



Département de Génie Mécanique

## MEMOIRE DE FIN D'ETUDE

En vue de l'obtention du diplôme de :

### MASTER

En Génie Mécanique

Option : **Energétique**

Présenté par :

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### Thème

**PREDICTION DE L'IRRADIATION SOLAIRE PAR MINITAB  
POUR LA REGION DE M'SILA**

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Année Universitaire : 2021 / 2022

N° d'ordre : GM/...../2022

People's Democratic Republic of Algeria  
Ministry of Higher Education and Scientific Research  
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الجمهورية الجزائرية الديمقراطية الشعبية  
وزارة التعليم العالي والبحث العلمي  
جامعة المسيلة  
كلية التكنولوجيا

Department of Mechanical Engineering

# A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE OF MASTER IN MECHANICAL ENGINEERING

**Option: Energy**

Presented by:

**MESSAOUDI Hicham & BENSAHSSA Hamza**

**Theme**

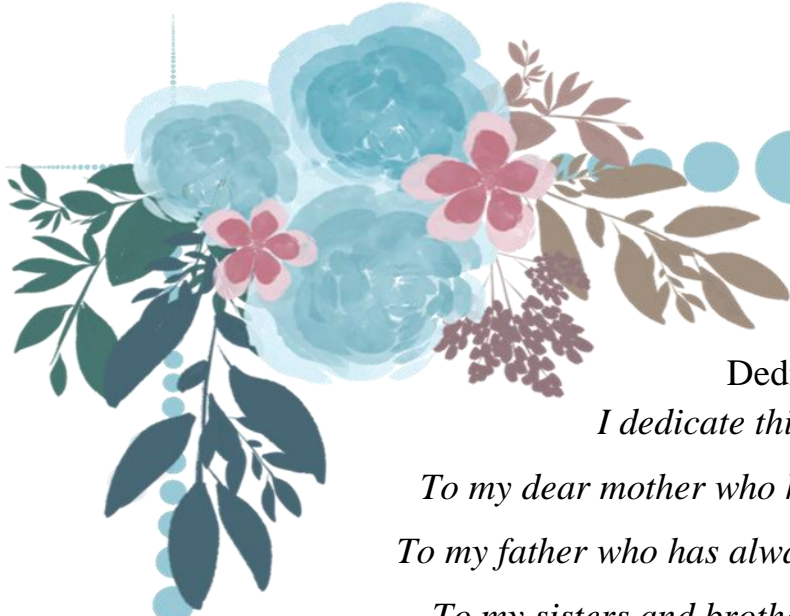
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*Academic Year : 2021 / 2022*

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Dedication

*I dedicate this modest work:*

*To my dear mother who has always been by my side*

*To my father who has always guided and supported me*

*To my sisters and brothers for their moral support*

*To my friends with whom I shared the best*

*moments of my life*

*To all the **Bensassa** family*

*To all those who have helped me near and far and who*

*Know*

***Bensassa hamza***





## ***DEDICATION***

*I dedicate this modest work:*

*To my parents whose dream was always to see me  
to succeed. Let them know that their place, in my heart  
and my thought remains and remains immense.*

*To my dear brothers and sisters for the support in the  
life and who understood me helped and supported.*

*To all the **Messaoudi** family and all those who supported me  
helped from near and far and who cannais me.*

***Messaoudi Hicham***



## *Acknowledgments*

After writing this dissertation

First of all praise to Allah the almighty the almighty who gave us the courage and the strength to carry out this modest work which is the fruit of our last five years of study and for all its benefits.

Our gratitude goes to Mr **Bakri Badis** for his supervision, his guidance, his advice and the availability he showed us to enable us to carry out this work.

We would also like to thank all the teachers in the mechanical engineering department

Finally, we would like to thank all those who have helped us directly or indirectly in the development of this work.

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**Table of acronyms**

<b><i>Acronyms</i></b>	<b><i>Meaning</i></b>
<b><i>G</i></b>	<i>Global radiation</i>
<b><i>D</i></b>	<i>Diffuse radiation</i>
<b><i>Y(h)</i></b>	<i>hourly Glarity index</i>
<b><i>Gd</i></b>	<i>Dialy Global irradiation</i>
<b><i>Dd</i></b>	<i>Diffuse component</i>
<b><i>Bd</i></b>	<i>Direct component</i>
<b><i>CD</i></b>	<i>Direct current</i>
<b><i>AC</i></b>	<i>Alternating current</i>
<b><i>PV</i></b>	<i>Photovoltaic</i>
<b><i>UPS</i></b>	<i>Systems typology chain</i>
<b><i>GPV</i></b>	<i>Photovoltaic generator</i>
<b><i>CCD</i></b>	<i>Composite centered design</i>
<b><i>DOE</i></b>	<i>Wizad's design of experiment</i>

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# *General Introduction*

# General Introduction

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## General introduction

Energy production represents a significant challenge in the years ahead. Indeed, the energy needs of industrialised companies continue to grow. As well, the countries developing countries will require more and more energy to complete their mission development. Today, a big part of the world's energy production is from fossil sources. The consumption of such sources results emissions and, consequently, an increase in pollution. The danger In addition, excess use of natural resources is decreasing reserves of this type of energy in a way that is dangerous for future generations.

Driven by a favorable context (political will, economic interest...), production decentralized development in many countries. Compliance with research and development, demonstration operations currently underway highlight a commercial development in the coming years of small means of production less than 100 kW such as photovoltaic systems, micro gas turbines associated with different storage systems such as batteries accumulators, super capacitors or inertial storage. A development of this type of production would result in a significant increase in power injection on low-voltage networks likely to cause difficulties operating.

The sun brings to the Earth a great light energy. But the problem lies in the fact that we receive energy in a form that is not necessarily that of. that this energy is usable. Therefore, we must use processes of energy conversion. For example, photovoltaic solar cells convert the sunlight's luminous energy into electric energy.

Decline in conventional sources of energy such as: Hydraulic, active solar heating, wind, geothermal, photovoltaic, biomass....

Over the past few years, solar power has increased in use worldwide, particularly in the United States. Market Transformation (concept based on industrial collaboration advocates and policymakers for greater adoption through economies of scale) plays a fundamental role in expanding the uptake of solar power. However, resources are currently finite identify optimal locations to increase the probability that industry advocates will be interested in take advantage of opportunities associated with solar energy technologies. This study aims to showcase a visual mapping tool that facilitates the transformation of the solar energy market.

## **General Introduction**

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The combination of data from various sources has created a unique process and output. The factors examined in this paper include the cost of electricity, the study of net metering policies, the cost of solar power systems, solar irradiation, the annual sun rates, annual snowfall rates, and annual precipitation rates. We looked at all the factors at the residential and commercial levels. The results classify states as most viable to least viable with respect to the combined input factors.

The findings show that states with a high market probability processing at the residential level also has a high probability of changing the market in commercial level.

# *Chapter I: Energy solar*

## **I.1 Introduction**

The sun is the first and main source of renewable energy. These rays are retained by glazed thermal sensors and are transformed to produce electrical energy or to heat water intended for sanitary use. To be able to exploit solar energy, we can use either photovoltaic solar panels or solar thermal panels.

### **I.1.1 Photovoltaic solar panels**

Are placed on the roofs of buildings or in any other place where they could be in direct contact with the sun's rays. They are composed of sensors that retain sunlight thanks to the silicon present in each of the cells of the panels and which releases electrons to create electricity. This can be transformed into alternating current using an inverter and used immediately (individual use) or stored in batteries or injected into the network.

### **I.1.2 Thermal solar panels**

As for them, they do not capture the sun's rays, but rather store the heat that comes from it and transmit it to the hot water tank to heat the water there through a closed circuit. This water can then be distributed throughout the house. This system can be used to heat rooms, swimming pools, dry crops or even cook food (thermal ovens).

## **I.2 Solar radiation**

### **1.2.1 Solar constant**

The solar energy received per unit of time at the upper limit of the atmosphere on a unit surface perpendicular to the solar rays and for an Earth-Solar distance equal to its mean value, is called the solar constant. The solar constant was estimated at 1367 W/m<sup>2</sup> by Claus Fröhlich and Christoph Wehrli of the World Radiometric Centre in Davos (Switzerland).[2]

### **1.2.2 Insolation time**

The duration of sunstroke is the number of hours in the day, between sunrise and sunset, when the sun is clearly visible. The survey is done by means of the Campbell-Stokes heliograph in which a crystal sphere concentrates the sun's rays on a paper that it burns while moving. Thus, only the moments when the sun is clearly visible are recorded; we are then talking about the duration of actual or effective insolation and depends on the fact that the sunrise is visible from the point of observation or hidden by the clouds.

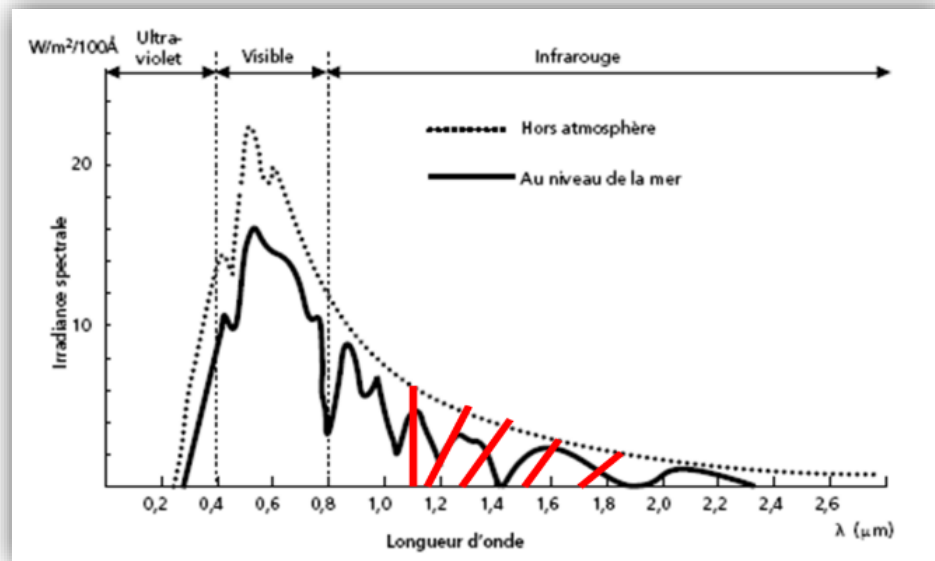
In the absence of the heliograph, it is possible from the calculation of the relative astronomical motion of the sun and the earth to evaluate the theoretical duration of the day; that is, the one that would be if the clouds did not hide the sun. This duration is calculated according to the latitude of the site and the apparent declination that itself depends on the period of the year considered. [1]

### 1.2.3 Spectral distribution of solar radiation

Solar radiation consists of photons with wavelengths ranging from ultraviolet (0.2  $\mu\text{m}$ ) to far infrared (2.5  $\mu\text{m}$ ).

The energy associated with this solar radiation breaks down approximately:

- 9% in the ultraviolet band (<0.4  $\mu\text{m}$ ),
- 47% in the visible band (0.4 to 0.8  $\mu\text{m}$ ),
- 44% in infrared band (>0.8  $\mu\text{m}$ ).



**Figure I.1:** Spectral analysis of solar radiation. [2]

Solar collectors must therefore be compatible with these wavelengths in order to trap photons and restore them in the form of heat or electrons.

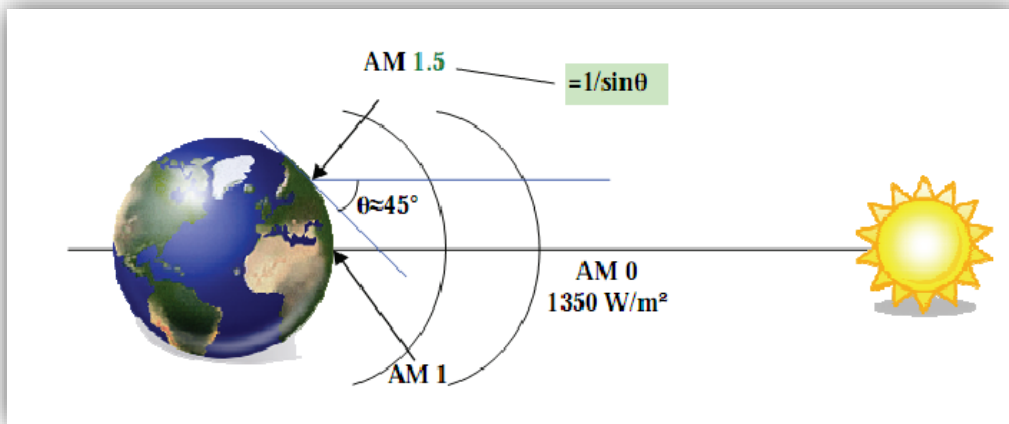
For the solar radiation to produce an electric current in a given material, thus acting as a sensor, the photons must first be absorbed by one or more materials sensitive to the wavelength of the photons, which are then collected to constitute a global electric current. [3]

**1.2.5 Air mass**

Air Mass, the ratio between the atmospheric thickness crossed by direct radiation to reach the ground and the thickness crossed over the site.

Using points O, A and M and angle h, the length of the path of the sun through the atmosphere:

$$OM = \frac{OA}{\sin h}$$



**Figure I. 2:** Standards for measuring the spectrum of light energy emitted by the sun, concept of the AM convention. [5]

It is important to understand the two aspects covered by the concept of mass air count. On the one hand, it characterizes the power carried by solar radiation (1367/m2 for AM0, 833 W/m2 for AM1, 5) and on the other hand, it is used to define a reference spectrum to calibrate the standard cells intended to qualify the performance of photovoltaic devices. Thus the standard cell qualification conditions are an AM1, 5, 1000W/m2 incident power and a temperature of 25°C.

Unless otherwise specified, it is for such conditions that the performance and specifications of a given photovoltaic device must be provided.

### 1.2.5 Nomenclature of the various radiation measuring instruments

#### ➤ Pyrradiomete

Instrument for measuring total radiation reaching a surface from a  $2\pi$  steradian solid angle; it is mainly used for measuring total descending radiation, the sum of solar and atmospheric radiation directed towards the ground.

#### ➤ Heliograph

Instrument for measuring and recording the duration of insolation.

#### ➤ Pyrheliometer

Instrument measuring direct solar radiation  $I$ , the apparatus is adjustable so that its receiving surface is normal to the solar rays.

#### ➤ Pyranometer

Instrument for measuring global radiation  $G$  reaching a flat surface from a solid  $2\pi$  steradian angle; when equipped with a sun visor, it can measure diffuse radiation  $D$ .

#### ➤ Differential pyrradiometer or bilanmeter

Measures the balance of total radiation, the difference between total descending radiation and total ascending radiation (solar and atmospheric radiation returned to space).

### 1.2.6 Composition of solar radiation

Following the attenuation of the solar radiation by the various atmospheric phenomena, the solar radiation on a surface on the ground is composed as follows:

#### ➤ Direct radiation

This is the fraction of solar radiation that comes directly to the ground, whose path is “linear” (there are, in fact, slight deviations) and unique at a given moment. If  $I$  is direct radiation. [12]

In the case of a horizontal plane the radiation is written:

$$I_h = I \times \sin h$$

With:  $h$  height of the sun.

➤ **Diffuse radiation**

Diffuse radiation is radiation from the entire celestial vault. This radiation is due to the absorption and diffusion of part of the solar radiation by the atmosphere and its reflection by the clouds. Thus, in a serene sky, it constitutes 20% of the total energy. In an overcast sky, it corresponds to the totality of the energy received on the ground. [2]

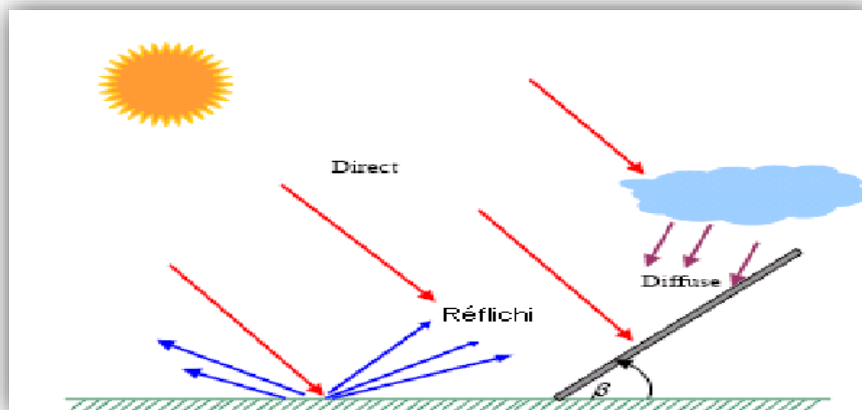
➤ **Reflected radiation**

Reflected solar radiation is radiation that is reflected from the ground or objects on its surface. This radiation depends on the albedo of the soil and can be important when the soil is particularly reflective (water, snow).

➤ **Global radiation**

- A horizontal surface:

It is the whole of the solar radiation that reaches a horizontal surface on the Earth's globe. It therefore includes the vertical component of direct solar radiation and diffuse solar radiation. [4]



**Figure I.3:** The three components of global solar radiation on an inclined plane. [2]

- An inclined surface:

Global radiation on an inclined surface is the sum of radiation: Direct, Diffuse and Reflected.

### I.3 Light Index

Hourly Light Index,  $K_t$ , which is the ratio of total ground irradiance  $G$  to extraterrestrial irradiance on a horizontal plane (see page 4, Index Table).

The conversion of irradiance to a light index,  $K_t$ , allows to reproduce the seasonal variations [22] and also allows to recover the irradiance on the ground because the extraterrestrial irradiance is a known quantity at all times and in all places.

#### I.3.1 The TAG model (Time-Dependent Autoregressive Gaussian)

This model generates synthetic hourly irradiance data using a stationary autoregressive model. As the only entry, it uses the average daily clarity index, noted  $K_{tm}$ .

$$Y(h) = K_{tm} y(h-1) + r_{TAG}(h)$$

$Y(h)$  is the hourly Clarity Index,  $K_t$ , normalized for a quasi-stationary time series. The resulting model makes it possible to model solar radiation at any place on the planet.

#### I.3.2 The model of Polo

Polo's model makes it possible to model a time series from the average daily hourly clarity index,  $K_{tm}$ , to which is added a random term:  $A(h)$ . Sign ( $s$ ), whose law of probability we will seek to identify.

$$K_t(h) = K_{tm} + A(h) \cdot \text{Sign}(s)$$

With:

- $K_{tm}$  is the daily average value of the clarity index.
- $A(h)$  is the random amplitude of the fluctuation of the clarity index,  $K_{tm}$ , for the hour  $h$ .
- is the achievement of a normal Gaussian distribution centered on zero mean and unit standard deviation.

## I.4 Solar irradiation

### I.4.1 Estimation of hourly illumination on an inclined surface

For the calculation and the equations below, solar irradiation during an hour is assumed to coincide digitally with solar illumination in the middle of that hour.

The overall incident illumination on an inclined surface consists of three components which are:

- Direct lighting.
- The diffuse illumination
- The illumination reflected from the ground.

Then and for an angle of inclination  $\beta$ , the global illuminance  $G(\beta)$  is given by the sum of the direct illuminance  $B(\beta)$ , the diffuse illuminance  $D(\beta)$  and the reflected illuminance  $R(\beta)$ :

$$G(\beta) = B(\beta) + D(\beta) + R(\beta)$$

### I.4.2 Irradiation on a horizontal plane

Estimation of the direct and diffuse component of horizontal irradiation from total daily irradiation.

The daily global irradiation  $G_d(0)$  on a horizontal surface can be divided into a diffuse component  $D_d(0)$  and a direct component  $B_d(0)$ .

The distribution of the solar scatter is irregular due to the variation of the climate. Nevertheless, the average characteristic of the diffusion is entirely regular and can be correlated with the light index of the atmosphere.

The availability of horizontal global hourly irradiation can be a means of sizing or determining the performance of a photovoltaic system. However, for the mathematical simulation of the operation of a photovoltaic system, the hourly values of the diffuse and direct component are necessary. Indeed, the diffuse and direct hourly component is essential to calculate the total hourly irradiation on the inclined surface of a photovoltaic generator. The models presented below use the correlation between the Hourly Atmospheric Light Index,  $M_t$  and the Hourly Diffuse Fraction,  $M_d$ . The hourly diffuse fraction  $M_d$  is defined by the following relationship:

$$M_d = \frac{Dh(0)}{Gh(0)}$$

And the hourly light index of the atmosphere  $M_t$ , such as:

$$M_t = \frac{Gh(0)}{G_{eh}(0)}$$

With:

$G_{eh}(0)$ : Global extraterrestrial irradiation time [Wh/m<sup>2</sup>].

$G_h(0)$ : Hourly horizontal global irradiation [Wh/m<sup>2</sup>].

$D_h(0)$ : Hourly horizontal diffuse irradiation [Wh/m<sup>2</sup>].

### I.5 Insolation time

Insolation, also known as sunshine, is the measurement of the solar radiation received by a surface over a given period of time, expressed in megajoules per square metre, MJ/m<sup>2</sup> (as recommended by the World Meteorological Organization) or in watt-hours per square metre, Wh/m<sup>2</sup> (mainly by the solar industry)[23]. This measurement divided by the recording time provides the power density measurement, called energy/irradiance illumination, expressed in watts per square meter (W/m<sup>2</sup>).

On the other hand, insolation occurs if the direct illumination received by a surface is greater than or equal to 120 watts per square metre [24]. In one place, this is subject to many parameters: geographical coordinates (sunrise and sunset hours), topographic (shading of distant terrain), meteorological (clouds, fog), natural (vegetation, wildlife) or human (buildings, passage of vehicles...) [25]. The possible insolation fraction is thus the ratio of the effective duration of insolation to the possible geographical or topographical duration of insolation in a place or the ratio of the effective duration of insolation to the possible astronomical duration of insolation.

### I.6 Geographic coordinates

Every point in the Earth's sphere is marked by its geographical coordinates.

The latitude ( $\lambda$ ) of a place corresponds to the angle with the equatorial plane, which makes the ray joining the center of the earth to this place. It varies between (0° and + 90°) at the North Pole and (0° and 90°) at the South Pole [6].

The longitude ( $\phi$ ) of a place corresponds to the angle made by the meridian plane passing because place with a meridian plane retained as origin. The original meridian was chosen as the plan through the Greenwich Observatory. By convention the meridians located to the east of this meridian are assigned the sign (+) and the sign (-) the meridians located to the west [7].

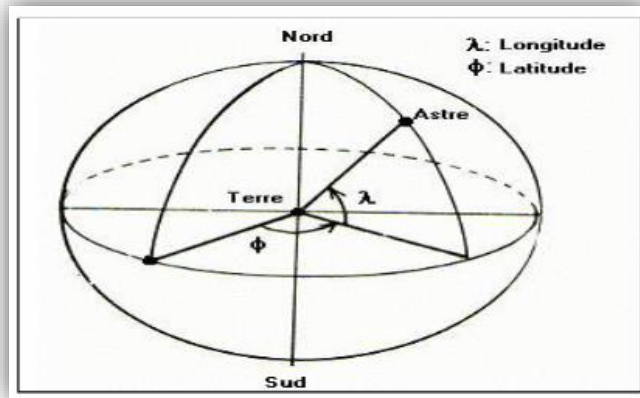


Figure I.4: Geographic coordinates.

### I.7 The position of the sun

For an observer on the Earth's surface, the sun describes an apparent trajectory that depends on the latitude and longitude of its location, see Figure 1.5.

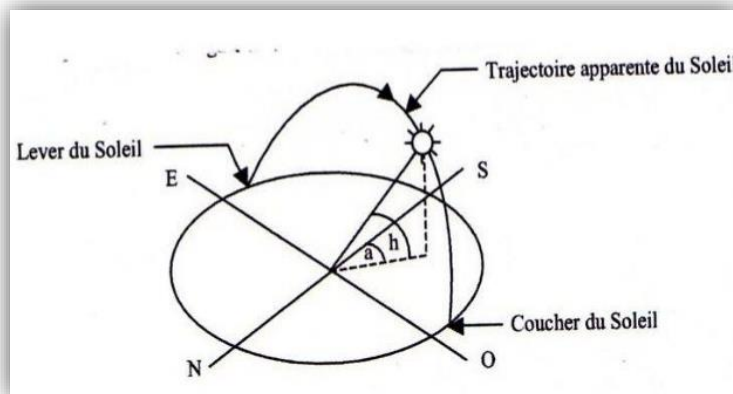


Figure I. 1: Locating the position of the sun [8].

For a given place, the position of the sun is located at every moment of the day and year by two different coordinate systems. [2]

- Relative to the equatorial plane of the earth (equatorial landmark). “Solar declination ( $\delta$ )/ Hourly angle of the sun  $H$ ”.
- Relative to the horizontal plane of the site (horizontal landmark). “Azimuth ( $a$ )/ height ( $h$ )”.

## I.8 Thermal solar energy

Solar thermal energy is a form of solar energy. It refers to the use of the thermal energy of solar radiation to heat a fluid (liquid or gas).

The energy received by the fluid can then be used directly (domestic hot water, heating, etc.) or indirectly (production of water vapor to drive generators and thus obtain electrical energy, production of cold, etc.).

The solar collector is the instrument used to transform solar radiation into heat.

The basic physical principles on which this energy production is based include absorption and thermal conduction. In the particular case of concentrated systems (thermodynamic solar power plant, solar furnace, etc.), reflection also plays an important role. [9]

Interest of solar thermal:

### I.8.1 Solar thermal energy capture has several advantages

- Heating: Heating sensors are relatively simple, rustic and durable.
- Electricity:
  - o traditionally used steam turbine systems are based on perfectly safe and proven components.
  - o In very sunny areas, profitability is proven. [10]
  - o Strong development potential in several developing countries, with a priori moderate impact on the environment. [11]
- Water purification: the solar distiller can provide sufficient drinking water in tropical and subtropical areas.

### I.8.2 Energy storage

The energy is stored at the generator inlet as heat ( $560^{\circ}\text{C}$ ) in molten salt tanks, allowing the plant to continue to operate in the absence of the Sun. This technique is used in the Solar

Three power plant built in Almeria, Spain, but this time the Sun-free range is changed to 16 hours, which allows it to operate night and day during periods of strong sunlight. This type of installation is intended for areas with high sunlight such as California or southern Spain. [12]

### **I.9 Direct heat production for the habitat**

More than three-quarters of the energy consumed in the habitat is used for the production of heat (heating, domestic hot water, cooking). Half of household electricity (50.4%) is used for this purpose.

The efficiency of these plants and then the delivery of electricity is around 30%. Let's take a closer look: the heat puts a Fluid under pressure, the pressure makes it possible to turn a turbine, the turbine supplies a generator, the electricity is routed and then transformed into heat. Energetically speaking, with three transformations and transport, it is not interesting to heat with electricity.

But this production of solar heat is intermittent and requires other energy (electrical supplement, gas or wood). At night, the solar panel can no longer benefit from the sunlight, so it can no longer directly meet the heat needs of the habitat. Solar systems therefore develop a short-term storage strategy (2 to 5 days). The presence of a storage tank dimensioned according to the needs of the dwelling is therefore necessary to be able to dispose at any time of heated water during the day.

### **I.10 Solar power stations**

Energy production systems allow solar energy to be concentrated at a precise point which can then reach a considerable temperature. Electrical production is then possible via, among other things, steam turbines or other combustion engines.

For this purpose, parabolic collectors heat a heat transfer fluid (water, molten salts, synthetic oils, or directly steam) circulating in pipes placed at the level of their geometric focus.

The irregularity specific to solar energy can be circumvented, either by storing the heat (with a reservoir of hot fluid), or by hybridizing the solar concentrators with a conventional thermal power plant (boiler and solar heat feeding the same steam turbine).

A Sterling motor connected to a generator can use either a parabolic concentrator system or flat heat transfer sensors, depending on its thermal gradient of operation.

## I.11 Solar photovoltaic energy

A photovoltaic installation consists of solar modules, themselves made of photovoltaic cells, based on silicon most often.

These generators convert solar energy directly into electricity (direct current). The power is expressed in Watt-peak (Wc), the unit that defines the electrical power available at the terminals of the generator in the optimal sunlight conditions.

One or more inverters convert the direct current produced into alternating current at 50Hz and 220 V. Depending on the choice chosen, all or part of the production is injected on the public network, and the rest is consumed by the producer. Where photovoltaic production is insufficient, the grid provides the necessary electricity, see Figure 1.6.

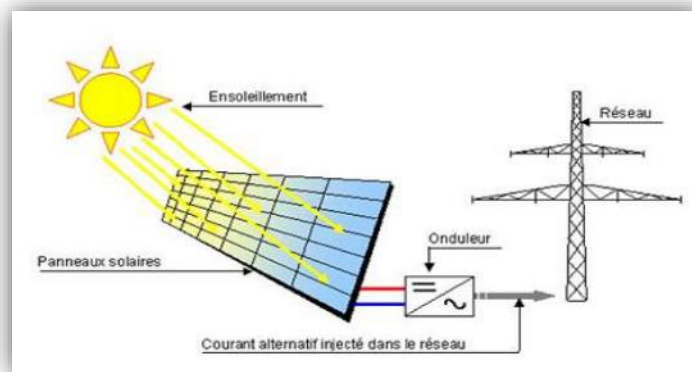
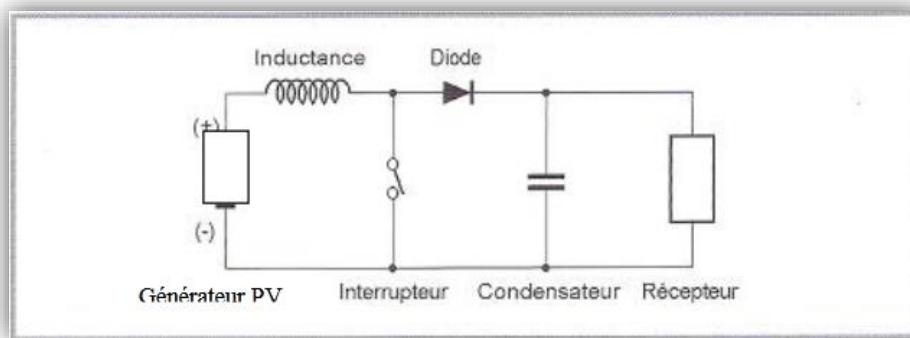


Figure I. 5: PV system connected to the network. [13]

## I.12 Photovoltaic conversion

There are converters that are devices used to transform the DC voltage provided by the panels or batteries to adapt it to receivers operating either at a different DC voltage, at an AC voltage. [14]

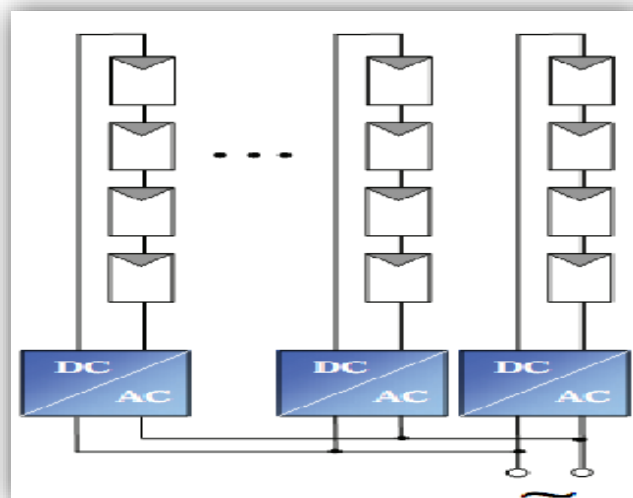
- Continuous converters (DC/DC): This type of component is used to transform the battery voltage into a different DC voltage to power a special device such as a mobile phone charger, a radio, a laptop...



**Figure I.6:** DC/DC up converter example. [14]

- UPS for network coupling

The most valuable photovoltaic applications at present are PV installations designed to power the public electricity grid.



**Figure I. 7:** Systems typology Chain UPS [15]

- DC/AC inverters

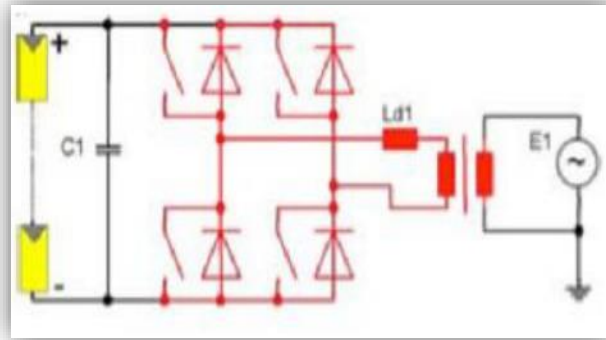


Figure I. 8: Single circuit using a transistor bridge. [15]

### I.13 Photovoltaic Cells

We call solar cell a converter that allows the conversion of solar energy into electrical energy. The solar cell or photocell is the basic element of a photovoltaic generator [16].

#### I.13.1 Operation of photovoltaic cells

Made from two layers of silicon, one P-doped (boron-doped) and the other N-doped (phosphorus-doped) thus creating a PN junction with a potential barrier. When the cell is exposed to solar radiation, the energy photons entering the solar cell transmit their energy to the junction atoms. [17]

If this energy is high enough, it can transfer the electrons from the valence band to the conduction band of the semiconductor material and thus create electron-hole pairs. The electrons (negative charges) and the holes (positive charges) are then kept separated by an electric field which constitutes a barrier of potential. If a charge is placed at the terminals of the cell, the electrons of the N zone join the holes of the P zone via the outer connection, giving rise to a potential difference and an electrical current that circulates. [17]

### I.14 Cells association

#### I.14.1 Serialization

A combination of  $N_s$  cells in series increases the voltage of the photovoltaic generator (GPV). The cells are then crossed by the same current and the characteristic resulting from

the serial grouping is obtained by the addition of the elementary voltages of each cell. The equation summarizes the electrical characteristics of a series of n cells [26].

$$V_{CO} = N_s \cdot V_{CO}$$

With:

$V_{CO}$ : The voltage of the open circuit.

The series combination thus increases the voltage of the whole and thus increases the power of the whole.

### I.14.2 Paralleling

On the other hand, a parallel association of  $N_p$  cells is possible and allows to increase the output current of the generator thus created. In a group of identical cells connected in parallel, the cells are subjected to the same voltage and the characteristic resulting from the group is obtained by the addition of currents. The equation in turn summarizes the electrical characteristics of a parallel association of  $N_p$  cells.

$$I_{CC} = N_p \cdot I_{CC}$$

With:

$I_{CC}$ : The short circuit current. [27]

## I.15 Solar energy in Algeria

The economic sector of energy in Algeria occupies a predominant place in Algeria's economy: hydrocarbons alone account for 30% of GDP, 60% of budget revenues and 95% of export revenues. In 2015, Algeria is the 18th largest oil producer, the 10th largest producer of natural gas and the 6th largest exporter of natural gas in the world.

The production and consumption of energy, including in the electricity sector, is over 99% derived from hydrocarbons. However, the Algerian government is beginning to consider green solutions by investing in renewable energy. According to the 2012 Algerian Renewable Energy Development and Energy Efficiency Program (PENREE), Algeria aims for an installed renewable capacity of 22,000 MW by 2030. But three years after this plan, the achievements are long overdue: the annual report of the Global Wind

Energy Council on wind energy does not even mention Algeria, and that of the International Solar Energy Agency only announces that Algeria has installed 300 MW. On 9 December 2011, the Algerian Electricity and Gas Company (Sonelgaz and Desertec

Industry ), Initiative signed a cooperation agreement in Brussels aimed at strengthening exchanges of technical expertise, the examination of ways and means for access to external markets and the common promotion of energy development renewable in Algeria and internationally[18]. In order for Algeria to preserve current energy reserves (oil and gas), the country has opted for the development and exploitation of solar energy. In order to implement its solar power exploitation program, Algeria commissioned Sonelgaz to build the Hassi R'Mel mixed power plant, commissioned in 2011 in Tilghemt in the wilaya of Laghouat in the south of the country, with a capacity of 150 megawatts (30 MW thermodynamic solar + 120 MW gas)[19]. New Energy Algeria (NEA) is responsible for the new and renewable energy sector [20]. Algeria's first private solar panel manufacturing plant is operational from March 2012 with a national integration rate of 90% [21]. Photovoltaic solar energy is a clean source of energy.

Algeria's energy strategy is based on accelerating the development of solar energy. The government plans to launch several solar photovoltaic projects with a total capacity of around 800 MWP by 2020. Other projects with a capacity of 200 MWP per year are expected to be carried out over the period 2021-2030.

## I.16 Solar potential

The Earth receives 174 peta watts ( $10^{15}$  watts, or PW) of solar radiation entering the upper atmosphere (solar irradiation), or about  $340 \text{ W/m}^2$  at its surface (average incident solar radiation). About 30% is reflected back into space, while the rest is absorbed by clouds, oceans and land mass. The spectrum of solar radiation on the Earth's surface is mainly divided between the visible spectrum and the near infrared, as well as a small part located in the near ultraviolet. The majority of the world's population lives in areas where the average level of solar irradiation (including night) is between  $150$  and  $300 \text{ W/m}^2$ , which represents 3,5 to 7,0 kWh/m<sup>2</sup> per day. In France, the total energy received in a year is  $1,100 \text{ kWh/m}^2$ , while at the equator, it is  $2,200 \text{ kWh/m}^2$ . [28]

The total solar energy absorbed each year by the Earth's atmosphere, oceans and land masses is approximately 3,850 zeta joules ( $10^{21}$  joules, or ZJ). In 2002, this represents more energy in an hour than human consumption in a year. For comparison, the wind contains 2.2 ZJ and photosynthesis captures about 3 ZJ per year in the biomasse. The amount of solar energy reaching the planet's surface is so large that in one year it represents about twice the amount of energy obtained from Earth's non-renewable resources — coal, Oil, Natural Gas and Uranium Combined—historically mined by humans. The total energy used by man in 2005 was 0.5 ZJ, of which 0.06 ZJ was in the form of electricity. [29]

## I.17 Conclusion

Solar energy is increasingly used. However, do we really need to develop this energy? Its strong point is that it does not pollute but let's not forget its main problem: it is only available during the day. Even if some systems can produce a few hours after sunset, electrical storage is still too inefficient for the sun to be used as the sole source of electricity. In addition, solar energy can never really be used for transport (at least in the near future), which is the main cause of air pollution. It should be noted that passive systems are of little interest because in addition to having always existed, they do not require massive investments: only a small additional cost is necessary for construction. However, their efficiency is lower than that of active systems.

# *Chapter II: Experimental designs*

## II.1 Introduction

The theory of "experimental designs" aims to study the selection of data in situations of controlled experiments. In marketing, the interest of experiments in the field or in the laboratory is particularly justified during operations to launch or repackage consumer goods and services [19]. In economics there is currently a veritable burgeoning of experiments aimed at studying the reactions of American households subjected to experimental transfer incomes (see the May 1971 issue of the American Economic Review); other experiments aimed at determining appropriate tax rates and tolls to combat pollution or traffic jams in congested urban centers are currently under study. The non-negligible cost of such experiments necessitates serious thought and planning at the pre-experimental level.

However, for reasons related to the difficulties of mathematical programming, the work of Elfving [1952] and Kiefer [1959] on optimum experimental designs, remained ignored for a long time. It was necessary to wait for the complementary works of Conlisk and Watts [1969] to see this technique used in the planning of experiments in economics. [1]

## II.2 Generality on the MINITAB

For example, you work for an offset printing company and some customers have complained about pages coming loose from book bindings. You suspect several factors: glue temperature, type of paper and cooling time. You want to determine the factors, or combinations of factors, that significantly influence the effectiveness of your company's binding technique. When you create a design of experiments in Minitab, the program automatically randomizes the order of runs in the design and displays it in the worksheet. The ordered sequence of combinations of factors is called trial order.

MINITAB is a statistical software originally developed by the Department of Statistics at the University of Pennsylvania (U.S.A.). It is particularly well suited to the statistical analysis of small, well-structured data tables: descriptive statistics, analysis of variance, methods relating to correlation and simple and multiple regression, time series, tests of independence,

nonparametric methods, principal component analysis, discriminant analysis, statistical quality control, experimental designs, etc.[2]

The WINDOWS graphical interface gives this software greater flexibility of use and better presentation of results. The use of dialog boxes, via the menu bar, avoids the user having to know the syntax.

### II.2.1 MINITAB programs

MINITAB programs, also called macros, group together a series of procedures that can be executed by a simple call via the SESSION window.

The interest of these macros is especially marked when the user has to repeat a large number of times a certain number of operations. The time spent on programming is then quickly compensated by the time saved during execution.

There are three types of programs: global macros, local macros and executable programs called “Execs”. These are the “ancestors” of macros. Less flexible and less powerful, they will not be discussed in this note. Global macros are easier to program than local macros because they work directly and only with worksheet variables (for example: C15, K10, K22, M11, M34, ...). More complex at the start, local macros are however more flexible to use thanks to the use of so-called local variables which only exist during the execution of the macro.[3]

### II.3 General definitions and ratings

Consider the non-random part of a behavior equation  $E(w) = f(z_1, \dots, z_k)$  where  $E(\cdot)$  represents the mathematical expectation operator and where some of the explanatory variables  $z_1, \dots, z_k$  are under the experimenter control. These variables are called factors or controllable variables (“design variables”), the explained variable  $w$  is called response variable and the function  $f$  the response function.

Consider an experiment on a sample of  $N$  experimental units in order to estimate  $f$  in the context of linear regression models:

$$Y_i = X_i b + e_i \quad i = 1, \dots, N$$

where the regressende  $Y_i$  is usually the response of the  $i^{\text{th}}$  unit, ( $Y_i = w_i$  for a response function with an additive error term), or else its logarithm ( $y_i = \log w_i$  for response functions with an error term of multiplicative error),  $X_i$  is the  $(1 \times K)$  row vector of regressors (transformed of the explanatory variables  $z_1, \dots, z_k$ ),  $b$  is the  $(K \times 1)$  vector of parameters to be estimated, and  $e_i$  is an error term random and unobservable. In matrix notation (1) is written:

$$\begin{array}{ccccccc} \mathbf{y} & = & \mathbf{X} & \mathbf{b} & + & \mathbf{e} & \\ (\mathbf{N} \times \mathbf{1}) & & (\mathbf{N} \times \mathbf{K}) & (\mathbf{K} \times \mathbf{1}) & & (\mathbf{N} \times \mathbf{1}) & \end{array}$$

Where the dimensions of the matrices are given in parentheses. Adding the 4 hypotheses, (i)  $X$  is of rank equal to  $K$ , (ii)  $X$  is non-random, (iii)  $E(e) = 0$ , and (iv)  $V(e) = \alpha^2 I$  (where  $F(\cdot)$  represents the variance-covariance matrix), we define the classical linear regression model, in which the best linear and unbiased estimator of  $b$  is  $\hat{b} = (X'X)^{-1} (X'y)$  with, for variance matrices- covariances:

$$V(\hat{b}) = \alpha^2 (X'X)^{-1} = \alpha^2 (\sum_i X_i X_i')^{-1}$$

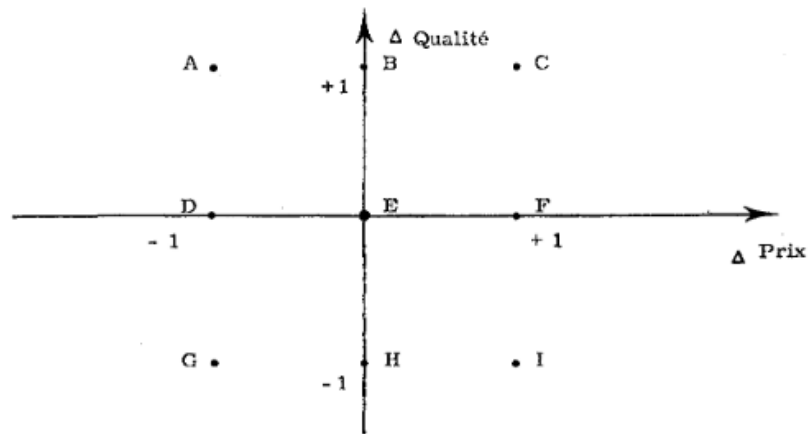
The experimental planning problem is to determine the levels or treatments of the controllable factors to allocate to each of the non-observations.

In other words we have to choose  $N$  controlled points (“design points”) in the feasible region ( $Z_p$ ) of the space of controlled variables. Given a functional form of the preceding linear regression model, this amounts to associating with each “controlled point” retained a line vector of regressors  $X_i$ .

This experiment involves  $N = 14$  supermarkets, 2 controllable variables (changes in price and quality of bananas) with three treatments each  $(-1, 0, +1)$  and a linear response function with interaction term (i.e.  $K = 4$  regressors). [19]

$$y_i = b_0 + b_1 \Delta P_i + b_2 \Delta Q_i + b_3 \Delta P_i \Delta Q_i + e_i \quad i = 1, \dots, 14$$

Where the response variable  $y_t$  represents the average weekly sale of bananas per customer of the  $i^{\text{th}}$  supermarket. The feasible region ( $Z_p$ ) is made up of the following nine points:



if for example the  $i^{\text{th}}$  line of regressors  $X_i$  is associated with the controllable point  $f$ , we then have  $X_i = (1, +1, -1, -1)$ . If it is G, then we have  $X_i = (1, -1, -1, +1)$ .

#### II.4 Methodology of the experimental plans

Design of experiments is essentially a strategy for planning experiments in order to obtain sound and adequate conclusions in an efficient and economical manner. The design of experiments methodology is based on the fact that a suitably organized experiment will frequently lead to a relatively simple statistical analysis and interpretation of the results [4]. Many studies consist in finding, if it exists, an optimum in a field of study called experimental field. The stages of a study by design of experiments are recalled here:

- Definition of objectives and responses,
- Choice of an experimental strategy,
- Definition of factors,
- Definition of the experimental domain,
- Definition of the empirical model,
- Construction of the experimental plan,
- Experimentation,

- Overall analysis of test results,
- Mathematical analysis of test results,
- Statistical analysis of the model,
- Graphical analysis of the model,
- Validation of the model and the information obtained.

The factorial experimental plans considered only two levels of study per factor and the mathematical models used were of the first degree (with or without interactions) with respect to each factor. These plans are the most used because they allow the screening of factors and sometimes lead to simple but sufficient models. However, there exist many cases where it is necessary to have a good modeling of the studied phenomena and where it is necessary to pass to second degree mathematical models. We then call on the planes for response surfaces [5].

## II.5 Surface plans and methodology of response surfaces

Surface designs represent a set of experimental planning techniques that help to better understand and optimize responses [5]. Response surface methodology is often used to develop models once the most important factors influencing the response under study have been determined.

An equation describing a response surface differs from the equation of a factorial plane by the addition of quadratic terms which make it possible to model a curvature in the response [6], [7]. The postulated mathematical model used with the response surface designs is a quadratic model with second-order interactions:

- For two factors:

$$y = a_0 + a_1x_1 + a_2x_2 + a_{12}x_1x_2 + a_{11}x_1^2 + a_{22}x_2^2 + \epsilon$$

- For three factors:

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_{13}x_1x_3 + a_{23}x_2x_3 + a_{11}x_1^2 + a_{22}x_2^2 + a_{33}x_3^2 + \epsilon$$

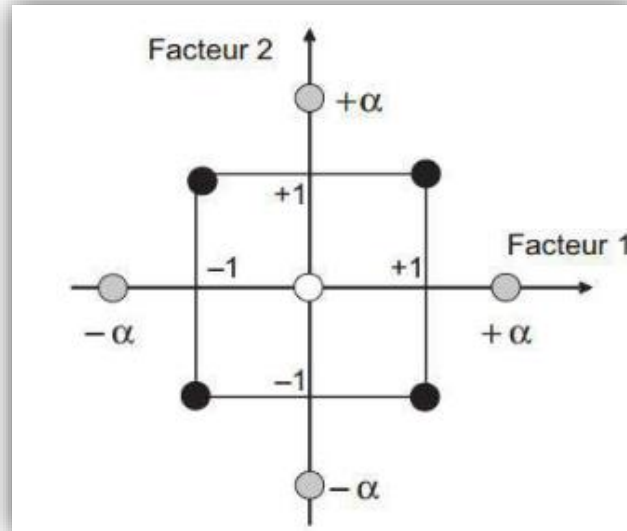
There are two main types of surface planes: centered composite planes and Box-Behnken planes [8], [9].

### II.5.1 Introduction to Composite Plans

The composite centered design (CCD) is the most widely used response surface design [6]; [10]. They lend themselves well to the sequential development of a study. The first part of the study is a complete or fractional factorial plan supplemented by points in the center to check the validity of the model (terms of the first degree and terms of interactions). If the validation tests are positive (the response measured at the center of the domain is statistically equal to

the response calculated at the same point), the study usually ends, but if they are negative, additional tests are undertaken to establish a second-degree model. Additional trials are represented by dots experiments located on the coordinate axes and by new center points. Points located on the coordinate axes are called star points [8]; [11]; [12]. Composite plans therefore have three parts (Figure.1):

- **The factorial plan:** it is a complete or fractional factorial plan with two levels by factors. The experimental points are at the vertices of the study domain.
- **The star plane:** the points of the star plane are on the axes and they are, in general, all located at the same distance from the center of the field of study.
- **Points at the center of the field of study:** We always provide experimental points located in the center of the field of study, and this for both factorial designs and star designs. The total number  $n$  of trials to be performed is the sum of the trials of the factorial design ( $n_f$ ), star design trials ( $n_\alpha$ ) and center trials ( $n_0$ ). The number  $n$  of trials of a composite design is given by the relation [17]:  $n = n_f + n_\alpha + n_0$



**Figure II. 1:** Composite plan for the study of two factors. Factor points are black, star points are light grey, center points are white [8].

### II.5.2 Presentation of the Box-Behnken plans

Box and Behnken proposed in 1960 these plans which allow to directly establish second degree models. All factors have three levels:  $-1$ ,  $0$  and  $+1$ . These plans are easy to implement and have the property of sequentiality. We can undertake the study of the first  $k$  factors, reserving the possibility of adding new ones without losing the results of the tests already carried out [13], [14].

The Box-Behnken design for three factors is built on a cube. For four factors this plane is built on a four-dimensional hypercube. We place the experimental points not at the vertices of the cube or the hypercube, but in the middle of the edges or in the center of the faces (squares) or in the center of the cubes. This provision has the consequence of distributing all the experimental points at equal distance from the center of the field of study, therefore on a sphere or on a hypersphere according to the number of dimensions. Points are added at the center of the study area. The Box-Behnken plan for three factors is shown in Fig.2. The cube has 12 points (experiments) in the middle of the edges of the cube. We usually add experience points to the center of the field of study, usually three. The Box-Behnken design for 3 factors therefore has  $12 + 3$  trials, i.e. 15 trials [8], [15], [16].

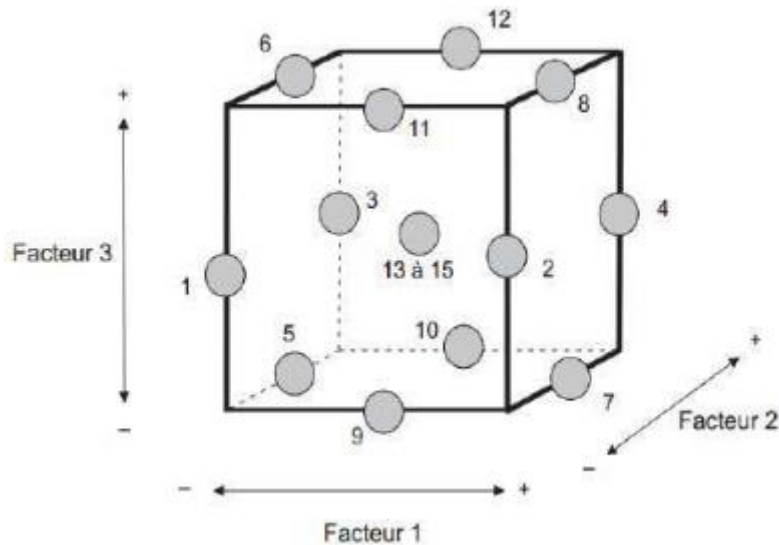


Figure II.2: Illustration du plan de Box-Behnken pour trois facteurs [8].

Since Box-Behnken designs have fewer points, their cost is less than that of centered composite designs for the same number of factors. They can efficiently estimate first- and second-order coefficients; however, the lack of a factorial design makes them unsuitable for sequential experiments. They cannot include trials from a factorial design.

Box-Behnken designs always have 3 levels per factor, unlike centered composite designs, which can have up to 5.

Similarly, unlike centered composite designs, Box-Behnken designs never include trials in which the set of factors has an extreme value, such as the set of low values [8], [13].

## II.6 Experiment plan by MINITAB

An experiment plan is a series of tests, in which you intentionally make changes to different input variables at once and observe the answers. In industry, experimental designs can be used to systematically study process or product variables that affect the quality of the process or product. After identifying process conditions and product components that affect quality, you can work to improve the feasibility, reliability, quality and performance of the product in the field.

Minitab offers the following experience plans:

- Screening plans
- Factor plans

- Response surface planes
- Mixing plans
- Plans of Taguchi

Experimental designs often consist of four phases: planning, screening (or process characterization), optimization and verification.

## II.7 Experiment plan by DOE

The Wizard's Design of Experiments (DOE) feature includes a subset of features available in Minitab and uses a sequential experiment procedure to simplify design creation and analysis. The first phase of the process consists of establishing screening plans to identify the most important factors. We then provide higher resolution planes to detect possible curvature and determine a final model to identify factor settings that optimize the response.

It also provides additional information about the following data checks in the wizard report:

- Blocks
- Outliers
- Detection capability

### II.7.1 Method

#### Sequential experimentation method

The Design of Experiments functions of the Wizard guide users through a sequential procedure for designing and analyzing experiments to identify influential factors and determine factor settings to optimize a response. Sequential experimentation consists of a set of small experiments whose results direct the continuation of the experiment from one stage to the next. The advantage of this sequential approach is that only a small number of experimental runs are executed at each stage, so you avoid wasting resources on unproductive runs.

The Assistant provides a subset of the DOE functions available in Minitab in a structured form that simplifies design creation and analysis. The steps of the procedure are as follows:

1. Creation of a screening plan for 6 to 15 factors.
2. Fitting a screening model that includes the main effects and analyzes the results to detect the most important factors.
3. Create a modeling plan including 2-5 of the most important factors determined in step 2.
4. Fit a linear model that includes main effects and 2-factor interactions, analyze the results, and look for a curvature in the relationship between the factors and the response.
5. If no curvature is detected in step 4, use this model to identify the factor settings that optimize the response.
6. If curvature is detected in step 4, the Wizard recommends adding points for curvature in the plane.
7. Fitting a quadratic model including squared terms to model the curvature and analyze the results.
8. Using the final model, identify factor settings that optimize the response.

The following sections provide detailed information about the following aspects of the Design of Experiments (DOE) Wizard:

- Screening plans
- Modeling plans
- Model adjustment

### ❖ Screening plans

In general, at the beginning of a sequential experimentation procedure, you have a large number of potential factors and then eliminate those whose effect on the response is minimal. Screening designs are experimental designs aimed at identifying the most influential factors within a larger set. The Wizard offers you screening designs for 6 to 15 factors.

#### ➤ Type:

The Assistant's screening designs are Plackett-Burman designs, a special type of 2-level, resolution III design. Plackett-Burman designs have two main advantages:

- They allow the main effects of factors to be estimated with very few experimental runs (as few as 12). Experimental testing can be costly, which makes these models more economical.
- Confusion between main effects and two-factor interactions is only partial (or fractional). Effects that cannot be assessed separately are said to be "confounded". In the Plackett-Burman designs, the confounding is considered partial because the contribution of each effect is only a fraction of the total magnitude of the interaction effect.

We found that for screening, the use of Plackett-Burman designs, which assess only main effects and not interaction terms, was a reasonably acceptable method. Screening designs make it possible to include a large number of factors. Because every term in the model requires at least one trial, and the number of interaction terms grows faster than the number of main effects, it is often impractical or uneconomical to fit a model with interactions. Furthermore, in most cases, only a small number of factors account for most response effects. The purpose of a screening design is to identify these factors, and Plackett-Burman designs allow users to identify these important main effects.

Also, as noted earlier, because the confusion between the terms is only partial in the Plackett-Burman designs, it is less likely that a significant main effect is actually a significant 2-way interaction.

### ❖ Modeling planes

When 2 to 5 important factors are identified, Minitab recommends creating a modeling plan to obtain a model to identify the factor settings that optimize the response.

#### ➤ Type:

The 2- or 5-factor modeling designs are full or V-resolution factorial designs. In particular, these designs allow all of the main effect and 2-factor interaction terms to be adjusted without any confusion. Some or all of the higher order terms (i.e. 3-factor interactions) may be

confused with the model terms. However, the higher order terms are assumed to be negligible compared to the main effect terms and the 2-factor interaction terms.

When we designed our blueprint catalog, our goal was to only offer blueprints with sufficient power. Therefore, we eliminated the 2-factor, 4-trial design in favor of a replicated 4-trial, 2-factor design [18].

### ❖ Adjusting Models Using Top-Down Selection

We investigated several methods of fitting models and found that top-down selection with a  $\alpha$  value of 0.10 seemed the most appropriate. When you fit a model, Minitab first includes all possible terms. Then, Minitab removes the least significant terms one at a time while maintaining the hierarchy of the model. Maintaining the hierarchy means that when an interaction term is significant, the linear terms of the two factors forming the interaction must also be included in the model. It is a form of top-down selection, aimed at automating a model selection process usually done manually. In all plans of the DOE function of the Assistant, the terms are independent or almost (in the case of the square terms). Therefore, multicollinearity, i.e. the existence of a correlation between factors, is unlikely. Multicollinearity can cause walkthroughs to miss the best model. Using a value of  $\alpha = 0.10$  instead of the usual value of  $\alpha = 0.05$  also increases the power of the tests, which increases the likelihood that important terms will be retained in the model.

### II.7.2 Data Verification

Blocks are used in experimental designs to minimize bias and error due to external influences on the experiment, such as noise variables, missing variables, or differences in how the trials were performed in each block. By placing the experimental tests performed together in blocks, you can determine if there are differences between the blocks and account for these differences in the model.

### II.7.3 Outliers

In the Wizard's Design of Experiments (DOE) procedures, we define outliers as observations with high normalized residuals, which is a common flag for identifying outliers in the Design of Experiments (DOE) procedures. model fitting [18]. Since outliers can have a

strong influence on the results of the analysis, it may be necessary to correct the data for the analysis to be valid.

### II.6.1 Detection capability

When performing experiments within a design, it is useful to know the effect size that can be detected by that design before collecting the data. If the design is not powerful enough to detect the desired effect size, it may be necessary to add trials. However, adding additional tests to a plan can be expensive, so it is important to determine if the extra power is really needed [18].

## II.8 Conclusion

This chapter briefly presents in a first part, the definitions and general notations of the MINITAB program.

The second part presents the methodology of the experimental plans and Surface plans and the methodology of the response surfaces, in particular the two plans composite plans and Box-Behnken plans. And finally we finish with the experimental plan by MINITAB and DOE.

You can predict the ideal settings based on the DOE results, but you should always exercise caution when extrapolating the results beyond the data file.

The knowledge of solar radiation, or solar irradiation, at the surface of the earth is of great interest in many fields. In terms of energy, the need to reduce greenhouse gas emissions requires the substitution of fossil fuels by renewable energies. However, the development of systems using solar energy requires data on solar radiation that is dense (spatially and temporally) and sufficiently precise to simulate, design, manage and optimize the operation of these systems. The work in Chapter 3 focuses on the implementation for estimating solar irradiance.

*Chapter III :*  
*Results and Discussion*

### III.1 Introduction

At present, the global energy consumption demand has risen sharply, as seen in oil prices. Many researchers are trying to formulate their own policies and research in the field of renewable energy utilization. Solar energy is one of the solutions to reduce the country's energy fossil fuel consumption, it often becomes their first choice of government policy. Except for PV modules that generate electricity and solar hot water, which can generate PVT (Photovoltaic Thermal) solar technology provides heat in the form of hot water or hot air and is designed to serve both heat and electricity needs.

In order to discover the most important factors and influences that affect solar energy, we have brought the most important factors that affect solar energy or radiation, so we have chosen the appropriate program that allows us to measure a group of factors that may affect radiation, the Minitab program that shows us the results in the form of designs and equations and analyze it.

### III.2 Prediction of irradiation solar using Minitab Software

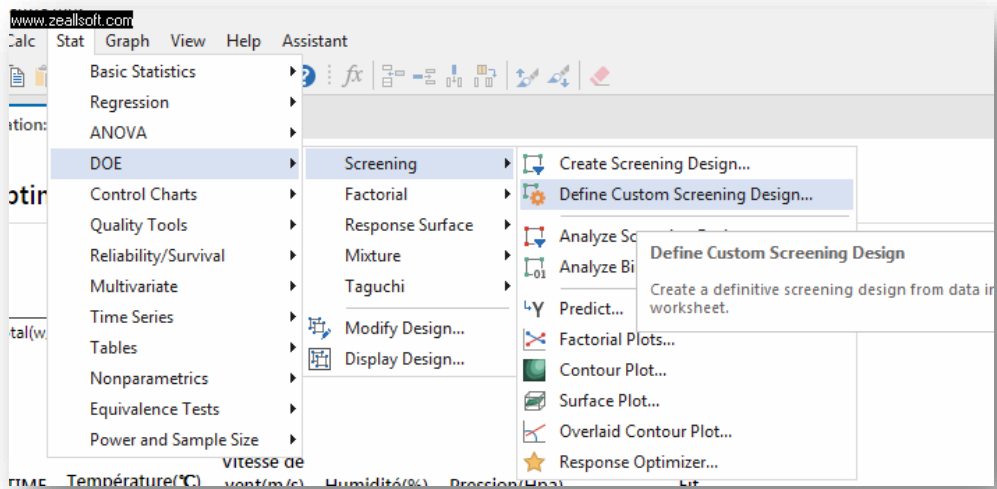
To get the best result for radiation we use a Minitab is a software package that helps us to analyze data, Minitab gives an extensive range of statistical equipment and simple graphs. It offers a short and effective solution that requires a high degree of evaluation. One of its properties is the DOE property that DOE (design of experiments) helps you investigate the effects of input variables (factors) on an output

variable (response) at the same time.

These experiments consist of a series of runs, or tests, in which purposeful changes are made to the input variables. Data are collected at each run.

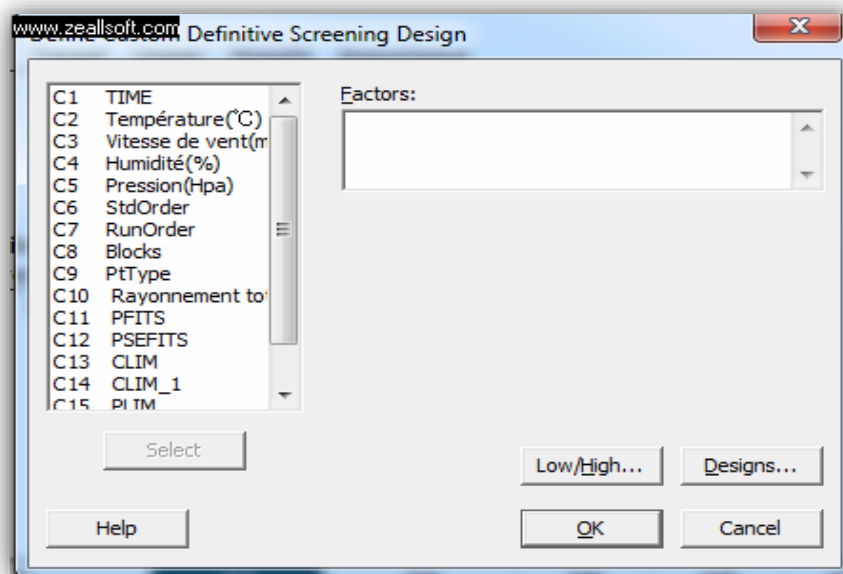
You use DOE to identify the process conditions and product components that affect quality, and then determine the factor settings that optimize result

When we put the influencing factors in Minitab, we press `STAT > DOE > define custom screening design`.



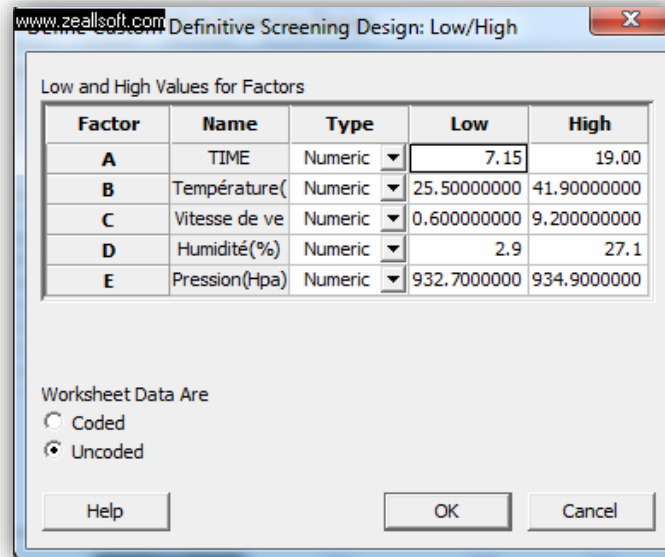
**Figure III.9:**Menu for creating a define custom screening design.

When we click on the selected (define custom screening design), a list of factors appears and we choose the factors .



**Figure III. 10:**Menu show selected factors

In this list(define custom screening design) low and high are selected automatically,from the data that has been set .



**Figure III. 11:** Menu low and high are selected automatical

- ❖ Verify that Store design in worksheet is selected
- ❖ Click OK in each dialog box

Each time you create a design, Minitab stores design information and factors in worksheet columns.

C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
Température(°C)	Vitesse de vent(m/s)	Humidité(%)	Pression(Hpa)	StdOrder	RunOrder	Blocks	PTType	Rayonnement total(w/m2)	PFITS
25.5	2.3	20.8	934.1	1	1	1	1	206.9	232.183
26.1	2.2	20.2	934.0	2	2	1	1	260.7	319.217
27.4	2.1	19.6	934.2	3	3	1	1	313.1	274.342
28.7	1.1	18.0	934.5	4	4	1	1	371.5	294.871
30.1	0.7	18.0	934.4	5	5	1	1	380.0	401.542
31.7	0.6	17.5	934.6	6	6	1	1	457.9	374.991
30.9	2.2	17.3	934.7	7	7	1	1	511.5	432.289
31.6	0.7	16.9	934.6	8	8	1	1	553.7	588.020
33.0	1.4	16.4	934.7	9	9	1	1	608.1	615.567
33.4	1.5	15.8	934.7	10	10	1	1	650.2	658.080
33.5	0.7	15.3	934.7	11	11	1	1	684.2	673.502
34.2	1.2	14.5	934.6	12	12	1	1	719.6	839.483
34.9	2.1	13.3	934.6	13	13	1	1	769.9	923.506
36.0	1.0	12.3	934.6	14	14	1	1	825.0	908.988
36.4	1.1	12.1	934.4	15	15	1	1	897.7	866.088
37.8	1.1	11.3	934.5	16	16	1	1	977.1	968.849
38.3	1.1	11.1	934.4	17	17	1	1	977.0	910.483
38.4	1.7	10.0	934.2	18	18	1	1	966.1	962.962
38.3	2.1	9.9	934.1	19	19	1	1	985.2	981.037
38.6	3.2	9.4	933.8	20	20	1	1	1002.2	951.649
37.8	2.4	9.7	933.6	21	21	1	1	969.5	962.734
38.5	2.7	8.2	933.5	22	22	1	1	949.2	952.108
40.0	0.6	7.9	933.6	23	23	1	1	922.6	771.846
40.6	9.2	3.2	933.4	24	24	1	1	917.7	886.902

Figure III. 12: Menufactors in worksheet columns

### III.2.1 Enter data into the worksheet(Radiation)

After you perform the experiment and collect the data, you can enter the data into the worksheet.

1. In the worksheet, click the column name cell of C10 and enter Radiation.
2. In the Radiationcolumn, enter the data as shown below.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
	TIME	Température(°C)	Vitesse de vent(m)	Humidité(%)	Pression(Hpa)	StdOrde	RunOrde	Blocks	PtType	Rayonnement total(w/m)		
1	7.15	25.5	2.3	20.8	934.1	1	1	1	1	206.9		
2	7.30	26.1	2.2	20.2	934.0	2	2	1	1	260.7		
3	7.45	27.4	2.1	19.6	934.2	3	3	1	1	313.1		
4	8.00	28.7	1.1	18.0	934.5	4	4	1	1	371.5		
5	8.15	30.1	0.7	18.0	934.4	5	5	1	1	380.0		
6	8.30	31.7	0.6	17.5	934.6	6	6	1	1	457.9		
7	8.45	30.9	2.2	17.3	934.7	7	7	1	1	511.5		
8	9.00	31.6	0.7	16.9	934.6	8	8	1	1	553.7		
9	9.15	33.0	1.4	16.4	934.7	9	9	1	1	608.1		
10	9.30	33.4	1.5	15.8	934.7	10	10	1	1	650.2		
11	9.45	33.5	0.7	15.3	934.7	11	11	1	1	684.2		
12	10.00	34.2	1.2	14.5	934.6	12	12	1	1	719.6		
13	10.15	34.9	2.1	13.3	934.6	13	13	1	1	769.9		
14	10.30	36.0	1.0	12.3	934.6	14	14	1	1	825.0		
15	10.45	36.4	1.1	12.1	934.4	15	15	1	1	897.7		
16	11.00	37.8	1.1	11.3	934.5	16	16	1	1	977.1		
17	11.15	38.3	1.1	11.1	934.4	17	17	1	1	977.0		
18	11.30	38.4	1.7	10.0	934.2	18	18	1	1	966.1		
19	11.45	38.3	2.1	9.9	934.1	19	19	1	1	985.2		
20	12.00	38.6	3.2	9.4	933.8	20	20	1	1	1002.2		
21	12.15	37.8	2.4	9.7	933.6	21	21	1	1	969.5		
22	12.30	38.5	2.7	8.2	933.5	22	22	1	1	949.2		
23	12.45	40.0	0.6	7.9	933.6	23	23	1	1	922.6		
24	13.00	40.6	9.2	3.2	933.4	24	24	1	1	917.7		
25	13.15	41.5	6.4	3.0	933.3	25	25	1	1	945.7		
26	13.30	41.9	6.8	2.9	933.0	26	26	1	1	377.6		
27	13.45	41.0	3.0	10.1	933.6	27	27	1	1	294.4		
28	14.00	36.8	7.0	14.0	932.7	28	28	1	1	293.0		
29	14.15	35.9	1.2	14.2	933.7	29	29	1	1	291.0		

Figure III. 13: Menu Represents the input of the companion factor

### III.3 Analyze the design

1. When you create a design and enter response data, Minitab enables the menu commands DOE > Screening, Analyze Screening Design,
2. , Screening Design and Analysis Factor Plots. In this example, you will first adjust the model.
3. Choose Stat > DOE > Screening > Analyze Screening Design.
4. In Responses, enter Radiation

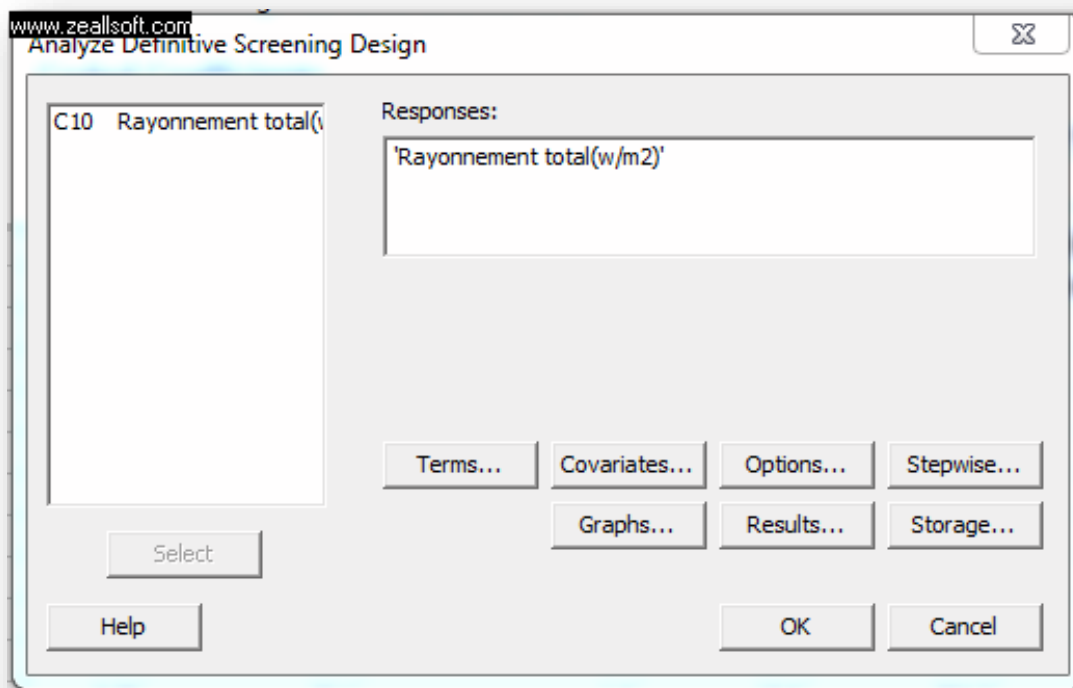


Figure III. 14: Menu Analyze Screening Design

### III.3.1 Model selection

We use the form Linear+interactio because we have a lot of interactor.

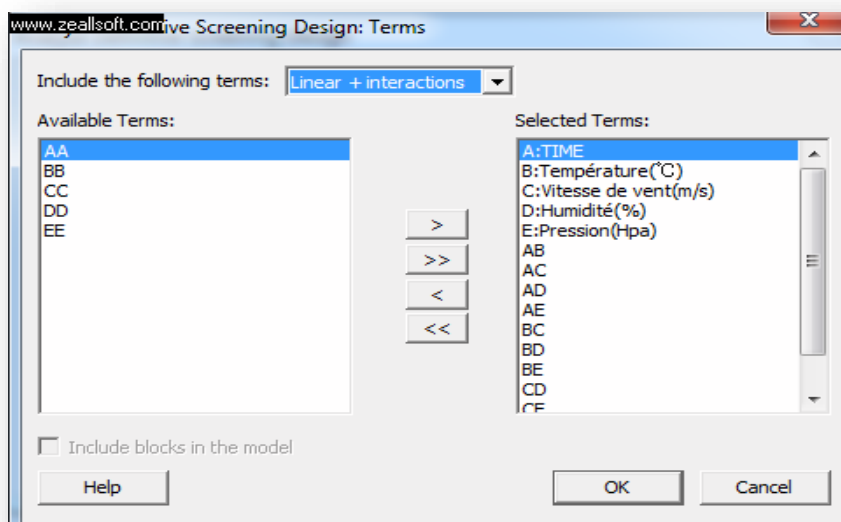


Figure III. 15: Menu Analyze Screening Design Terms

### III.4 Results and discussion

#### Linear+interacti

Coded Coefficients					
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1358	157	8.65	0.000	
TIME	1050	380	2.76	0.009	195.39
Température(°C)	-1366	462	-2.96	0.006	189.06
Vitesse de vent(m/s)	-219	141	-1.55	0.130	25.79
Humidité(%)	-1342	469	-2.86	0.007	205.50
Pression(Hpa)	387	185	2.10	0.044	36.53
TIME*Température(°C)	-2503	648	-3.86	0.001	136.40
TIME*Vitesse de vent(m/s)	-519	273	-1.90	0.066	22.24
TIME*Humidité(%)	-3519	996	-3.53	0.001	337.55
TIME*Pression(Hpa)	379	320	1.18	0.245	48.03
Température(°C)*Vitesse de vent(m/s)	980	689	1.42	0.164	179.83
Température(°C)*Humidité(%)	-106	329	-0.32	0.750	26.30
Température(°C)*Pression(Hpa)	469	551	0.85	0.401	52.59
Vitesse de vent(m/s)*Humidité(%)	852	523	1.63	0.113	68.86
Vitesse de vent(m/s)*Pression(Hpa)	92	143	0.64	0.524	7.84
Humidité(%)*Pression(Hpa)	-432	615	-0.70	0.488	99.00

Figure III.16: The results of the coded coefficients

Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
110.192	90.13%	85.50%	62.80%

Figure III.17: The equation of the Model Summary

## Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	3546694	236446	19.47	0.000
Linear	5	317361	63472	5.23	0.001
TIME	1	92815	92815	7.64	0.009
Température(°C)	1	106215	106215	8.75	0.006
Vitesse de vent(m/s)	1	29344	29344	2.42	0.130
Humidité(%)	1	99614	99614	8.20	0.007
Pression(Hpa)	1	53315	53315	4.39	0.044
2-Way Interactions	10	1148511	114851	9.46	0.000
TIME*Température(°C)	1	181294	181294	14.93	0.001
TIME*Vitesse de vent(m/s)	1	43913	43913	3.62	0.066
TIME*Humidité(%)	1	151551	151551	12.48	0.001
TIME*Pression(Hpa)	1	17038	17038	1.40	0.245
Température(°C)*Vitesse de vent(m/s)	1	24589	24589	2.03	0.164
Température(°C)*Humidité(%)	1	1250	1250	0.10	0.750
Température(°C)*Pression(Hpa)	1	8794	8794	0.72	0.401
Vitesse de vent(m/s)*Humidité(%)	1	32234	32234	2.65	0.113
Vitesse de vent(m/s)*Pression(Hpa)	1	5039	5039	0.41	0.524
Humidité(%)*Pression(Hpa)	1	5988	5988	0.49	0.488
Error	32	388550	12142		
Total	47	3935244			

Figure III. 18: The Analysis of variance .

## Regression Equation in Uncoded Units

$$\begin{aligned}
 \text{Rayonnement total(w/m}^2\text{)} = & 1629023 - 51588 \text{ TIME} - 48116 \text{ Température(}^\circ\text{C)} \\
 & - 19152 \text{ Vitesse de vent(m/s)} + 30801 \text{ Humidité(\%)} \\
 & - 1768 \text{ Pression(Hpa)} - 51.5 \text{ TIME*Température(}^\circ\text{C)} \\
 & - 20.4 \text{ TIME*Vitesse de vent(m/s)} - 49.1 \text{ TIME*Humidité(\%)} \\
 & + 58.2 \text{ TIME*Pression(Hpa)} \\
 & + 27.8 \text{ Température(}^\circ\text{C)*Vitesse de vent(m/s)} \\
 & - 1.06 \text{ Température(}^\circ\text{C)*Humidité(\%)} \\
 & + 51.9 \text{ Température(}^\circ\text{C)*Pression(Hpa)} \\
 & + 16.4 \text{ Vitesse de vent(m/s)*Humidité(\%)} \\
 & + 19.5 \text{ Vitesse de vent(m/s)*Pression(Hpa)} \\
 & - 32.5 \text{ Humidité(\%)*Pression(Hpa)}
 \end{aligned}$$

Figure III.19: The Regression Equation in uncoded units

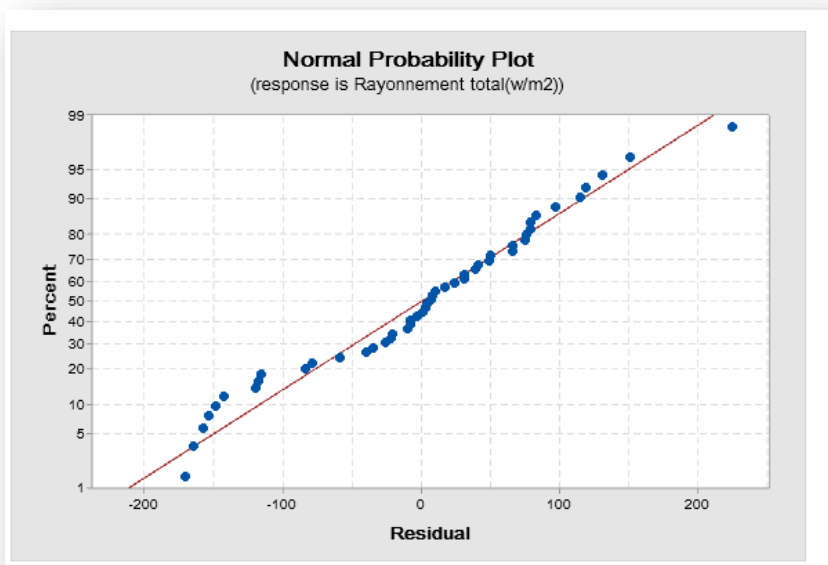


Figure III. 20: The Graph of Normal Probability Plot

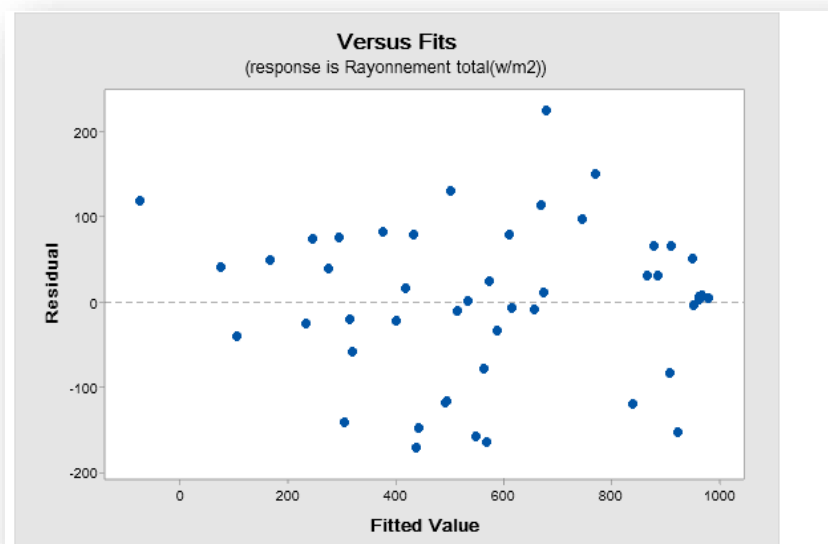
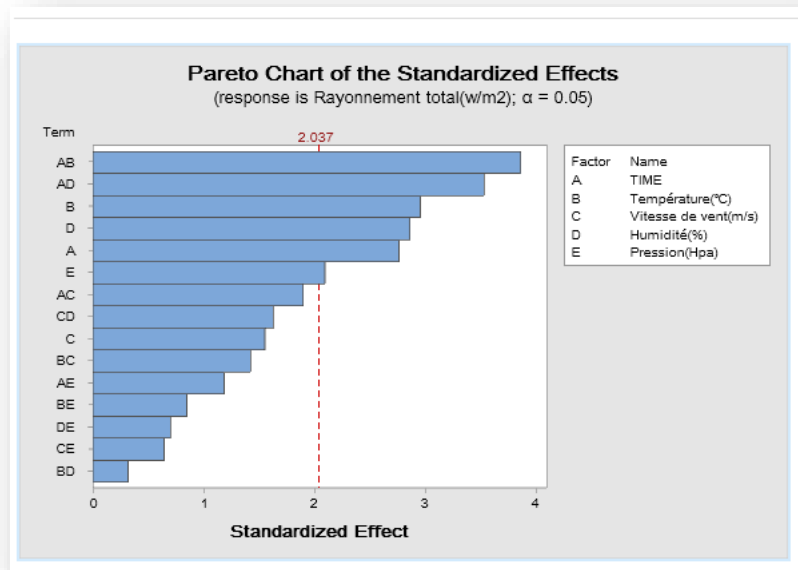


Figure III.21: The Graph of Versus Fits .



**Figure III.22:** The Graph of Pareto chart of the Standardized Effects.

From the first figure, it is clear that the residuals are distributed normally, and it can be judged through the drawings, as the values in plot probability Normal form a large number of points very close to the line, and in value Fitted form the points do not take a specific shape Scattered randomly, and in the histogram a vertex, and in the order Observation form there are no red points, meaning that the data distributed within the range

In the other figure (chart Paret) We notice that almost all factors are greater than the reference line (The t-value corresponding to the statistical function / 2.037) this It indicates that these variables are statistically significant, and it is noted that the factor B has the greatest impact on the results, as it is the main factor among the The five factors. This figure can show interactions between two or more factors

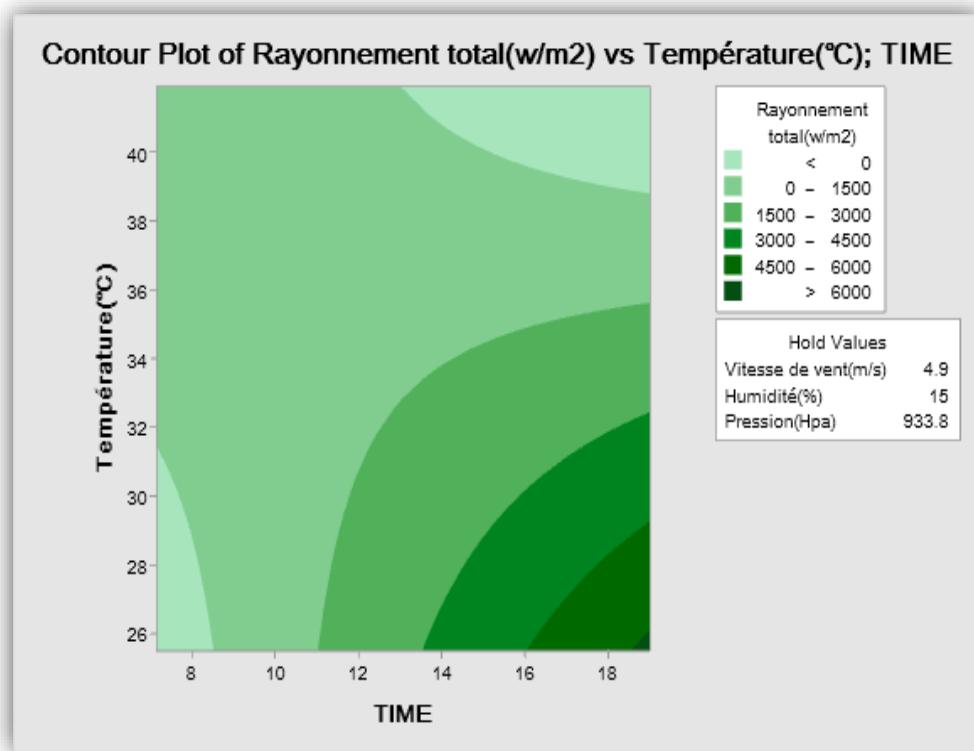
It is clear from the analysis of the Value-P value corresponding to the factors humidity, wind speed, time, temperature and pressure that these five factors affect any of them on the dependent variable radiation The Value-P is greater than 0.4. Also, the effect ratio of sq-R is high and equal to (90.13)

### III.5 Contour plot

Show how the dependent variable is related to two/or more variables of type Continuous with a two-dimensional vision (plot contour)

The graph is represented by gradient colors and some numbered lines, which shows what the relationship between two continuous variables and the dependent variable looks like

-Plotting a process can be done. Stat >DOE> Screening> define custom screening design .



**Figure III. 23:**The Graphs Contour Plots of Radiation vs Temperature; Time .

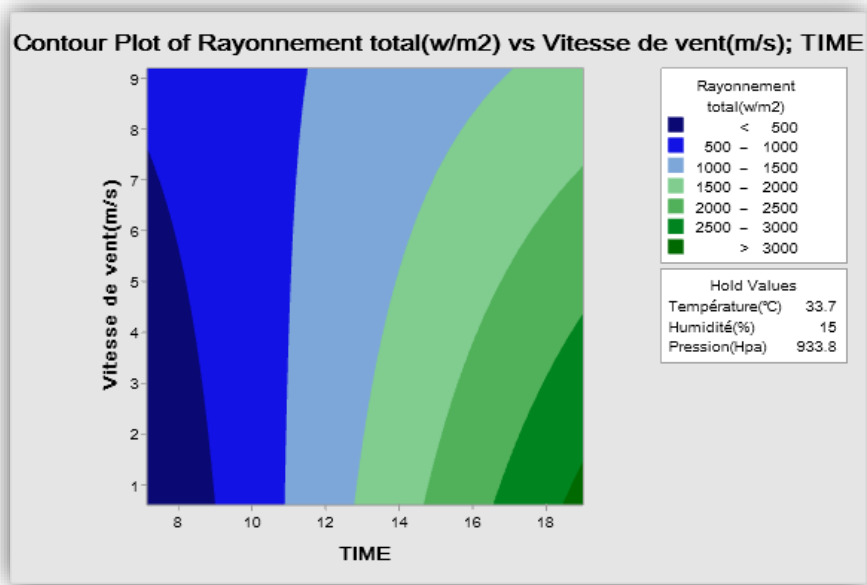


Figure III. 24: The Graphs Contour Plots of Radiation vs Wind speed; Time

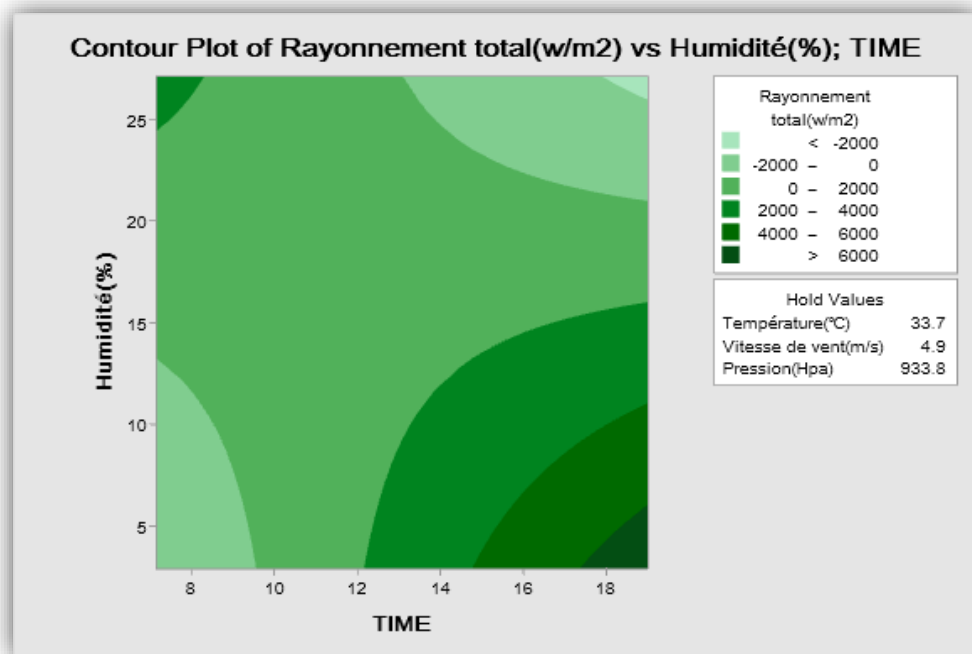


Figure III. 25: The Graphs Contour Plots of Radiation vs Humidity; Time .

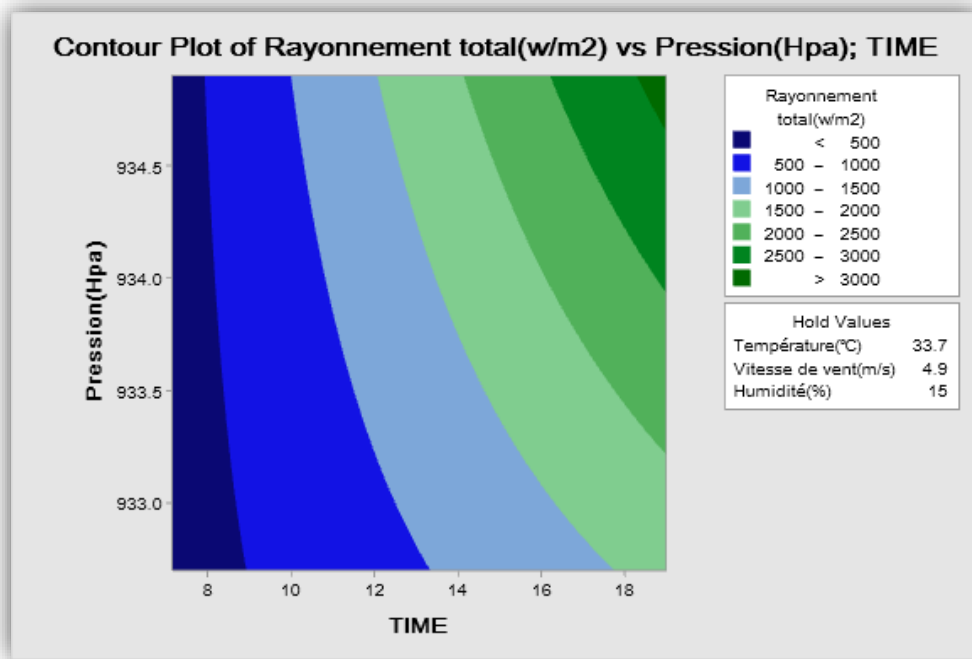


Figure III. 26: The Graphs Contour Plots of Radiation vs pressure; Time .

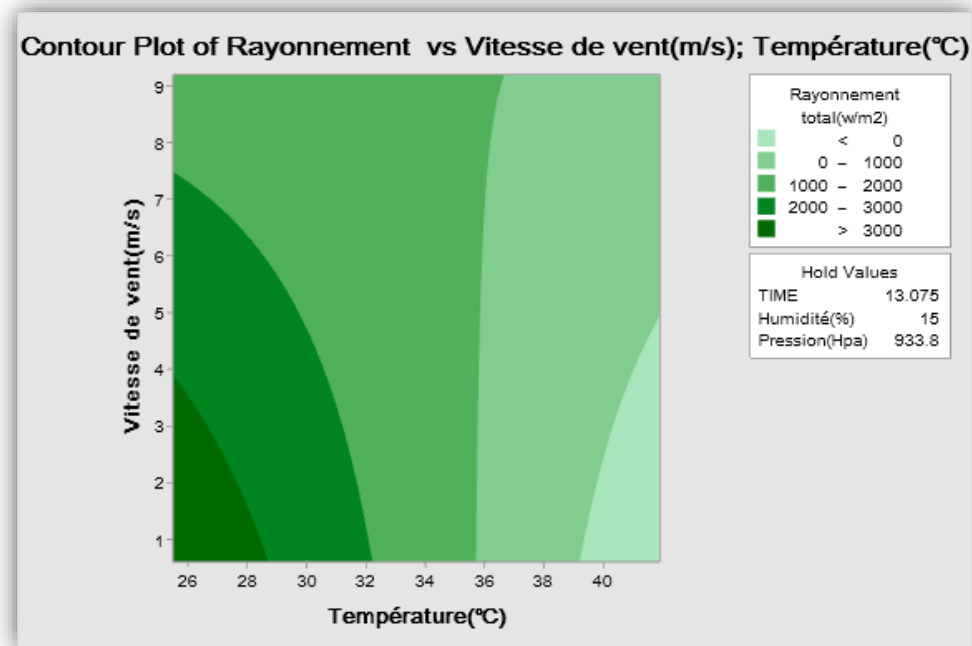


Figure III. 27: The Graphs Contour Plots of Radiation vs Wind speed; Température .

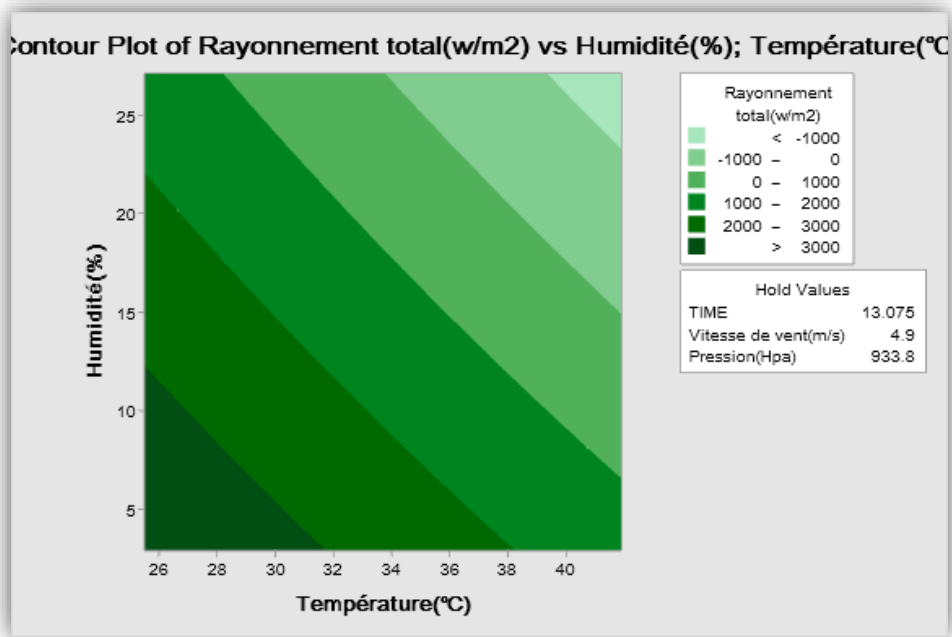


Figure III. 28: The Graphs Contour Plots of Radiation vs Humidity; Temperature

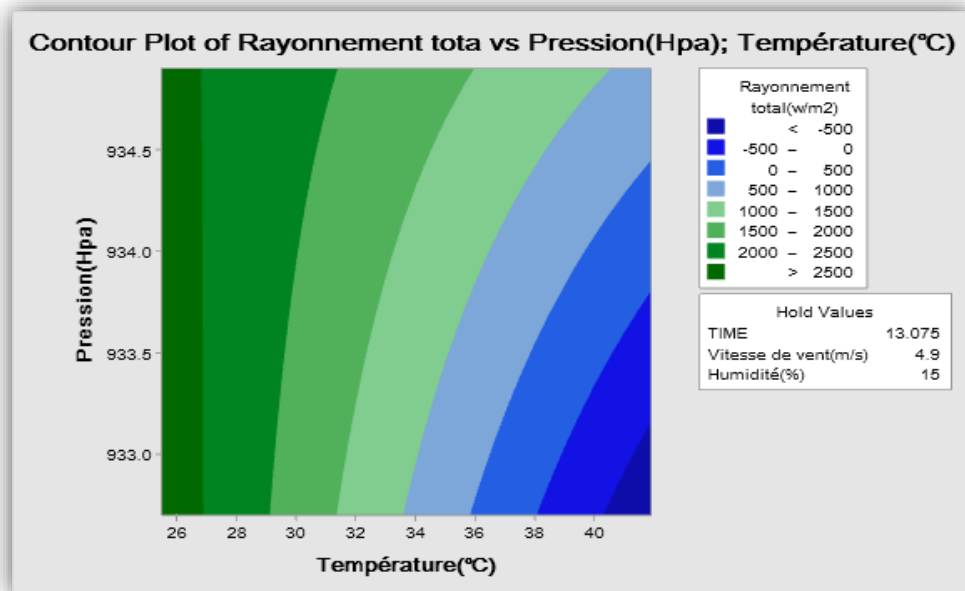


Figure III. 29: The Graphs Contour Plots of Radiation vs pressure; Temperature

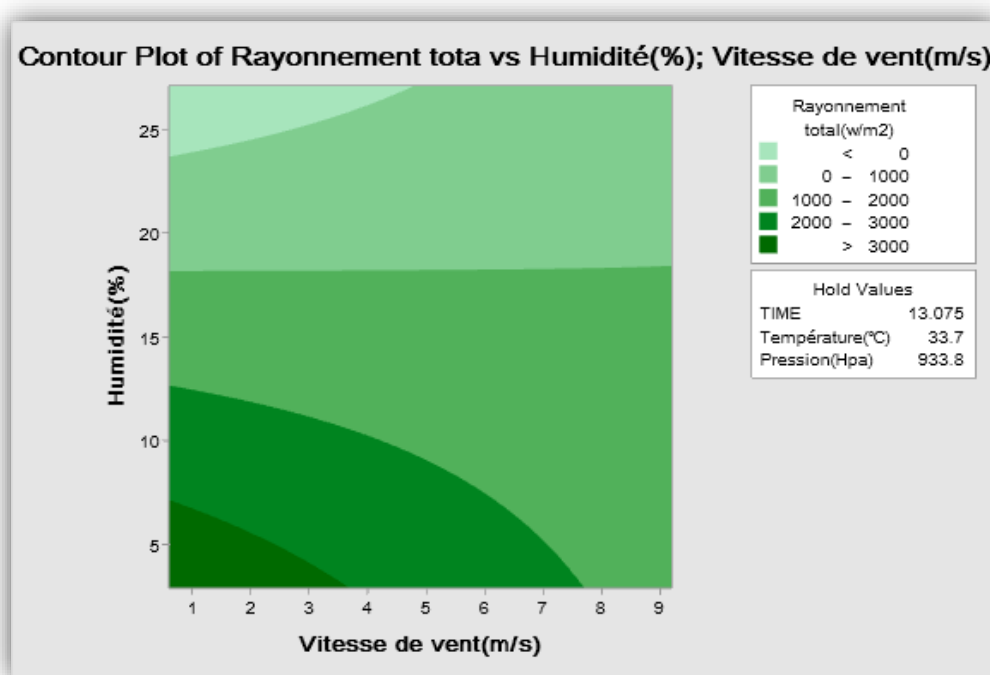


Figure III. 30: The Graphs Contour Plots of Radiation vs Humidity; Wind speed.

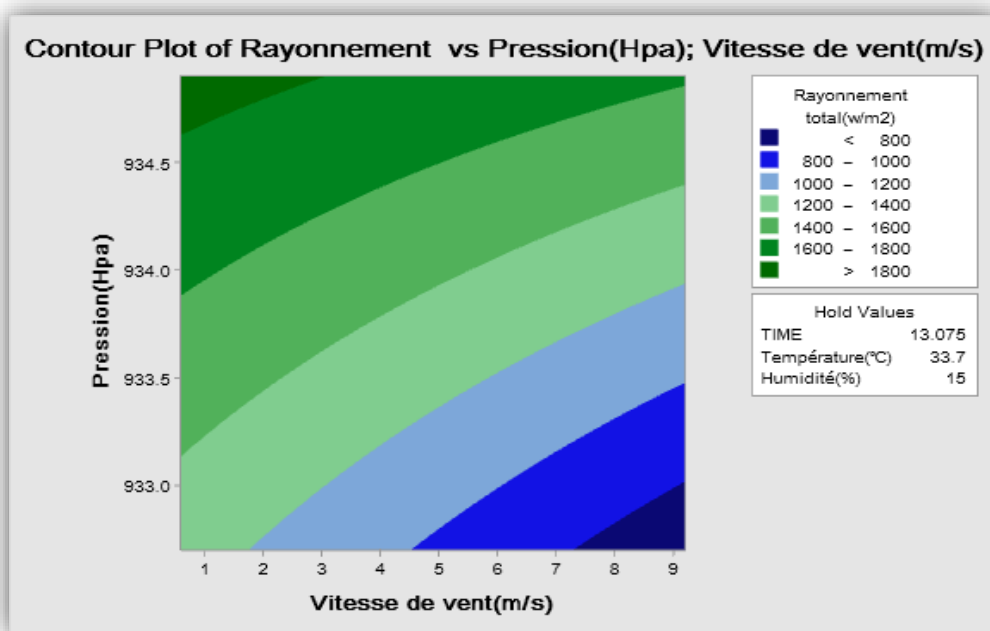


Figure III. 31: The Graphs Contour Plots of Radiation vs pressure; Wind speed.

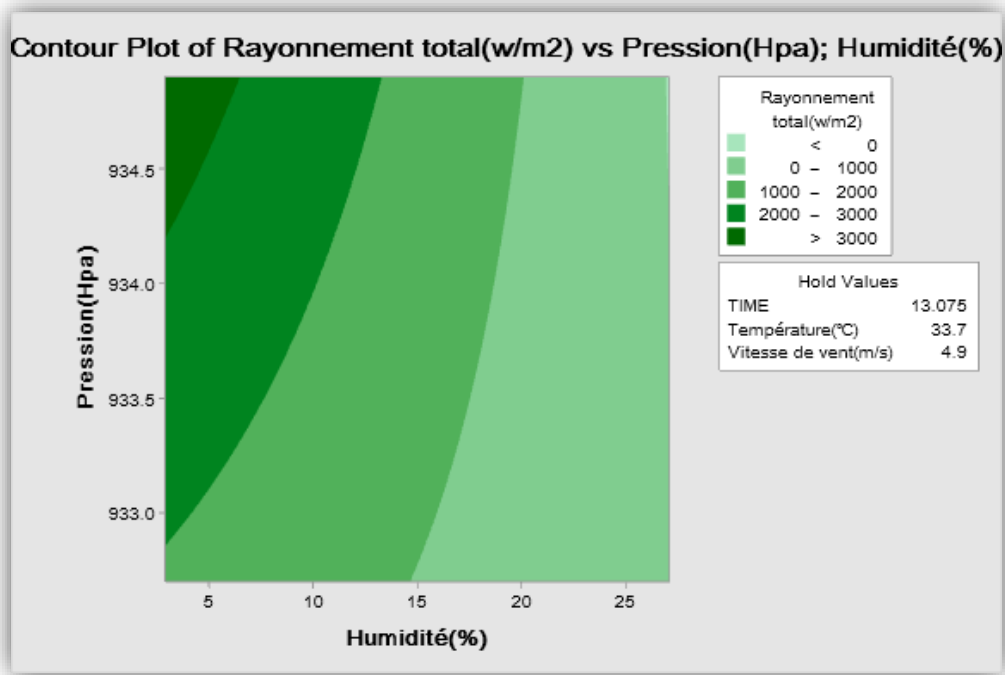


Figure III. 32: The Graphs Contour Plots of Radiation vs pressure; Humidity .

### III.6 Factorial plots

Presentation of the graph of the interaction between two independent variables and their effect on a dependent variable (plots factorial) .

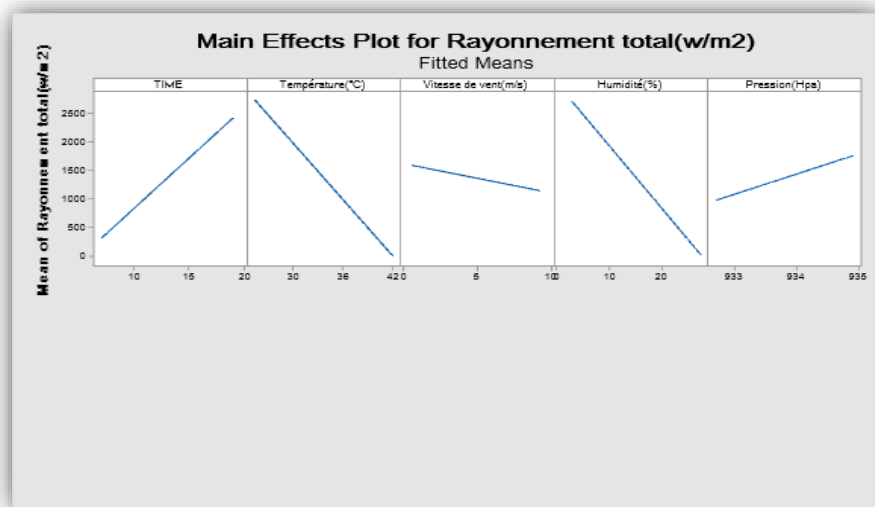


Figure III. 33: The Graphs Main Effects Plot for Radiation total.

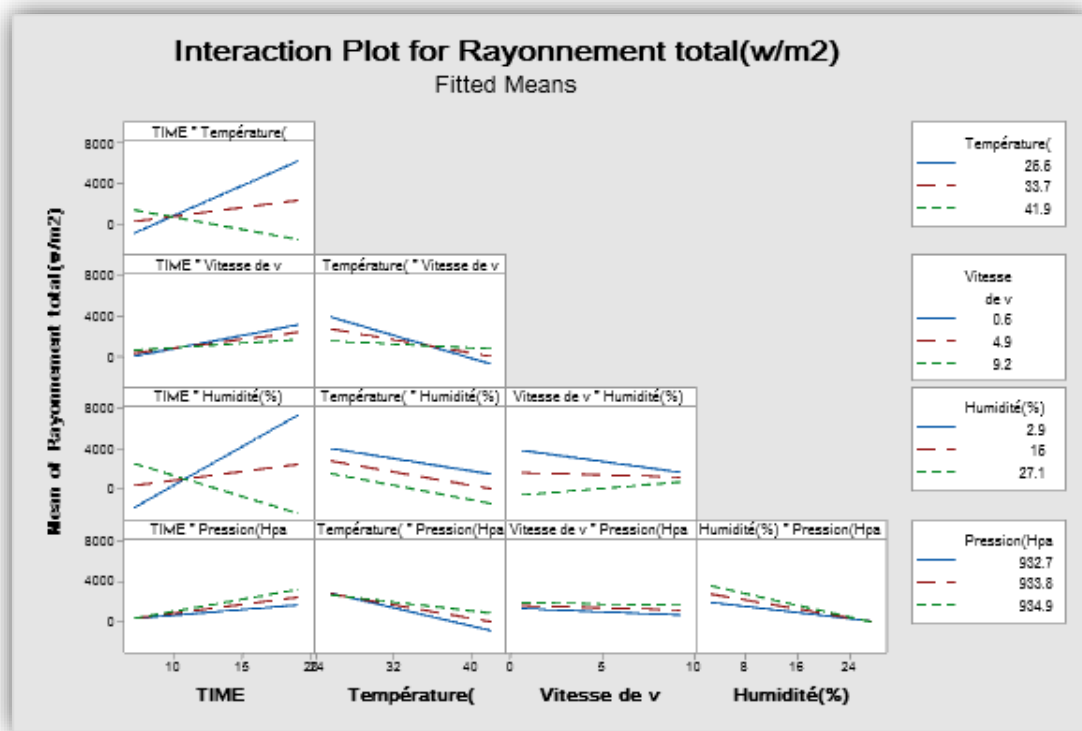


Figure III. 34: Interaction Plot Radiation

### III.6.1 Analysis

**1-TIME\*Temperature:** we notice from the diagram that the higher the temperature compared to time, the more radiation increase

**2-TIME\*Wind speed:**we note from the graph that the higher the wind speed compared to time, the slower the radiation increases

**3-TIME\*Humidity:**what can be observed from the graph is that the humidity increases compared to time, which leads to a significant decrease in radiation after it was high.

**4-TIME\*the pressure:**we can notice from the graph that the pressure is lower where the radiation is greater and more pressure compared to time.

**5- Temperature\*wind speed:**What we notice from the graph is that the wind speed is decreasing where the radiation is high compared to the temperature, the temperature is decreasing .

**6- Temperature\* Humidity:**what we notice from the graph is that humidity decreases as the radiation is greater than it in terms of temperature .

**7- Temperature\* the pressure:**what we notice from the graph is that the pressure decreases and the radiation follows it, as in terms of temperature

**8- wind speed\* Humidity:**we can notice from the graph that represents the wind speed in terms of the rays that the humidity decreases, which is accompanied by an increase in the radiation compared to the wind speed, which is almost constant.

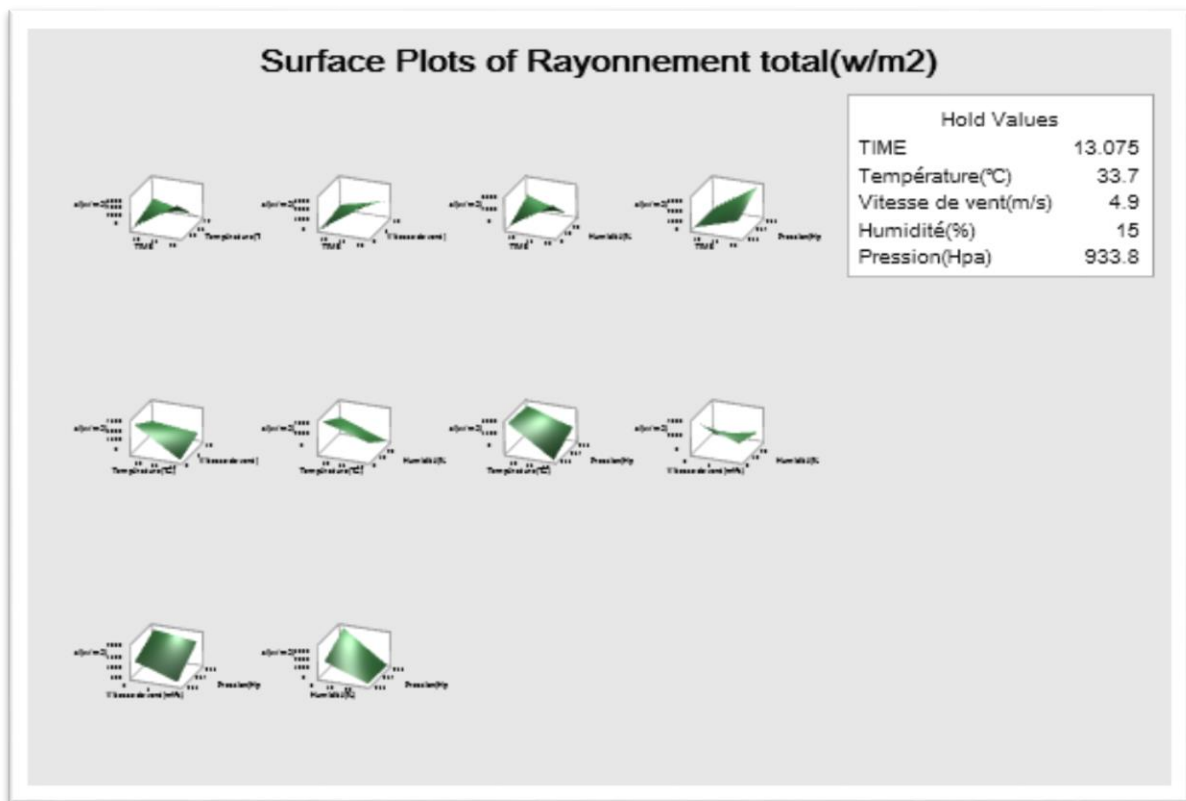
**9- wind speed\* the pressure:**we can see from the graph that the pressure is almost constant and the radiation is almost constant compared to the wind speed, which is almost constant .

**10- Humidity\* the pressure:**We can notice from the graph that as the pressure and humidity decrease, the radiation decreases .

### III.7 Surface plot

Show how the dependent variable relates to variables of type Continuous with a two-dimensional view (plot Surface)

Presentation of a three-dimensional drawing showing the shape of the relationship between connected variables and a dependent variable.



**Figure III. 35:**Surface plot of Radiation total.

### III.8 Overlaid contour plot

Show a graph showing the relationship between a dependent variable/multiple dependent variables (up to 25 variables) and two related dependent variables, one on the axis

(X) and the other on the (Y) axis (they overlap the drawn lines) and are divided into regions according to the dependent variable

Plotting a process can be done. Stat >DOE>Screening>define custom screening design .

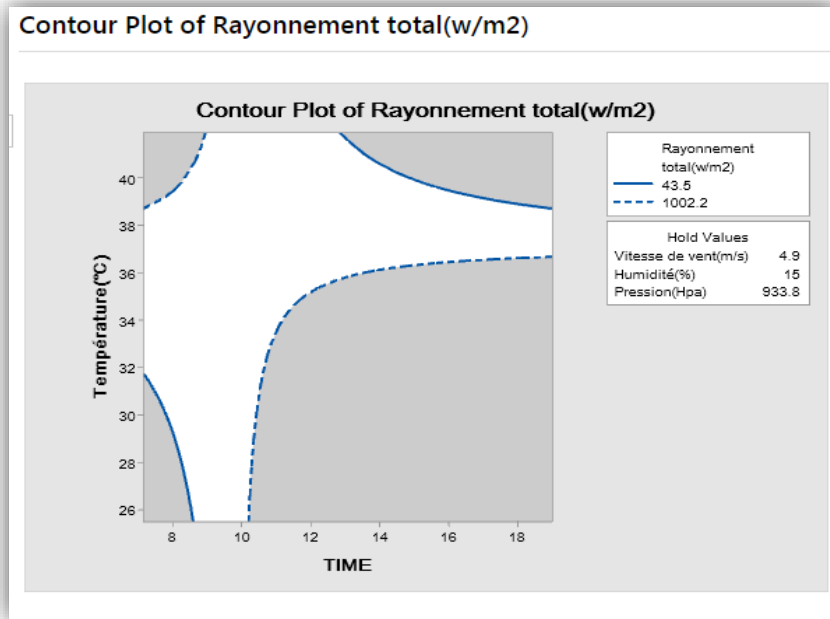


Figure III. 36: The Graphs Contour Plot. temperature of time .

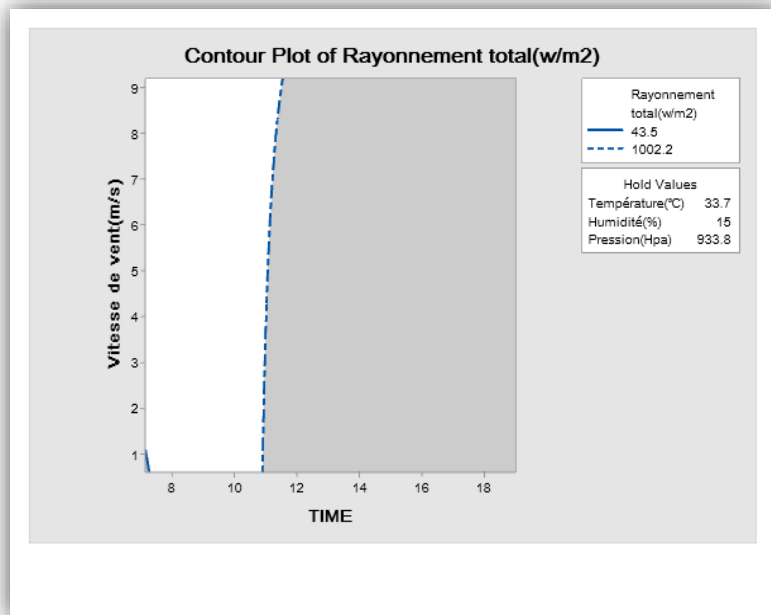


Figure III. 37: The Graphs Contour Plot. Wind speed of time.

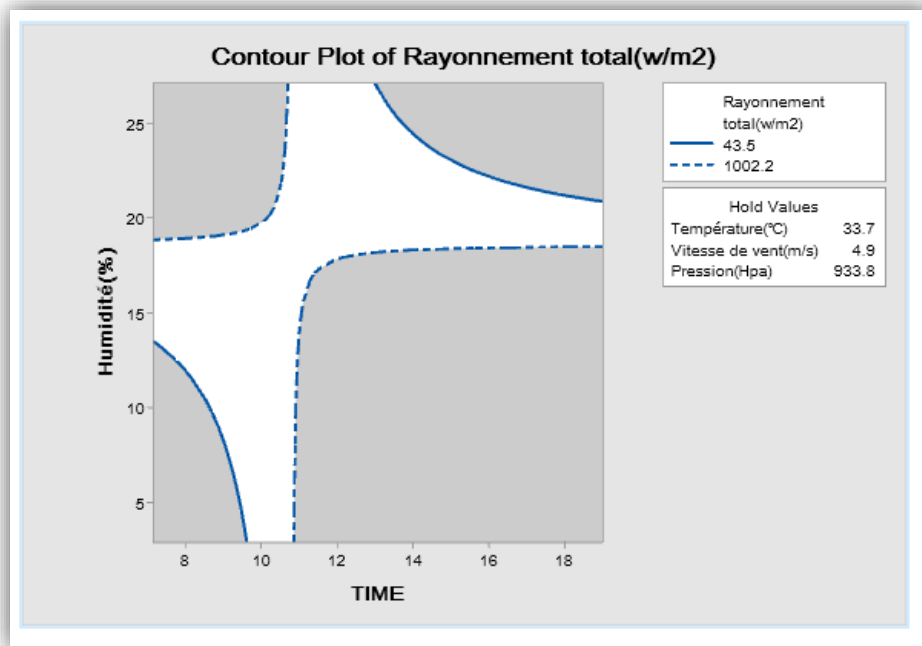


Figure III.38: The Graphs Contour Plot. Humidity of time

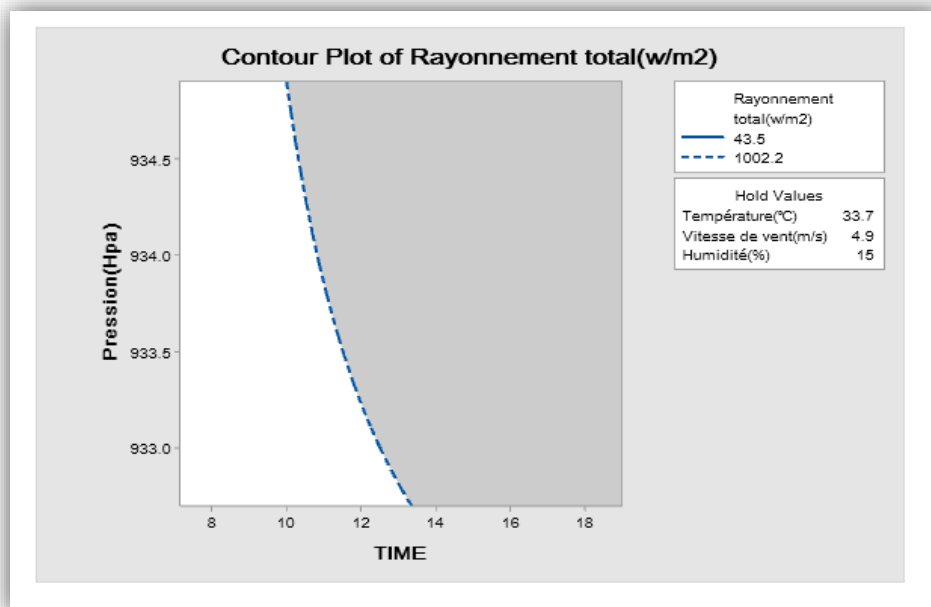


Figure III. 39: The Graphs Contour Plot. the pressure of time.

### III.9 Conclusion

In this chapter, we focused on the implementation for estimating solar irradiation, to get the ensemble of the factors that influence the radiation. Using the Minitab software. And our analysis helps us to conclude that radiation depends on five major factors, which are humidity, wind speed, time, temperature, and pressure.

We can see the relationship between each factor and the variable radiation. For the first factor which is humidity, we conclude that there is an inverse relationship with the radiation, where the increase of the humidity leads to a decrease in the radiation. At the same time, the temperature and the radiation increase have the same changes, which means when the temperature increases, the radiation increases too. The third factor which is wind speed, influences the radiation negatively, so its impact is to slow down the radiation increase. Pressure is one of those important factors, we noticed that the lower the pressure is, the higher the radiation is. And for the last factor which is time, we can say that it is related to the other four factors, and its effects depend on the others factors' conditions.

# *General conclusion*

### General conclusion

In this work, an approach is used for the prediction of the solar irradiation of a day in a site characterized by a dry climate (M'sila) and favorable to solar installations using Minitab software.

This radiation can be used every day towards Earth for useful and amazing work. If we can take advantage of these rays, we can use it to save the energy we need. The importance of this is provided free of charge every day and is renewable energy. And it doesn't pollute the environment but it doesn't prevent it from having negatives, we need to provide them with areas with appropriate factors, so we need to adopt and develop this energy and make it a reliable energy in the future and the way it is stored better. What we have processed in this work is solar radiation prediction in the M'sila region, you can predict the perfect settings based on DoE results, but you should always be careful when extrapolating results outside the data file, Our analysis helps us to conclude that radiation depends on five main factors, namely humidity, wind speed, time, temperature and pressure. We conclude that there is an inverse relationship with radiation where increased moisture leads to reduced radiation. At the same time, the temperature and radiation increase with the same changes, we noticed that the lower the pressure, the higher the radiation..... So we deduce its effects depend on the conditions of the factors and the radiation is good in the M'sila region in the summer and the appropriate times depend on the factors influencing.

As a perspective, and to extend this study to the prediction of other meteorological parameters, for example the duration of insulation which is a very important parameter as we have seen for the prediction of solar irradiation .

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# *Abstract*

## Abstract

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### *Abstract*

The use of solar photovoltaic energy appears to be a necessity for the future. We present here a deep learning method for estimating solar irradiation with minitab software. For prediction, an algorithm based on the design of experiment method to model prediction shows better performance..

**Keywords:** Solar irradiation, design of experiment, prediction

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### **Résumé**

L'utilisation de l'énergie solaire photovoltaïque semble être une nécessité pour l'avenir. Nous présentons ici une méthode d'apprentissage profond pour estimer l'irradiation solaire avec le logiciel minitab. Pour la prédiction, un algorithme basé sur la méthode de conception d'expériences pour modéliser la prédiction montre de meilleures performances.

**Mots clés :** Irradiation solaire, plan d'expérience, Prédiction,

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### **المخلص**

يبدو أن استخدام الطاقة الشمسية الكهروضوئية ضرورة في المستقبل ، ونقدم هنا طريقة تعلم عميقة لتقدير الإشعاع الشمسي باستخدام برنامج minitab. بالنسبة للتنبؤ ، تُظهر خوارزمية تعتمد على تصميم طريقة التجربة لنمذجة التنبؤ أداءً أفضل..

**الكلمات المفتاحية:** الإشعاع الشمسي ، تصميم التجربة ، التنبؤ

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