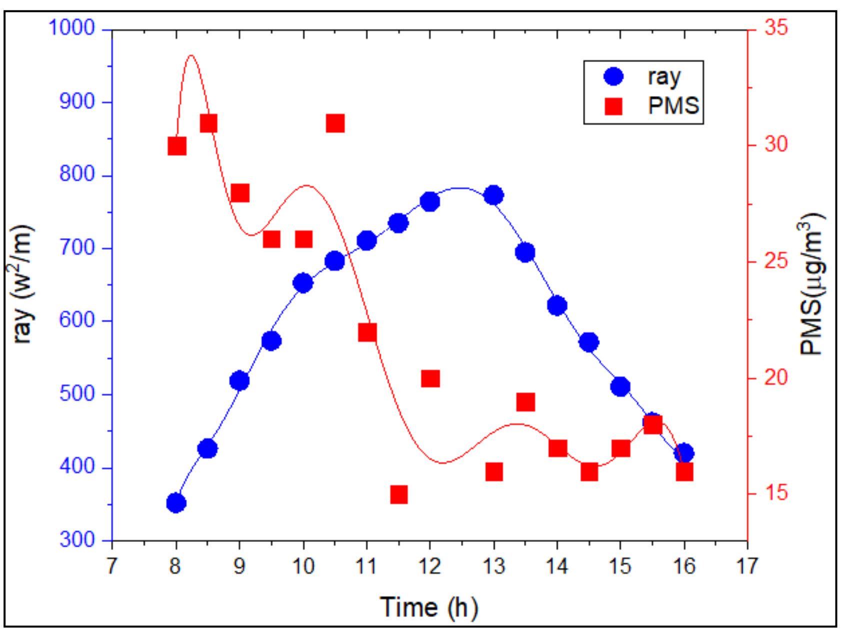

Figure.IV.5 : variation of particulate matters in synchrony with changes in solar radiation over time (partial 16-04-2021).

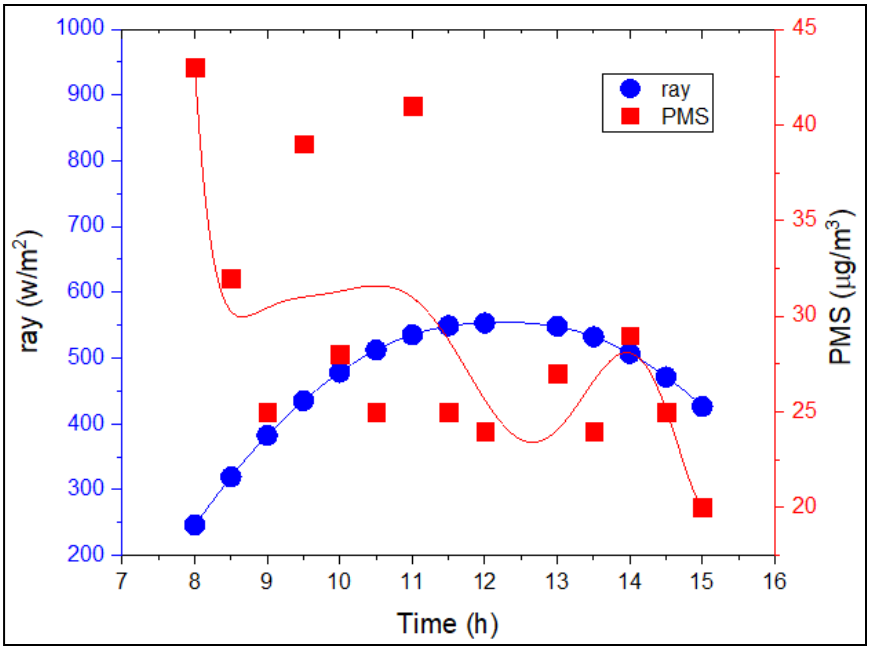

Figure.IV.6 : variation of particulate matters in synchrony with changes in solar radiation over time (Cloudy 13-04-2021).

Figure 4, 5, and 6 show the variation in the value of the total particulate matter in the Biskra site according to the state of the sky in the month of April. So that the value of the particles varies according to the type of sky, where we notice in Figure 4 while the sky is clear that the maximum value of the particles is at sunrise and gradually decreases to a minimum value at noon while the solar radiation is at its maximum. However, the value of the particles takes higher values in when the sky is cloudy (Fig. 6) compared to the partial sky (Fig. 5) or clear (Fig. 4) where there is a high in the solar radiation .

This can be seen through the different values of particles according to the type of sky, where the maximum value of particles in the sunrise period of the sky is clear PMS=30 where the solar radiation is Ray=300w/m2 ,whilst In partial sky it is PMS=31 and solar radiation is Ray=330w/m2, while in the cloudy sky the particles reach the highest value and reach to PMS=43 with solar radiation equal to Ray=240w/m2.

IV.4.Variation of temperature TS (sum of ambient, dew and WBT) as a function of according the global solar radiation depending on the type of sky :

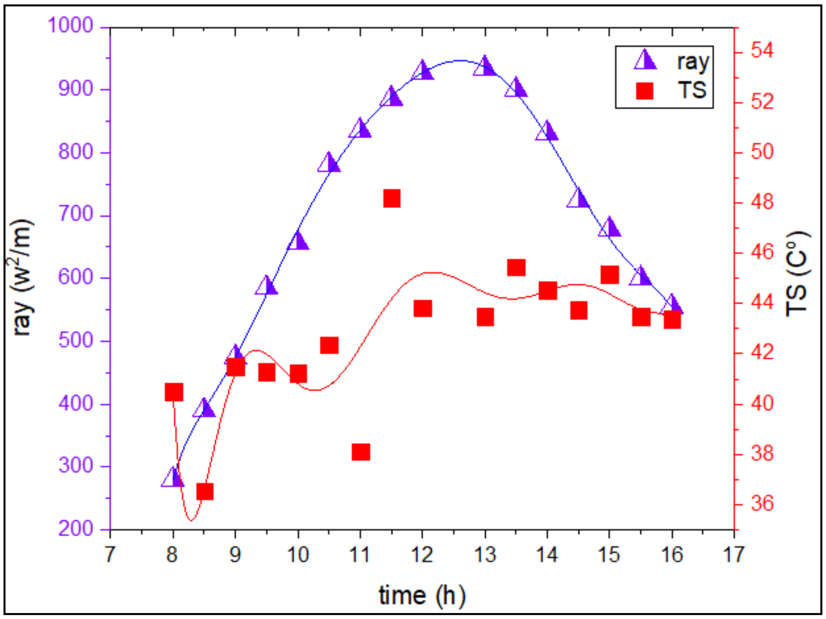

Figure.IV.7 : variations of Temperature (TS) in synchrony with changes in solar radiation over time (Clear 06-04-2021).

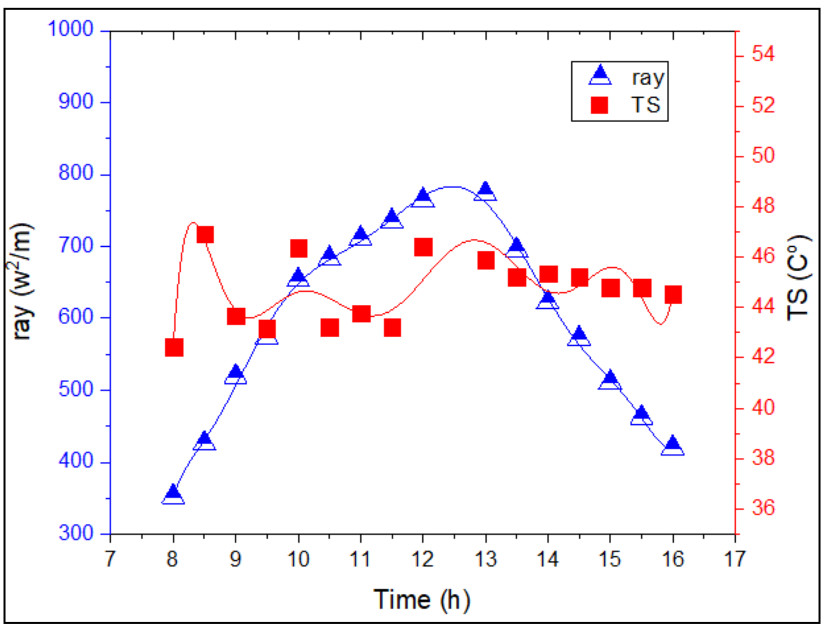

Figure.IV.8 : variations of Temperature (TS) in synchrony with changes in solar radiation over time (Partial 16-04-2021).

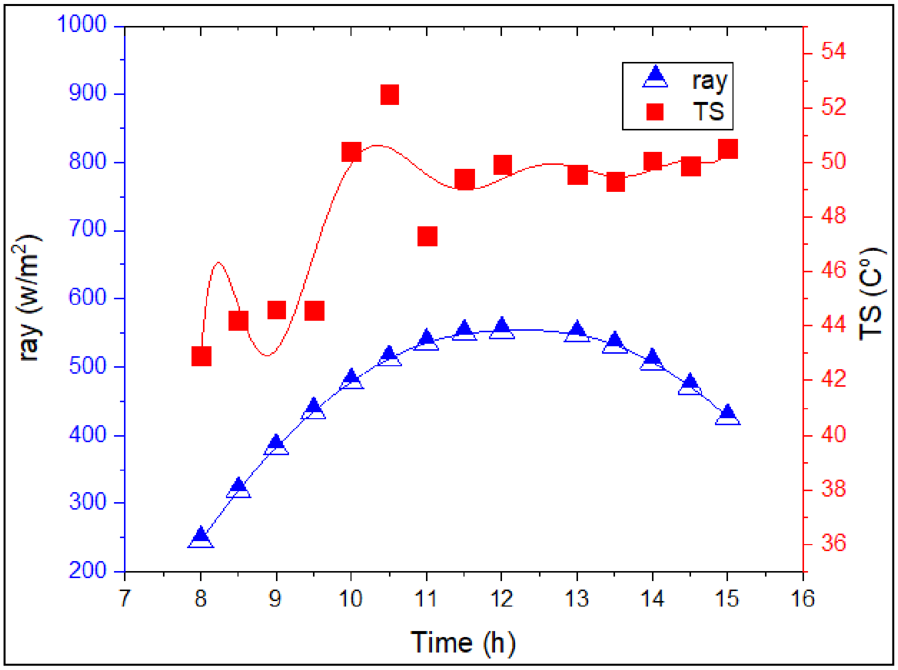

Figure.IV.9 : variations of Temperature (TS) in synchrony with changes in solar radiation over time (Cloudy 13-04-2021).

Figures 7, 8, and 9 show the variation of TS values (sum of ambient temperatures, dew and WBT) according to solar radiation according to the state of the sky.

Where we notice that the TS values curve takes the form of a sinusoidal function, where the maximum and minimum values range between 47° and 43° (Fig. 7 and 8). However, we also note that its value is high on a cloudy day, reaching a maximum value of 53° (Fig. 9). That is, it rises whenever there is a cloudy blocking the solar radiation

IV.5.Variation of particles (PM1, PM2.5 and PM10) according to the type of sky :

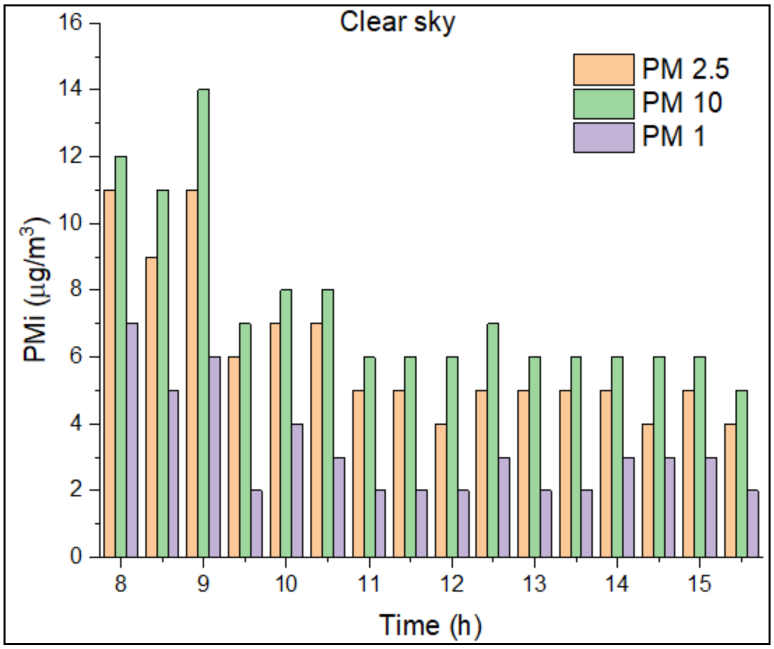

Figure.IV.10 : Bar chart showing the changes of PM2.5, PM10 and PM1 values over time (Clear 06-04-2021).

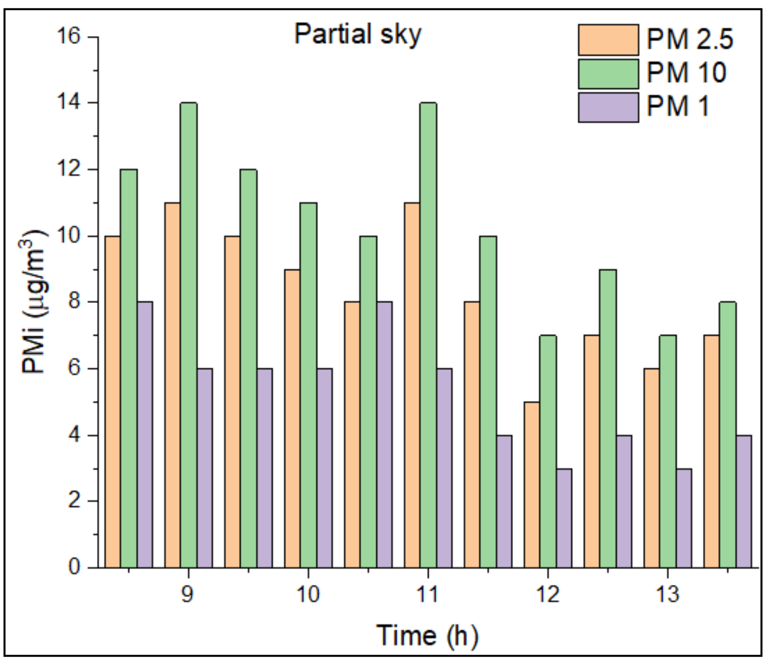

Figure.IV.11 : Bar chart showing the changes of PM2.5, PM10 and PM1 values over time (Partial 16-04-2021).

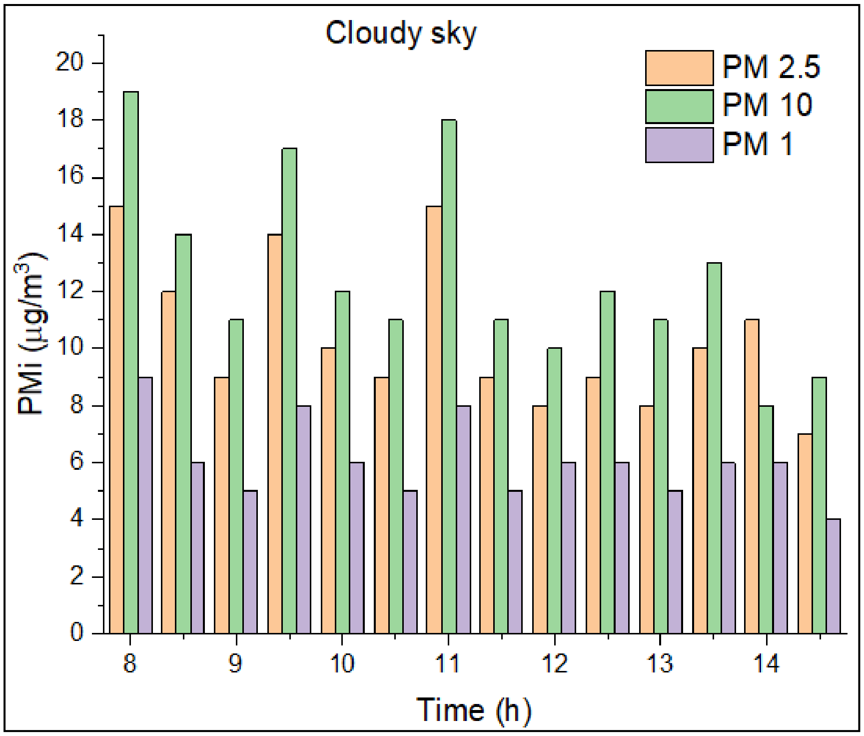

Figure.IV.12 : Bar chart showing the changes of PM2.5, PM10 and PM1 values over time (Cloudy 13-04-2021).

Figures 10, 11, and 12 show a bar chart for the values of PM2.5, PM10, and PM1 particulate matter by day type according to the state of the sky. Where we notice that the value of particles in general is at its maximum value during the sunrise period and decreases over time until noon, where it reaches its minimum value. This is due to the influence of solar radiation. Therefore, its value varies with the type of sky, whereby it is in maximum value whenever the sky is partial to cloudy.

IV.6.Variation of ambient temperature, dew temperature and WBT temperature according to the type of sky :

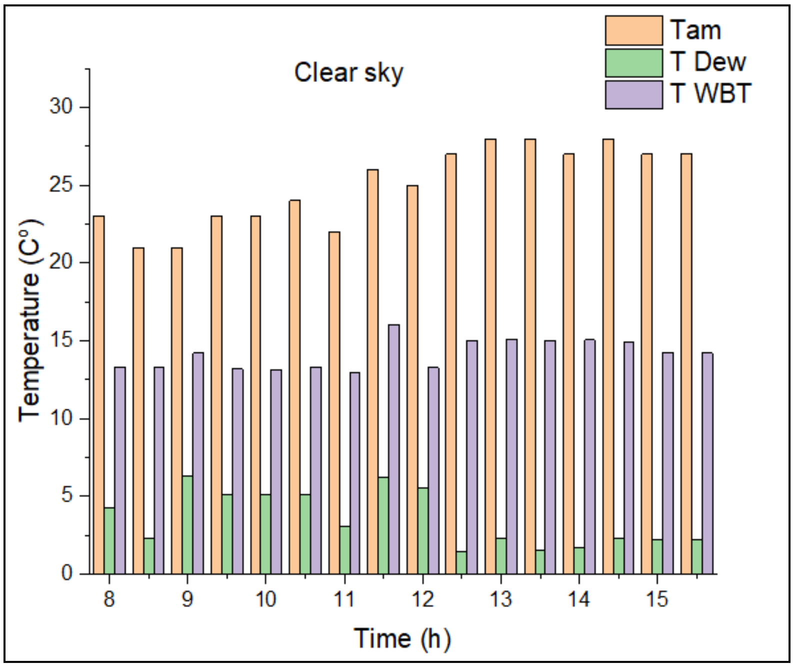

Figure.IV.13 : Bar chart showing changes in ambient temperature, dew temperature and WBT temperature over time (Clear 06-04-2021).

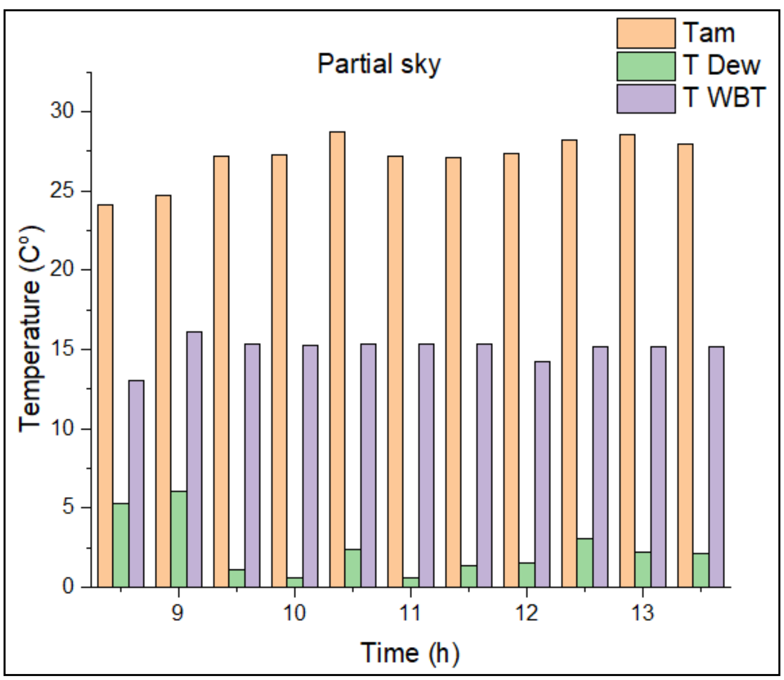

Figure.IV.14 : Bar chart showing changes in ambient temperature, dew temperature and WBT temperature over time (Partial 16-04-2021).

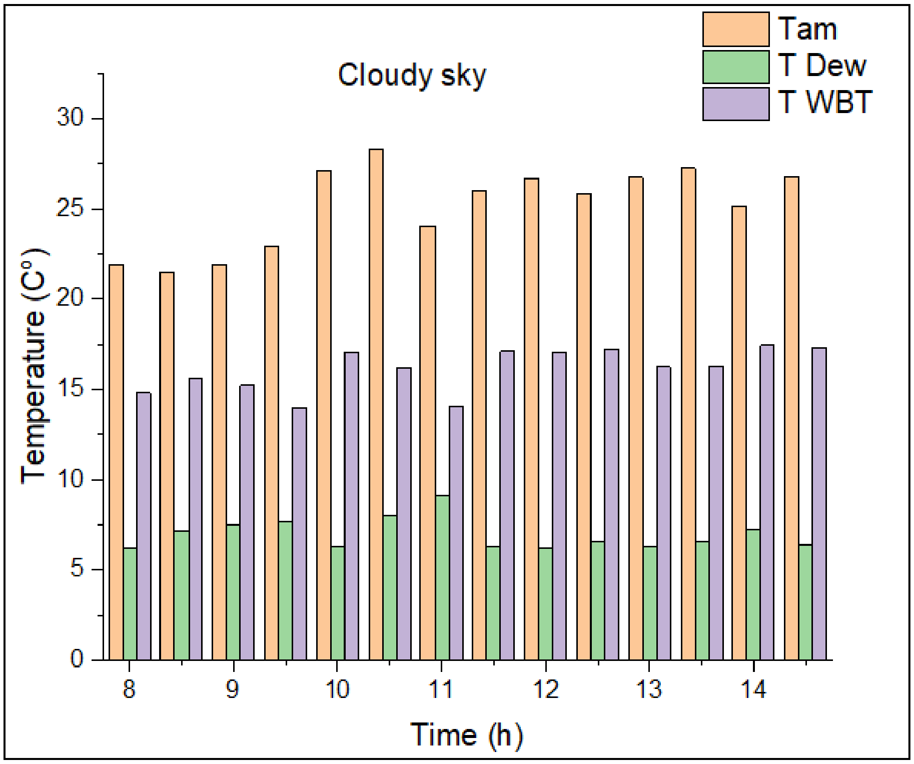

Figure.IV.15 : Bar chart showing changes in ambient temperature, dew temperature and WBT temperature over time (Cloudy 13-04-2021).

Figures 13, 14, and 15 show a bar chart for temperatures (ambient, dew, and WBT) according to the state of the sky. So that we notice in the case of a clear sky that the ambient temperature rises over time from the sunrise period until noon, due to the increase in solar radiation, in contrast to the dew and WBT temperatures, which change slightly. And when comparing the previous temperature values in the case of partial or cloudy skies, we find a clear and obvious difference in the temperature (dew and WBT), so that their value increases, especially in the case of cloudy skies.

IV.7.Variation of humidity and wind speed as a functions of time depending on the type of sky :

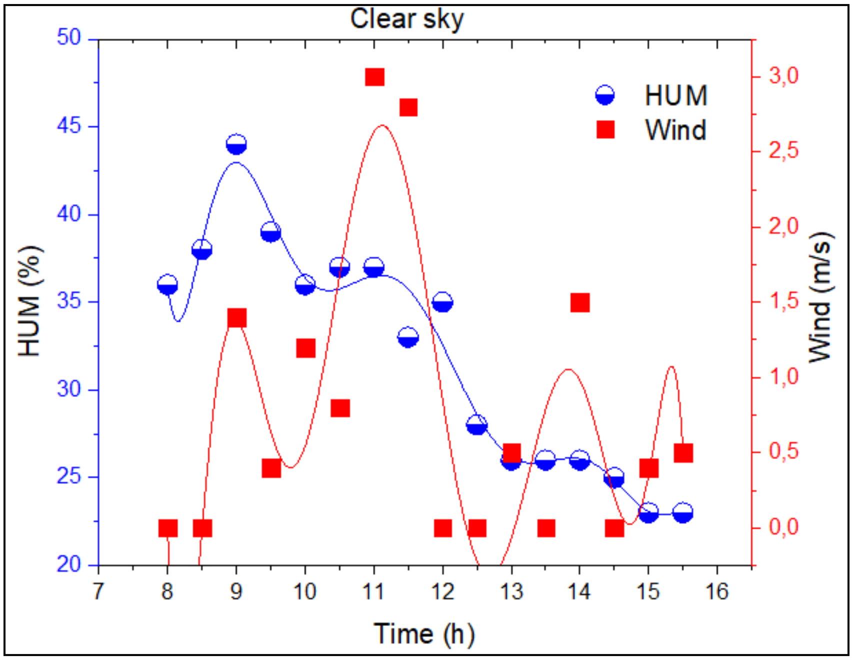

Figure.IV.16 : Variations of humidity and wind speed over time (Clear 06-04-2021).

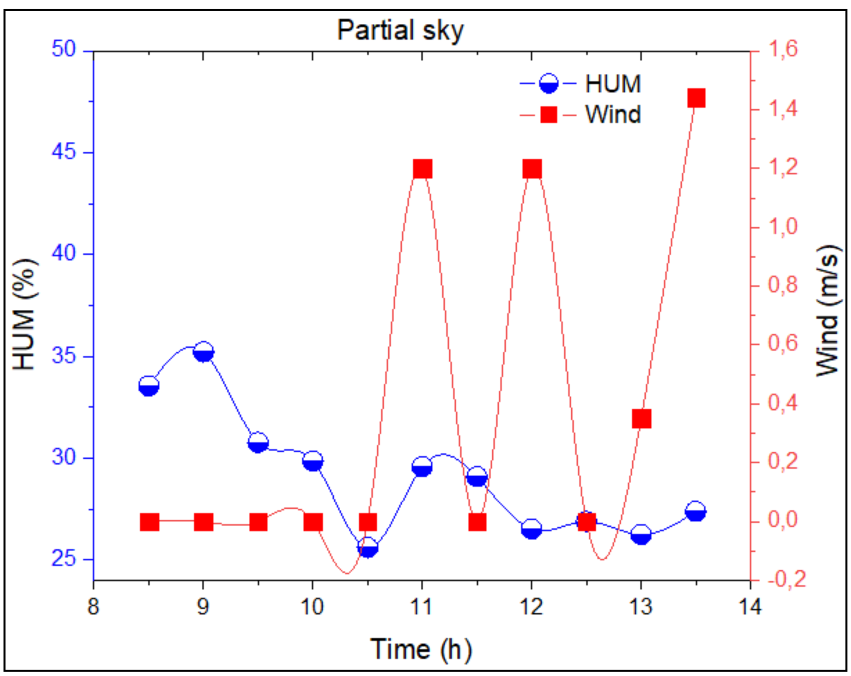

Figure.IV.17 : Variations of humidity and wind speed over time (Partial 16-04-2021).

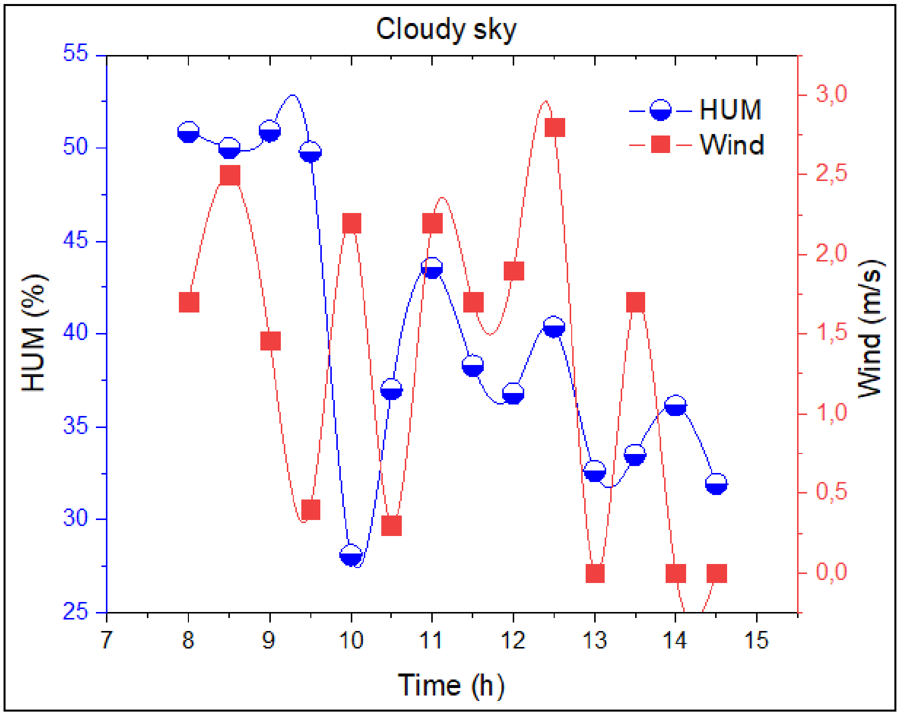

Figure.IV.18 : Variations of humidity and wind speed over time (Cloudy 13-04-2021).

Figures 16, 17 and 18 show the variation in humidity and wind values by terms of time in the Biskra location according to the type of sky. And from what we note that:

The percentage of humidity is at its maximum value in the period of sunrise, as it reaches 36% and 43% in the case of a clear and partial sky, and the maximum value in the case of a cloudy sky reaches 53%. However, we record a continuous decrease in humidity after that, and its minimum values are usually in the afternoon period.

We also note that the winds are volatile in this season, giving a side effect on other climatic factors.

IV.8.Conclusion :

After translating our data on the horizontal plane of Biskra into curves and analyzing them. We conclude that the proposed model is close to that measured during the experiment.

GENERAL CONCLUSION

GENERAL CONCLUSION:

We were able to forecast the beam and diffuse solar radiation on the horizontal area in Biskra thanks to the prediction model. This section of the prediction modeling study looked at the relationship between atmospheric factors and air quality (particulate matter) PM2.5, PM10, and PM1, and it was very important to our research and improved its accuracy in terms of atmospheric factors. We also know that pollution alters the nature of solar radiation based on atmospheric density. As a result, we wrote the prediction model treatment in a way that will assist the researcher in their work.

Finally, we can say a perfect model was obtained that estimated the global solar radiation. The aim of this article was to present a comprehensive overview of writing a mathematical model that contributes to the process of prediction regarding the sun's rays and compares them with the measured results in the experiment. In this paper, I tried to correlate the value of the constants resulting from the discovered model; simply discovering that the constants of solar radiation change according to climate condition and type of sky, and this made me link the constants with the values of pollution in the atmosphere (particulate matter).

ملخص :

يكرس عملنا دراسة تجريبية ونظرية للإشعاع الشمسي العالمي حيث هدفت هذه الدراسة إلى كتابة نموذج رياضي يساهم في توفير جميع نقاط التغيير للإشعاع الشمسي حسب التباين في زاوية الارتفاع الشمسي. اقترح هذا العمل نموذجًا كافيًا للتنبؤ بالإشعاع الشمسي على منطقة أفقية في سياقات مختلفة وإضافة عامل جودة الهواء مثل الجسيمات الدقيقة (وتسمى أيضًا تلوث الجسيمات، مصطلح يشير إلى مزيج من الجسيمات الصلبة والقطرات السائلة الموجودة في الهواء. بعض الجسيمات ، مثل الغبار والأوساخ والسخام) والتي تمثل عنصرًا جديدًا، نعلم أن تأثير التلوث على الضوء يتحقق بامتصاص الإشعاع الشمسي الذي يحجب جزءًا منه. حيث يعتمد هذا النموذج على البيانات التي تم قياسها في الفترة ربيع 2021. أختبرت نتائج قياسات العام الحالي مع النموذج الرياضي المعمول به حيث أعطت توافق في القيم مع وجود أخطاء دنيا.

الكلمات المفتاحية : الإشعاع الشمسي ، الجسيمات الدقيقة ، عامل جودة الهواء.

Abstract :

Our work is devoted to an experimental and theoretical study of global solar radiation, with the goal of developing a mathematical model that contributes to providing all the change points of solar radiation based on the angle of solar elevation variation. This study proposed a model capable of predicting solar radiation over a horizontal area in various contexts and included an air quality factor such as particulate matter (also known as particulate pollution, this term refers to a mixture of solid particles and liquid droplets, dust, dirt, and soot) that represent a new element, We know that pollution affects light by absorbing solar radiation and blocking a portion of it. Whereas this model is based on data collected in the spring of 2021. The current year's measurements were tested with the applicable mathematical model, and they provided agreement in the values with minimal errors.

Key words : Solar radiation, Particulate matter, Air quality factor.