

Abstract:

The growing concerns about rising energy prices and limited energy resources for laying hen's farms provide ample reason to identify and examine the current energy use requirements and costs. This project presents different technical approaches for energy conservation in the egg production farms. The main approach was first to evaluate the quantitative energy requirements through held interviews, then using Simulink and DIALux, series of simulations and calculations were conducted in order to seek for the most efficient light bulb and how many of them to be installed. Furthermore, an application named the Light Cost Calculator using MATLAB app-designer were developed to estimate the amount of saved money in case of using the suggested light bulb over the actual installed ones. It was found that installing thirty-five 5 watts, 470 lumens classic LED bulbs is much more efficient and super economical compared to the actual 40 watts incandescent bulbs. Afterwards, the intension was to seek for more energy conservation options, so knowing that the cooling and ventilation system represents 25 percent from the overall energy usage, an application called the Fan Selector using app-designer were developed to seek for more efficient electric fans. The possibility of using BLDC fans were also investigated. The obtained feedback from the Fan Selector application pointed out that using four BLDC fans is at least twice efficient than using normal AC fans in a farm of 10000 hens with 1.5Kg each, in average. The application also revealed that a considerable amount of money will be saved when using these BLDC fans. The last phase was the integration of photovoltaic solar system in the egg production farm. The proposed system is a standalone 12 kW peak system. It is equipped with battery banks of 1500 Ah, eight strings of six modules connected in series in conjunction with two three phase string inverters. This thesis aims to combine all the previous strategies starting from replacing the traditional incandescent bulbs, seeking for the most electric fans and eventually investing in solar energy to minimize the electricity usage and therefore maximize the profits.

Keywords: Poultry farms, Lighting, Ventilation system, DIALux, Photovoltaic, Sizing, BlueSol, Simulink, App-designer.

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List of abbreviations:

PV: Photovoltaic.

V_{oc}: Open Circuit Voltage.

STC: Standard Test Conditions.

P_p: Peak Power.

MPP: Maximum Power Point.

SOC: State of Charge.

DOD: Depth of Discharge.

MDOD: Maximum allowable level of discharge.

V_{mp}: Maximum Power Voltage.

I_{mp}: Maximum Power Current.

I_{ph}: Photo-Current.

R_s: Series Resistance.

R_{sh}: Shunt Resistance.

DC: Direct Current.

AC: Alternating Current.

C_b: Battery Capacity.

T_{avg}: The average sun hour per day.

E_r: The generated energy by the PV solar array.

V_a: The generated voltage by a solar cell.

V_{DC}: The DC voltage of the system.

I_{DC}: The total load DC current.

N_s: Number of modules per string.

N_p: Number of parallel strings.

N_m: Total number of modules.

N_{controller}: Number of charge controllers.

P_{out}: Inverter power rating.

E: Luminous power.

CRI: Color Rendering Index.

I_θ: The luminous intensity of the source in the direction of the illuminated point.

N: The number of luminaires.

N_L: The number of columns of luminaires.

N_w: The number of rows of luminaires.

L: The length of the warehouse.

W: The width of the warehouse.

MH: The luminaire mounting height.

CU: The luminaire utilization factor.

LLF: Light lost factor.

LL: The initial rate lamp lumens.

A: The area of the space to be lighted.

n: The number of bulbs per luminaire.

LED: **Light emitting diode.**

SP: Static Pressure.

FE: Fan Efficiency.

AD: Air Delivery.

W_t: The body weight of a laying hen in Kg.

N_b: Number of laying birds in the warehouse.

EOCS: Economical Operating Cost Saving.

ER: Electricity Rate charged by Sonelgaz (DA/Kwh)

AOH: Average Operating Hours per one trimester.

IM: Induction Motor.

BLDC: Brushless DC motor.

E27: It refers to the size of a light globe screw base.

Hp: Horse Power.

IES: Illuminating Engineering Society.

GUI: Graphical User Interface.

Php: Fan power input in horse power.

SLD: Single Line Diagram.

ΔV%: The voltage drop percentage of the nominal voltage.

Ep, y: The energy produced by the system on an annual basis.

General introduction:

The sun provides the energy to sustain life in our solar system. In one hour, the earth receives enough energy from the sun to meet its energy needs for nearly a year. Photovoltaic is the direct conversion of sunlight to electricity. The photovoltaic solar systems are already an important part of our lives. The simplest PV solar systems power many of the small calculators and wrist watches that we use every day. More complicated systems provide electricity for pumping water, powering communications equipment, and even lighting our homes and running our household appliances [1]

One of the most important photovoltaic applications is the agriculture sector. Livestock buildings in general and poultry facilities specifically are energy consumers. Indeed, with the increasing cost of power being driven further and faster by the increasing bird demands, it is time poultry growers seriously consider opportunities in solar power. The problem is a system that harnesses this “free energy” is anything but free. In fact, it can be very costly, particularly if done incorrectly without full understanding of how it all works. On the other hand, if done properly with all the right supporting factors, a grower has the opportunity to lock in his future electricity costs at a constant lower rate while paying for the system. Once a system is paid for, a grower can thereafter be virtually self-sustaining in electricity well into the future with little more than the cost of insurance and maintenance for the solar system [2]

However, one issue is that these poultry warehouses are still using non efficient traditional electric systems. For instance, mostly all the egg production farms are still relying on the traditional incandescent bulbs to stimulate the lighting system for the laying birds. Such bulbs are super inefficient and they waste up to 95 percent of the consumed energy into heat, whereas only 5 percent is transferred into light. One more thing is that these bulbs consume up to 50 percent of the total electricity usage in the farm. In the other hand the ventilation and cooling system is one of the major energy sucking sources in all the poultry warehouses.

For this reason, in this work, how laying hen’s farmers can cut cost and get more efficient concerning the optimal electrical installation will be investigated. Furthermore the design and simulation of a stand-alone photovoltaic (PV) system to ensure the load demands for a laying hen’s farm will be carried out.

Specified objectives:

The main objectives for this master thesis project are:

- Perform a light design simulation to investigate the most efficient light bulb that can be used in a laying hen's farm.
- How to provide an optimum environment with minimum energy expenditure is well educated through qualitzing and quantizing the used electrical fans.
- Produce our own energy through proposing and simulating a stand-alone PV system for one of the visited poultry farms.

Thesis structure:

Chapter 1: a general introduction of the PV system is presented as well as the procedure to design and size the PV arrays in order to supply electricity.

Chapter 2: a technical debrief of the lighting system design will be covered, in addition to how to properly size and select the most efficient electrical fan to be installed in a laying hen's farm.

Chapter 3: lighting and ventilation system simulation for egg production farms, case study.

Chapter 4: The proper sizing of the solar photovoltaic plant using the BlueSol software.

Chapter 1: Solar Photovoltaic System Engineering

Solar photovoltaic (PV) is the most cost-effective solar technology available in the market for electricity generation. Its technical simplicity and the plummeting of its prices during the last decade have enabled this technology to penetrate several markets, especially at a distributed generation level. In order to design PV arrays it is important to know the physics behind it and the parameters that can affect its performance.

In this section, essential definitions about PV systems will be defined as well as the procedure to design PV arrays in order to supply electricity.

1. 1 PV fundamental concepts and definitions:

One of the main advantages of the PV systems is that they are capable of directing, transforming the energy of the Sun into electricity. PV cells are made of materials with high photoelectric properties, capable of producing electrons when sunlight strikes them without the intervention of a secondary energy carrier. After this, it is only necessary to convert the direct current into alternate current capable of entering to the power grid. There are some basic concepts that must be clear before entering the designing part. In order to facilitate the understanding of such, **Figure 1.1** illustrates the typical I-V curve (output current I as a function of applied voltage V) of a PV module which represents the output current of a PV cell or module under certain weather conditions when some voltage is being applied [1]. In order to understand further definitions and principles, some essential concepts are presented below:

a. Manufacturer terms:

- **Short Circuit Current (I_{sc})** is the maximum possible current that can be generated by a solar module at rated irradiance and temperature and the voltage is equal to zero.
- **Open Circuit Voltage (V_{oc})** is the voltage of the PV module when no current flows through it.
- **Standard Test Conditions (STC)** are a set of environmental parameters under which the PV module is able to work under rated values. Usually these values are irradiance 1000 W/m^2 , ambient temperature $25 \text{ }^\circ\text{C}$ and 1.5 Air Mass ratio.
- **Peak Power (P_p)** is the power produced by the PV module when it works under rated conditions.
- **Maximum Power Point (MPP)** is the voltage-current pair where the PV module delivers the maximum power output possible for certain irradiance and temperature.
- **Maximum Power Voltage (V_{mp})** is the voltage at which the MPP can be reached. This will be the rated voltage provided by the manufacturer if it works at STC.
- **Maximum Power Current (I_{mp})** is the current output when the maximum power voltage is applied.

b. Photovoltaic physics terms:

- **Photo-Current (I_{ph})** is the maximum possible current that can be generated by a solar module at a certain irradiance level and ambient temperature.
- **Series Resistance (R_s)** is the series resistance that accounts for base resistivity, metal-semiconductor contact resistance. Basically, it represents the losses due connections of the PV or solar cells to each other.
- **Shunt Resistance (R_{sh})** is a parasitic parameter that measures imperfections in the manufacturer process and alternative path that the current could take. The lower this value is, the higher the current losses will be [2].
- **Solar radiation** is the Sun output, it ranges from high-energy, short-wavelength gamma rays to low-energy, long-wave radiation known as radio waves. In between these extremes, starting from the short-wave end of the spectrum are x-rays, ultraviolet radiation, visible light, and heat (infrared radiation). While the Sun releases numerous forms of energy, most of it (about 40%) is infrared radiation (heat) and visible light (about 55%). Traveling at a speed of 186,000 miles per second, solar energy takes 8.3 minutes to make its 93-million-mile journey from the Sun to the Earth [2].
- **Irradiance** is the amount of solar radiation striking a square meter of the Earth's atmosphere or the Earth's surface is known as irradiance. It is measured in watts per square meter. Solar irradiance measured just before the Sun's radiation enters the Earth's atmosphere is about 1366 W/m^2 . On a clear day, nearly 30% of the Sun's radiant energy is absorbed and converted into heat or reflected by dust and water vapor in the Earth's atmosphere. By the time the incoming solar radiation reaches a solar array on a roof, the incoming solar radiation is reduced to about 1000 W/ m^2 [2].
- **Irradiation** is an important measurement which most of the solar installers need to know. It is irradiance over time, the amount of energy they can expect to strike a PV array. Irradiance over a period of time is referred to as solar irradiation [2].

c. Related terminologies:

- **Solar cell** is an electrical device capable to generate electricity in the presence of solar radiation.
- **PV module** is a group of solar cells usually connected in series. Typical PV modules can have 36, 60 and even 90 cells [3].
- **PV string** is a group of PV modules connected in series.
- **PV array** is a group of PV strings connected to each other in parallel to a load. In the case of large scale projects they are usually connected to a centralized inverter.
- **Battery bank** is a set of batteries connected in parallel and/or series that can storage the DC current generated by the PV for further use.

- **Inverter** is an electrical device capable to convert direct current (DC) power output from the PV module to alternating current (AC) power use in other electrical devices or the power grid.

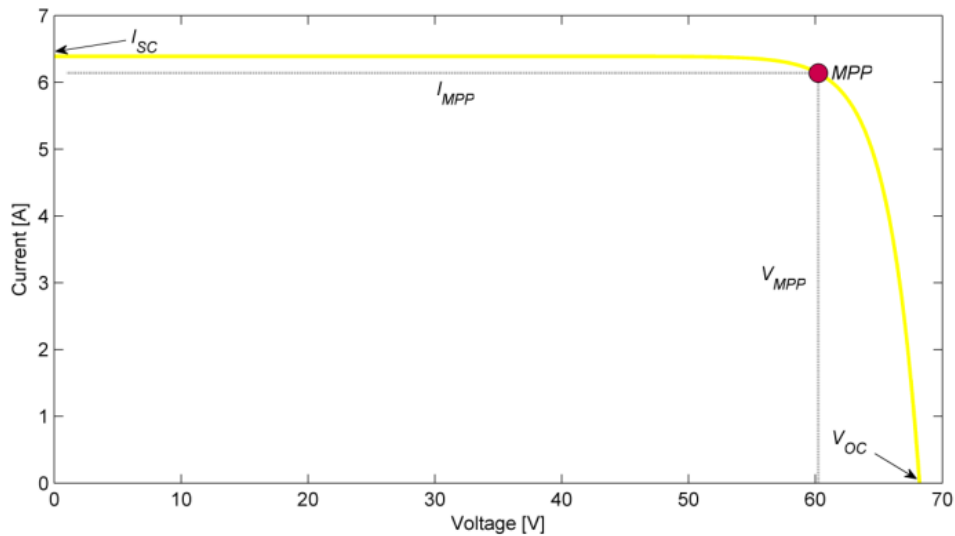


Figure 1.1 Characteristic of I-V curve for a PV module [1]

The I-V curve represents the performance of a single PV panel, string or array. It defines the maximum power point of operation possible under the current weather conditions. At rated conditions (usually STC), the PV system will give rated power. However, this will not happen most of the time because the performance of the PV is highly dependent on weather conditions. As such, the curve will change when the radiation and ambient temperature do.

1.2 Structure of a PV system:

Solar PV system includes different components that should be selected according to your system type, site location and applications. A balance system of numerous components, that are wired together to form the entire fully functional system capable of supplying electric power are:

1.2.1 PV generator:

Since an individual cell produces only about V_d which is equal to 0.6 volts, however real-life applications requires too much higher voltages, PV cells are pre-wired in series and enclosed in weather-resistant package, known as “PV Module”.

Typical modules comprise 36, 54 or 72 of cells wired in series. Multiple modules, in turn, can be wired in series to increase voltage and in parallel to increase current, the product of which is power. An important element in PV system design is deciding how many modules should be connected in series and how many in parallel to deliver whatever energy is needed [3].

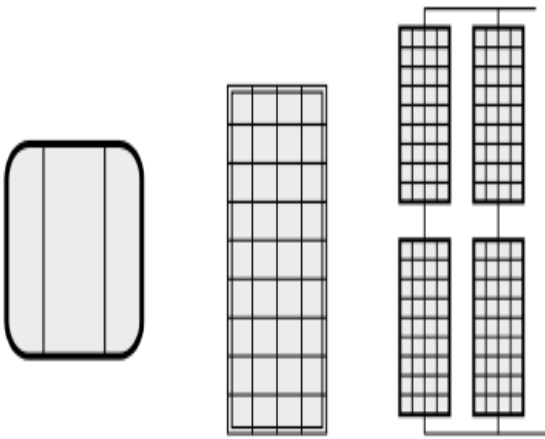


Figure 1.2 Solar cell, module and array [3].

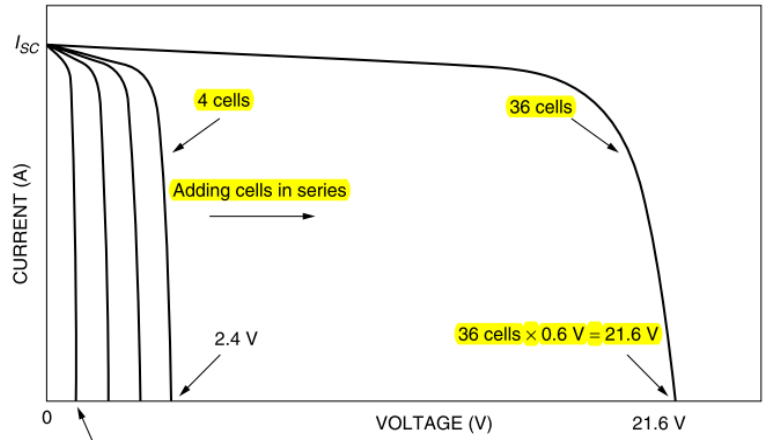


Figure 1.3 The I-V curve for different number of cells [3].

The voltage that appears across a module that is made from n cells can be estimated using this equation:

$$V_{module} = n(V_d - R_s \times I) \quad (1.1)$$

The PV generator is mounted on a mechanical support with or without tracking system.

1.2.2 Storage unity:

Storage elements are super important due to the fact that solar energy supply is intermittent. Different energy storage technologies are available but the most used one with PV system is the battery [3].

These batteries can come really in handy where the PV generator fails to meet the load demand.

Some super useful concepts related to batteries are briefly explained below [3]:

- **Capacity (C_b)** is the amount of electrical energy the battery contains, measured in ampere hours (AH):

$$C_b = \text{Amps} \times \text{Hours} \quad (1.2)$$

- **State of Charge (SOC)** is the available battery capacity.
- **Depth of Discharge (DOD)** is the energy drawn from the battery.
- **Efficiency** which represents the output energy over the input one (typically 80-85%)

Even though different exotic technologies are available now for the design of high performance batteries. It is the familiar lead-acid or lithium batteries that continue to be the workhorse of PV system [3].

1.2.3 Power conditioning and control circuits:

For each combination of temperature and irradiance, the PV module will have a unique I-V curve and MPP. As an example, it can be seen in **Figure 1.4** that there is only one value for the current and the voltage where the PV module will deliver the maximum power output possible. In order to reach this point of operation, the working voltage of the PV must be regulated. This can be done with a maximum power point tracker (MPPT). Without a MPPT the PV module has to work at a fixed load voltage which normally is not the most efficient point since the weather conditions will vary during the day and the voltage will remain the same [4].

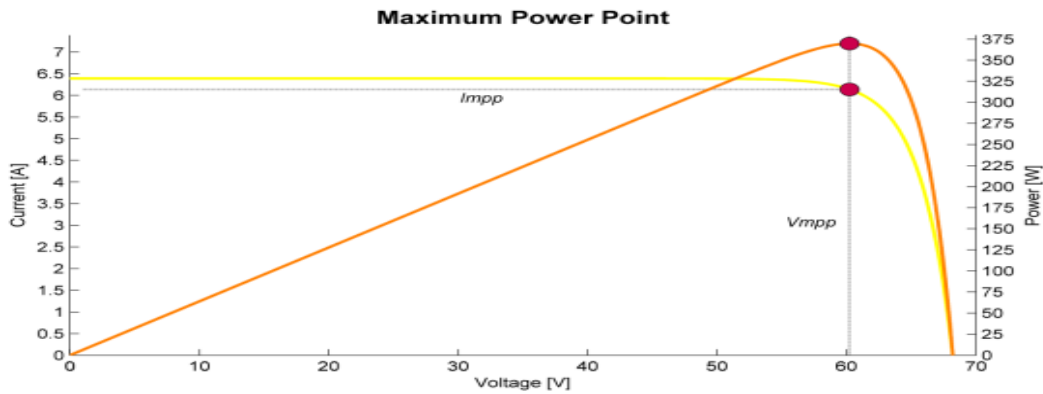


Figure 1.4 Maximum power point for irradiance of 800w/m^2 and ambient temperature of 28°C [4]

For large scale PV applications the MPPT is included in an inverter. DC/AC inverters work with an input window voltage in which the voltage of the array can be controlled in order to always reach the MPP of the array. Another reason to control the voltage in large scale PV is that working outside the voltage window of the inverter will increase the ripple factor of the DC voltage and the quality of the AC power will decrease. If the MPP of the array is located outside the voltage window, the working voltage can be set somewhere close to these limits in order to not interrupt the power supply.

For arrays connected to a battery bank, charge controllers can be used. These devices work as DC/DC converters that use internal algorithms based on the I-V and power curves showed before to control and determine the V_{mpp} for that instant. After that, the voltage can be converted to a constant load voltage if necessary [4].

1.2.4 Buck-up generator:

Having a backup power associated with your solar power system can still be desirable for peace of mind. The backup generator can use a number of different types of fuel such as natural gas, gasoline, diesel, or propane.

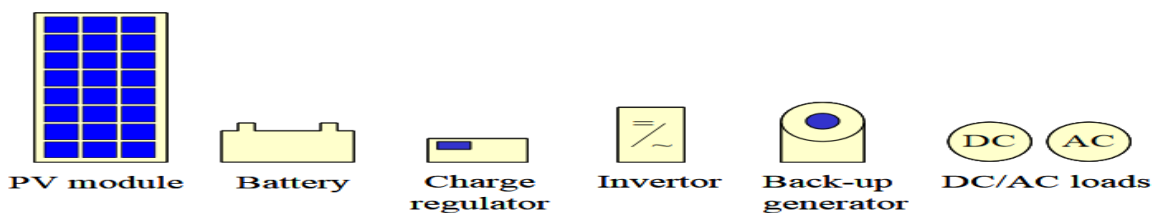


Figure 1.5 The component of PV system [4].

1.3 Partial shading:

One of the problems that PV farms can have is partial shading. This occurs when a section of the PV module is covered by a shadow and one or more of its cells have a different irradiance than the ones that are fully illuminated. This results in a different I-V curve and point of operation for the shadowed cells. The fully illuminated cells will deliver a higher current. Since all the cells are connected in series, the shadowed cells are obliged to let through the higher current. The only way that this can happen is that the cell produces a negative voltage and works in reverse bias, this means that the shadowed cell will work as a load. Letting a higher flow of current going through a shadowed cell will produce hot spots and the cell can get severely damaged due to significant increase on its temperature [1].

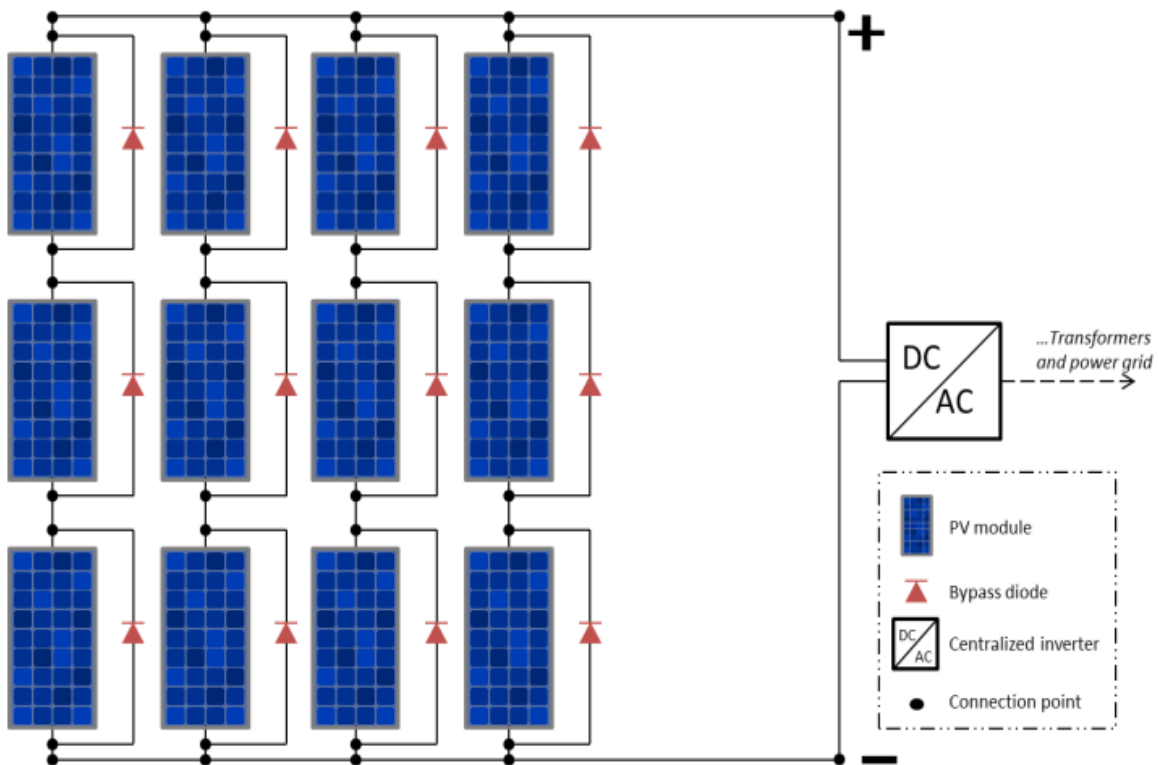


Figure 1.6. Layout of PV array with four strings for a centralized inverter configuration [1].

To avoid this, bypass diodes are used to offer an alternative path to the current when these situations occur. A bypass diode can be activated if 20% of irradiance reduction is presented on the shadowed cell. Since it is considered too expensive to use a bypass diode for each cell, usually they are used with a group of cells. A common practice is to use a diode every 18 cells [1].

Similar to the case of the PV modules and its cells, if a PV string has one of its modules under shadow it may be necessary to bypass it completely to avoid irreversible damage on the module. When the bypass diodes are activated, a power reduction on the string is presented due to an alteration of its I-V and its optimal power point. As an example, let's take one of the strings of **Figure 1.6**. Assuming one of the PV is fully illuminated getting 1000 W/m^2 and the other two 10% and 17% less irradiance respectively, the power curve would be as presented in **Figure 1.7**

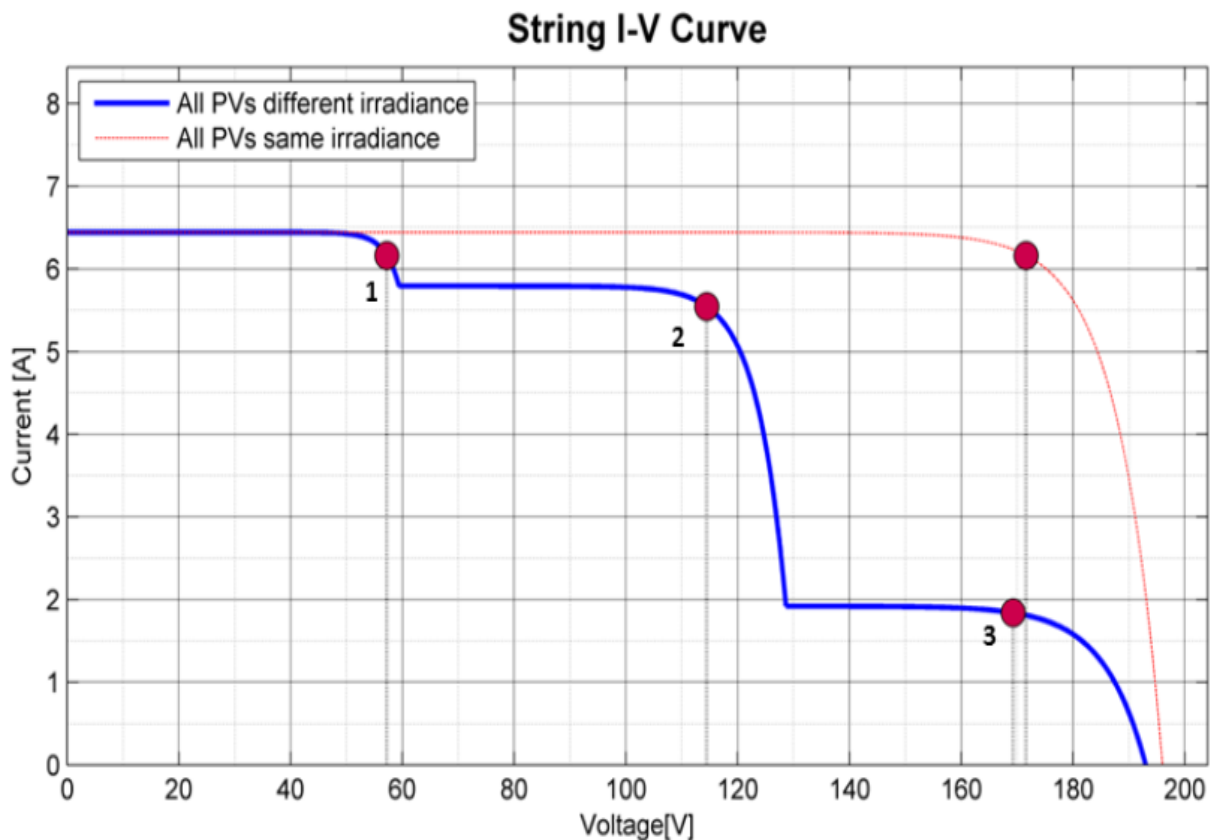


Figure 1.7. Effect of partial shading on a three PV system module [1].

The fully lighted PV string is under 1000 W/m^2 , whereas the other two strings have 10 percent and 70 percent less irradiance respectively [1].

Compared to the ideal scenario where all the PV modules are under the same irradiance (red curve), the string curve under partial shading presents a clear power reduction. Since all the PV modules cannot give the same current, the array will have three local MPP and only one of the PV modules will work under maximum power capacity in each of them.

In situations like this it is very important to have bypass diodes and good control strategies in order to avoid damage to the system and try to get the higher power output possible. If the string is set to work under point three conditions all the PV modules will generate power and none of them will be bypassed, however the power output and the current will be very low compared to the maximum available. At point two there will be more output current and less voltage compared to point three, also, as it can be observed in **Figure 1.8**, the power output will be the maximum possible.

However, if this point is chosen the PV module number three needs to be completely bypassed since the current chosen is too high for it to handle under those conditions. Finally, at point 3 higher and lower voltage than point two are used. At this point it may not be necessary to bypass the PV module number two since the difference in irradiance is not too high [1].

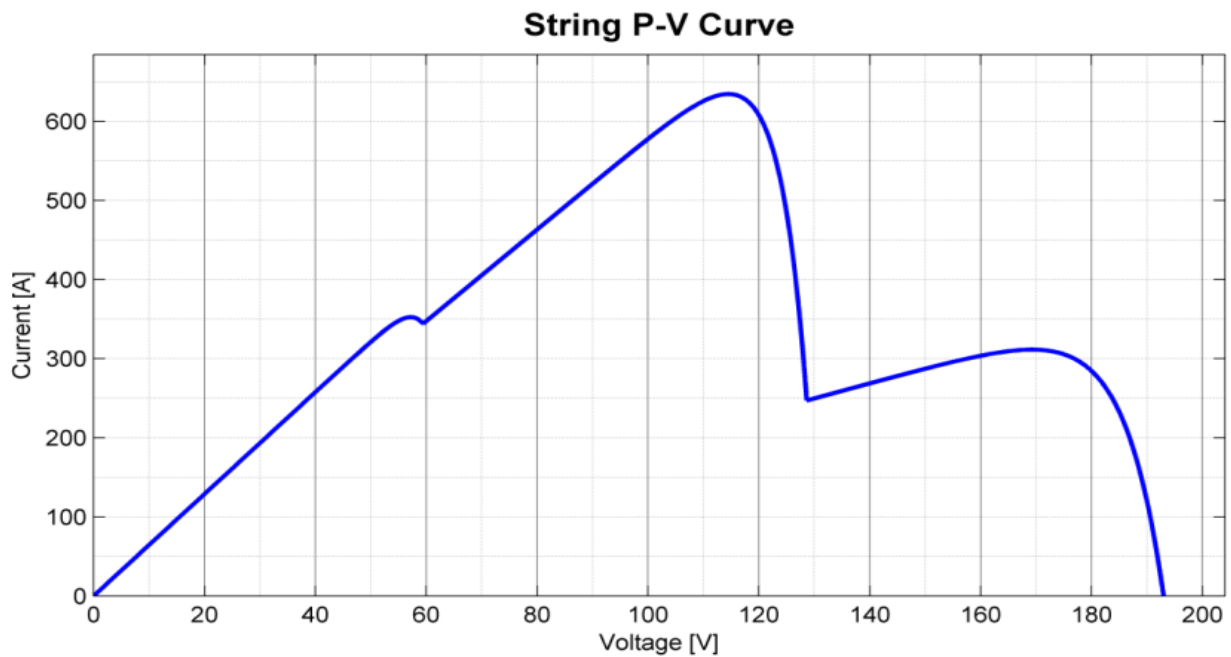


Figure 1.8. Effect of partial shading on single PV string [1].

It is important to keep in mind that the maximum power point of the shadowed string may not be necessary the ideal working point. Assuming the other three strings are fully illuminated (see **Figure 1.6**) the working voltage of the whole array will be the one used in these strings (since they are four in total and only one is partially shaded) and the shaded string will have to work somewhere around point three.

If more strings would have been under shaded condition, the optimal MPP may lay outside the voltage window of the inverter. In this case, the working voltage can be set to a value close to the lower limit of the window in order to do not stop the power production [1]

As it could be seen centralized PV arrays have the disadvantage that all the strings have to work at the same voltage. This can reduce significantly the power output of the PV array, especially if the system is located around structures that can generate shadow at certain points of the day or year. However, large scale PV systems are usually located in plain terrains outside the cities where no shadows from structures can be place on them at any time of the year. The source of shadow may also come from the string in front but this can be easily anticipated in the design stage. It will be needed to keep in mind that if the distance between each string is increased the land usage and the cable distance may increase. These two factors are proportional to the cost of the project. However, this will be very unique to each location due to solar position, local labor and material costs.

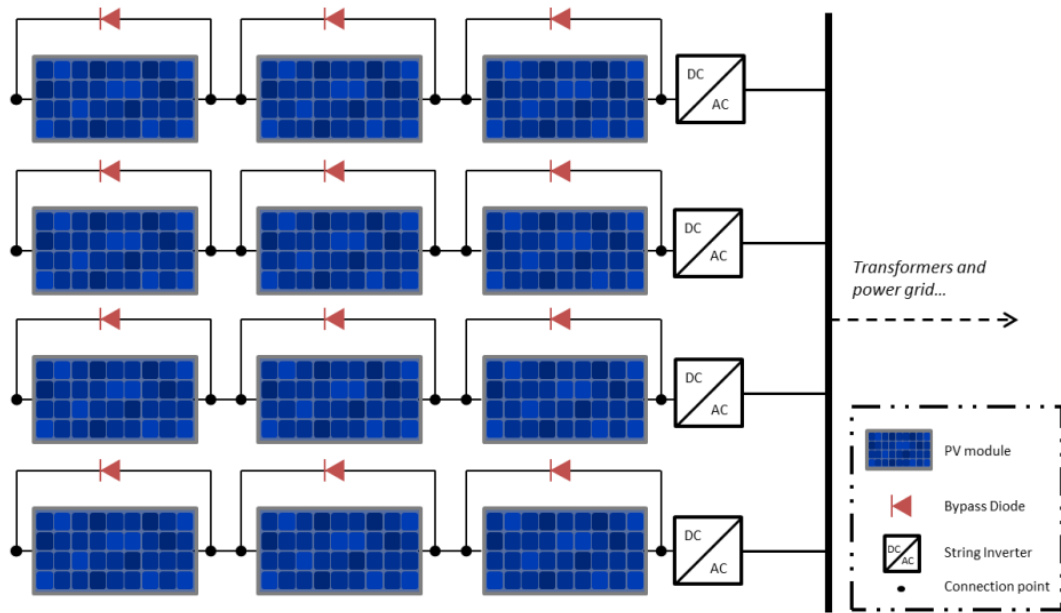


Figure 1.9. Layout of PV array with four strings with string inverters configuration [1].

1.4 Types of PV systems:

The choice of which and how the previous components to be integrated into the system decides the desirable application of the PV system.

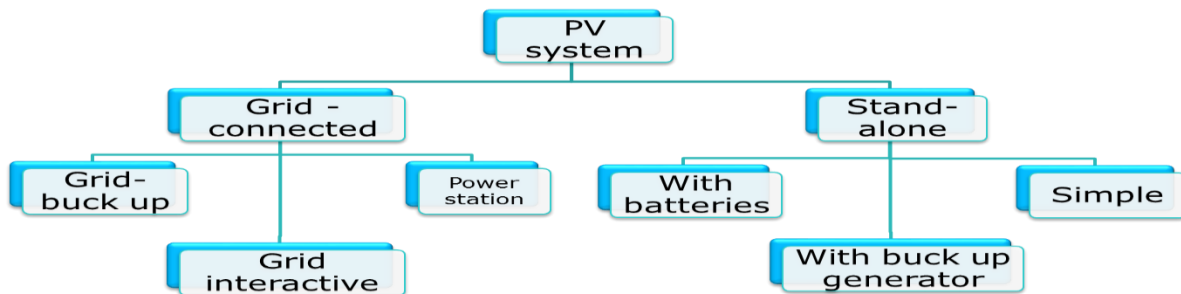


Figure 1.10 Types of photovoltaic systems [3].

PV systems can be very simple, just a PV module and load, as in the direct powering of a water pump motor, or more complex, as in a system to power a house. While a water pump may only need to operate when the sun shines, the house system will need to operate day and night. It also may have to run both AC and DC loads, have reserve power and may include a back-up generator. Depending on the system configuration, we can distinguish three main types of PV systems: stand-alone, grid-connected, and hybrid. In either case, basic PV system principles and elements remain the same. Systems are adapted to meet particular energy requirements by varying the type and quantity of the basic elements [2].

1.4.1 Direct coupled PV system:

In a direct-coupled PV system, the PV array is connected directly to the load. Therefore, the load can operate only whenever there is solar radiation, so such a system has very limited applications.

A typical application of this type of system is for water pumping, i.e., the system operates as long as sunshine is available, and instead of storing electrical energy, water is usually stored.

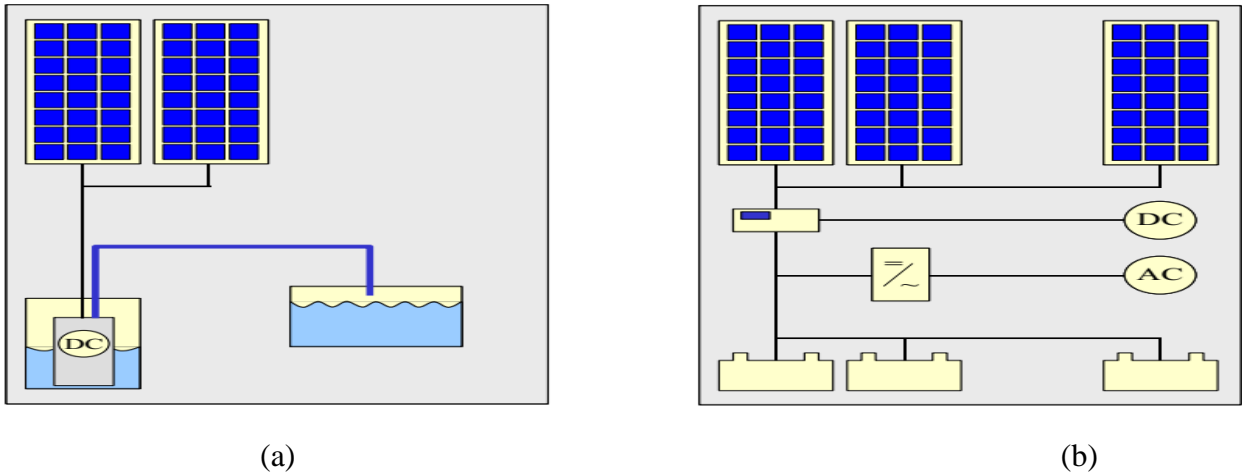


Figure 1.11 Schematic representation of (a) a simple DC PV system to power a water pump, (b) a complex PV system including batteries, power conditioners, and both DC and AC loads [2].

1.4.2 Standalone system:

Stand-alone PV systems are used in areas that are not easily accessible or have no access to an electric grid. A stand-alone system is independent of the electricity grid, with the energy produced normally being stored in batteries. A typical stand-alone system would consist of a PV module or modules, batteries, and a charge controller. An inverter may also be included in the system to convert the direct current generated by the PV modules to the alternating current form required by normal appliances.

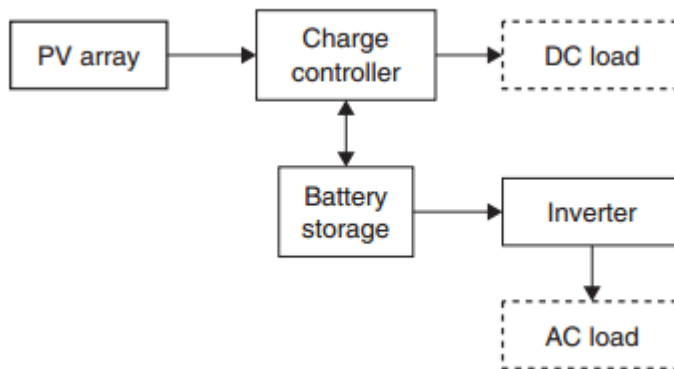


Figure 1.12 Schematic diagram of a stand-alone PV application [4].

A schematic diagram of a stand-alone system is shown in **Figure 1.12**. It can be seen that this system can satisfy both DC and AC loads simultaneously.

1.4.3 Grid connected system:

Nowadays, it is a usual practice to connect PV systems to the local electricity network. This means that, during the day, the electricity generated by the PV system can either be used immediately (which is normal for systems installed in offices, other commercial buildings, and industrial applications) or be sold to one of the electricity supply companies (which is more common for domestic systems, where the occupier may be out during the day).

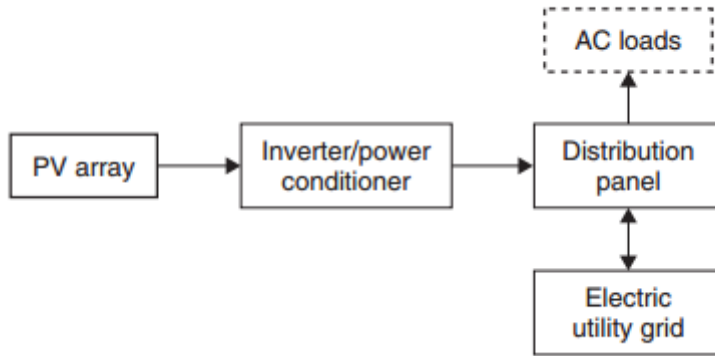


Figure 1.13. Schematic diagram for a grid connected system [4].

In the evening, when the solar system is unable to provide the electricity required, power can be bought back from the network. In effect, the grid is acting as an energy storage system, which means the PV system does not need to include battery storage.

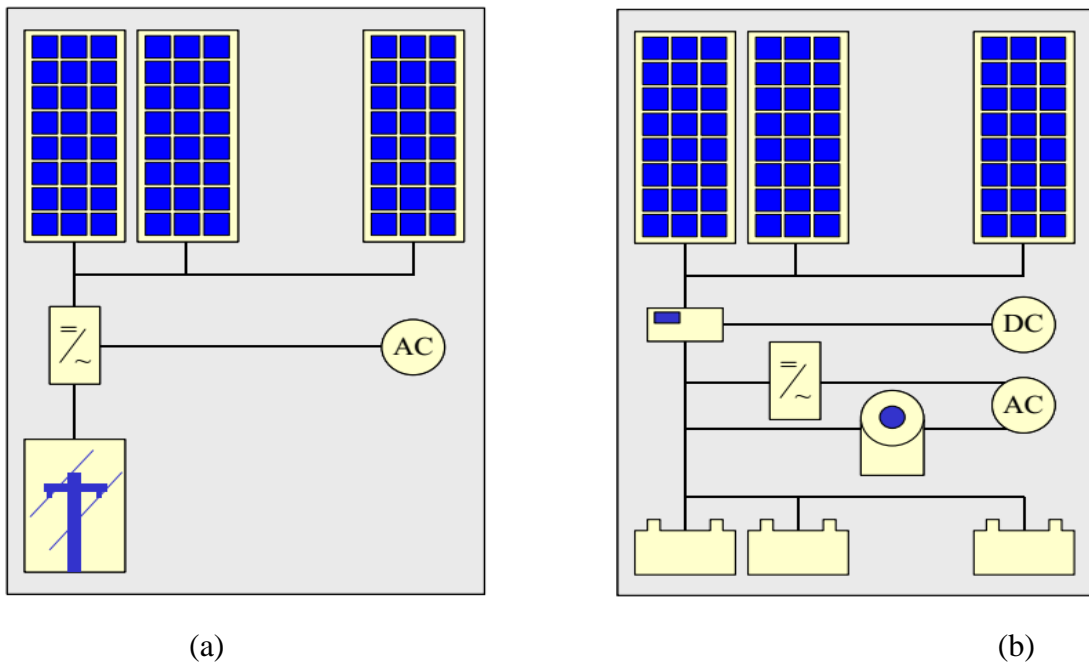


Figure 1.14 Schematic representation of (a) a grid-connected PV system, (b) a hybrid system [2].

1.4.4 Hybrid connected system:

In the hybrid-connected system, more than one type of electricity generator is employed. The second type of electricity generator can be renewable, such as a wind turbine, or conventional, such as a diesel engine generator or the utility grid. A schematic diagram of a hybrid-connected system is shown in **Figure 1.14b**. Again, in this system, both DC and AC loads can be satisfied simultaneously.

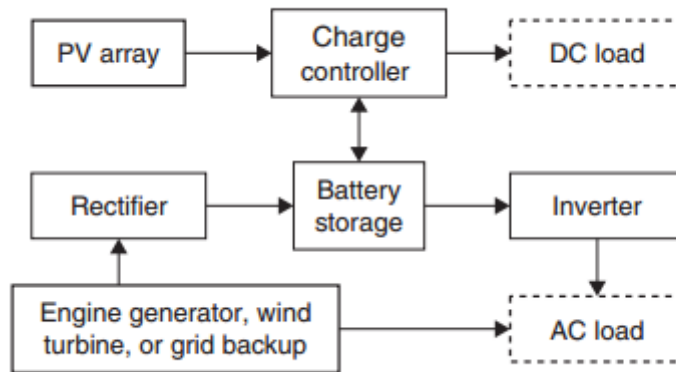


Figure 1.15 Schematic diagram for a hybrid system application [4]

1.5 PV power system design guide:

Sizing of a PV system means determining how much energy is required to run the system and how many PV modules are required to generate it. A PV system has to generate enough energy to cover the energy consumption of the loads (lights, appliances, equipment) and energy used by the system itself. The accurate design of a PV system is usually carried out using a computer model, which calculates the energy yield of the PV system for a particular location. The size and configuration of solar array is then optimized in order to match the energy yield of the system to the energy consumption of the system. The energy yield of a PV system depends on the type of PV modules, the characteristics of a PV inverter, the orientation of the modules, and meteorological conditions.

If such models are not available, then a rough estimate of the sizing of a PV array and batteries can be calculated using the following design rules:

- Determine the total load current and operational time.
- Add system losses.
- Determine the solar irradiation in daily equivalent sun hours (T_{avg}).
- Determine total solar array current requirements.
- Determine optimum module arrangement for solar array.
- Determine battery size for recommended reserve time.

Much more details will be well explained in the upcoming sections.

1.5.1 Input parameters:

The PV system design guide can be divided into three parts. The first part is in charge of collecting all the desired data which involves determining the load profiles, the technical data from the PV modules, storage bank and the inverter, as well as the meteorological data at the specified location.

First of all, all the electrical devices available at the plant must be itemized with their power ratings and time of operation during the day to obtain the average energy demand in Watt-hour per day. Later on, the total daily energy in Watt-hours (E_T) is estimated.

The average sun hour per day (T_{avg}), and the DC-voltage of the system (V_{DC}) must be determined. To avoid under sizing, losses must be considered by dividing E upon the product of efficiencies of all components in the system to get the required energy (E_r).

$$E_r = \frac{E_T}{\eta_{overall}} \quad (1.3)$$

To obtain the peak power, the previous result is divided by the average sun hours per day.

$$Pp = \frac{E_r}{T_{avg}} \quad (1.4)$$

The total load current (I_{DC}) needed can be calculated by dividing the peak power over the DC voltage of the system:

$$I_{DC} = \frac{P_p}{V_{DC}} \quad (1.5)$$

Once these factors are made available we move to the sizing process.

1.5.2 Sizing of the PV solar plant:

Once the input parameters are set, the next step is to size the solar plant. When sizing a PV solar plant, the following must be accurately acquired:

- The necessary number of strings and how many modules are connected per each string.
- Sizing the battery bank or banks according to the plant needs and days of autonomy.
- Which charge regulator to use and how many of them are required?
- Which inverter to use and how many in case of a string inverter?

a. Sizing of the solar array:

Modules must be connected in series and parallel according to the need to meet the desired voltage and current:

First, the number of parallel strings equals the whole modules current divided by the rated current of one module I_r [5].

$$N_p = \frac{\textit{Whole Module Current}}{\textit{Rated Current of one Module}} = \frac{I_{DC}}{I_r} \quad (1.6)$$

Second, the number of series modules equals the DC voltage of the system divided by the rated voltage of each module V_r [5].

$$N_s = \frac{\textit{System DC voltage}}{\textit{Module Rated voltage}} = \frac{V_{DC}}{V_r} \quad (1.7)$$

Finally, the total number of modules N_m [5] is equal to:

$$N_m = N_s \times N_p \quad (1.8)$$

b. Sizing of the battery bank:

The amount of rough energy storage required is equal to the multiplication of the total energy demand and the number of autonomy days:

$$E_{rough} = E_T \times D. \quad (1.9)$$

For safety, the result obtained is divided by the maximum allowable level of discharge (MDOD):

$$E_{safe} = \frac{\textit{Energy Storage required}}{\textit{MDOD}} = \frac{E_{rough}}{\textit{MDOD}} \quad (1.10)$$

At this moment, we need to make a decision regarding the rated voltage of each battery (V_b) to be used in the battery bank. The capacity of the battery bank needed in ampere-hours can be evaluated by the following equation [5]:

$$C = \frac{E_{safe}}{V_b} \quad (1.11)$$

Another decision has to be made regarding the capacity C_b of each of the batteries of that bank. The total number of batteries is obtained by dividing the capacity of the battery bank in ampere-hours by the capacity of one of the selected battery in ampere-hours:

$$N_{batteries} = \frac{C}{C_b} \quad (1.12)$$

The connection of the battery bank can be then easily figured out. The number of series batteries N_s can be found using:

$$N_s = \frac{V_{DC}}{V_b} \quad (1.13)$$

Then, the number of parallel paths N_p :

$$N_p = \frac{N_{batteries}}{N_s} \quad (1.14)$$

Once the sizing of the battery bank is made available [5], we proceed to the next system component.

c. Sizing of the voltage controller:

According to its function it controls the flow of current. A good voltage regulator must be able to withstand the maximum current produced by the array as well as the maximum load current. Sizing of the voltage regulator can be obtained by multiplying the short circuit current of the modules connected in parallel by a safety factor F_{safe} [5]. The result gives the rated current of the voltage regulator (I_{Tr}):

$$I_{Tr} = I_{sc} \times N_p \times F_{safe} \quad (1.15)$$

The factor of safety is employed to make sure that the regulator handles the maximum current produced by the array that could exceed the tabulated value and to allow the system to expand slightly.

The number of controller [5] equals the Array short current Amps divided by the Amps for each controller:

$$N_{controller} = \frac{I_{Tr}}{I_{controller}} \quad (1.16)$$

d. Sizing of the inverter:

When sizing an inverter [5], the actual power drawn from ‘k’ appliances that will run at the same time must be determined as a first step.

$$P_{out} = (1.3) \times \sum_{i=1}^K P_i \quad (1.17)$$

The rating of the inverter must be greater than the total watt of appliances (P_i).

The inverter must have the same nominal voltage V_{DC} as the battery used. Plus, it must be able to handle the maximum voltage produced by the array.

e. Sizing of the system wiring:

Selecting the correct size and type of wire will enhance the performance and reliability of the PV system according to the National Electrical Code (NEC).

1.5.3 The output of PVPP:

The size or capacity of the installed PV solar power plant must at least cover the daily electrical consumption in case of a standalone PV system. Such system is the one to be the investigated system in the simulation part.

1.6 PV systems installation and operation:

1.6.1 PV system installation:

In most cases PV modules contain sheets of glass, which protect the solar cells, and therefore they should be handled with care. Orientation of the panel has to be accurate to within 20° of the right direction. The support structure determines a tilt-angle of a module. In roof-mounted systems, adjustment of the orientation and tilt angle is usually quite difficult [2]

Lead-acid batteries that have vents should be supplied dry-charged so that they can be filled with acid at the site of installation. After the battery is filled, acid should never be emptied out. When installing batteries, special care should be taken to connect them with the right polarity and in the right configuration (series-parallel) [2]

For systems connected to the mains, there is only one voltage rating for the whole installation. However, the low DC voltage in PV systems could have several different voltages at the same time. The correct polarity should be maintained in all connections. Using a red wire for all positive connections and a black one for negative (ground) is advisable [2].

1.6.2 PV system operation:

PV systems can generate high voltages. Safety is therefore very important in order to avoid accidents and damage of expensive components and equipment. For safety reasons, solar arrays are normally earthed, either by placing a matrix of metal in the ground under the array, or by using conventional earth rods [2].

It is normally not necessary to protect solar array from direct lightning strikes, provided that their mounting structure is well earthed. However, inverters or other electronics controls connected to the array should be protected. Blocking diodes are installed in solar arrays to prevent reverse current flows into the modules, which may damage the modules and cause energy losses. By-pass diodes are incorporated into modules to prevent damage of arrays when some cells or modules become shaded.

PV system requires regular maintenance to ensure proper operation and the full life of components. Some of the most important maintenance tasks are cleaning of modules front, removal obstacles, tree branches, etc. which cause shadowing of the modules. Battery charge check, if it remains very low the system should be re-designed, topping of battery electrolyte. The rest of components of PV systems require little or no maintenance [2].

Conclusion:

So far, the most relevant technical concepts of PV system engineering have been covered in this chapter, starting from the solar electric system design till finishing up by the photovoltaic system operation and installation.

However, since this thesis aims to integrate the PV solar system in the agriculture field, laying hen's farms to be more specific. Then it would be really handfull to step inside these farms and shade the light upon their installed electric system concerning the lighting design and ventilation systems. All of which will be well explained in the next chapter.

Chapter 2: Lighting and Ventilation System Design for Egg Production Farms.

Light is an essential aspect of poultry production. In most housing systems, artificial light is utilized to maximize egg production. Today, a variety of different bulbs are available to illuminate the inside of a poultry house, all of which have benefits and shortcomings. Understanding the different lighting options available for poultry, as well as the management of light is essential to achieve the best production.

In the other hand, the importance of providing the birds with the correct environment is becoming overlooked due to the rapidly increasing cost. Indeed, trying to limit the amount of heat units used is in most cases a false economy. However, when selecting the most efficient fan on the market, energy savings are possible.

In this chapter, a technical debrief of the lighting system design will be covered in conjunction with satisfying the requirements of manufacturability and availability of poultry farms' lighting system. Afterwards, how to properly size and select the most efficient electrical fan, which can be installed in a laying hen's farm, will be well educated.

Part I: Generalities about the lighting system design:

Lighting designers must be aware of different technical concepts especially when designing for non-residential buildings. Different technical concepts will be presented in this section such as laws of illumination, different types of luminaires and finishing with understanding the lighting system for the poultry farms.

2.1 Lighting fundamental definitions:

- **Luminous flux** it is the total emitted visible light from a bulb, measured in lumens [6].
- **Luminous intensity (I)** represents the directional flux which quantifies the luminous flux emitted by a light source in a certain direction, measured in candelas or candles [6].

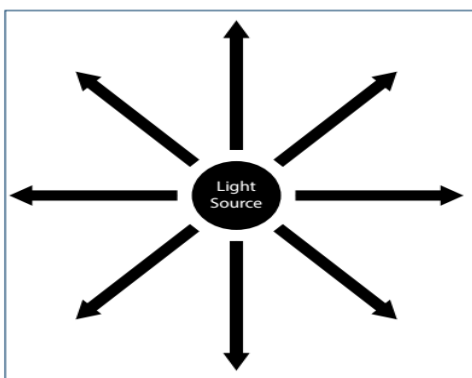


Figure 2.1 Demonstration of luminous flux [6].

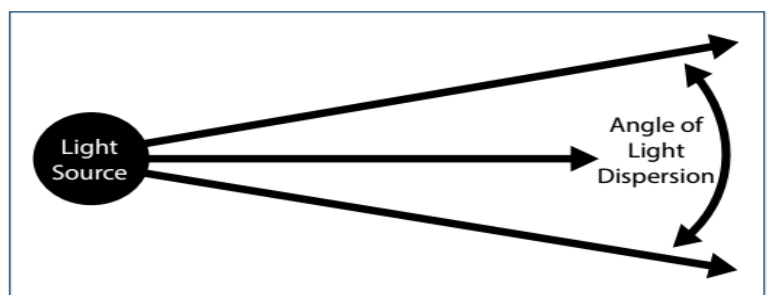


Figure 2.2 Demonstration of luminous intensity [6].

- **Luminous power (E)** is the luminous flux per area illuminated by the light, measured in lux or foot candles (fc) [6]. The calculation is $1 \text{ lux} = 1 \text{ lumen/m}^2$ or $1 \text{ lux} = 0.0929 \text{ fc}$. The conversion between the two units is $1 \text{ fc} = 10.76 \text{ lux}$ or $1 \text{ lux} = 0.0929 \text{ fc}$. This means that the same light will be brighter closer to the light source, and dimmer farther away as the beam spreads out [6]. Luminous power is equivalently called the **illuminance** as it is illustrated in **Figure 2.3**.
- **Luminance** is a measure of the light reflected from a surface measured in candela / m^2 [6].
- **Luminous efficacy** is the ratio of the luminous flux emitted by a lamp to the power the lamp consumes this is measured in lumens per watt [6].
- **Color rendering index (CRI)** measures how an artificial light source displays the color of an object compared to the color of that object in natural light. CRI is measured on a scale of 0–100, with 100 being the closest to natural light. Overall, CRI differences less than 5 (i.e. 80 to 84) are not noticeable to the human eye. The CRI system was originally developed for incandescent lights.

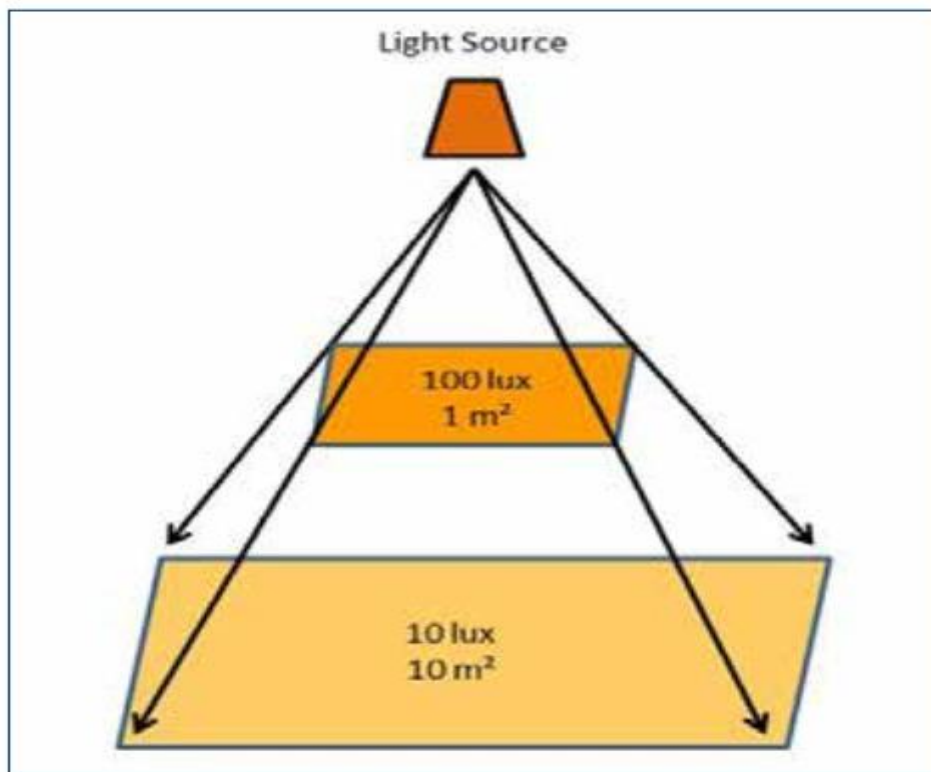


Figure 2.3 Demonstration of different light intensities at different distances from the same light source [6].

2.2 Laws of illumination:

For the lighting design to be as efficient as possible, there are certain rules such as the uniformity of light, avoiding the shadowing, that must be followed. However these rules will be meaningless with the proper knowledge of the illumination laws which allow the light designer to calculate the illuminance at any point of the plane.

2.2.1 The inverse square law of illuminance:

This law states that the Illuminance (E) at any point on a plane perpendicular to the line joining the point and source is inversely proportional to the square of the distance between the source and the plane [7]. The following equation describes this concept exactly:

$$E = \frac{\text{Luminous Intensity}}{d^2} = \frac{I}{d^2} \quad (2.1)$$

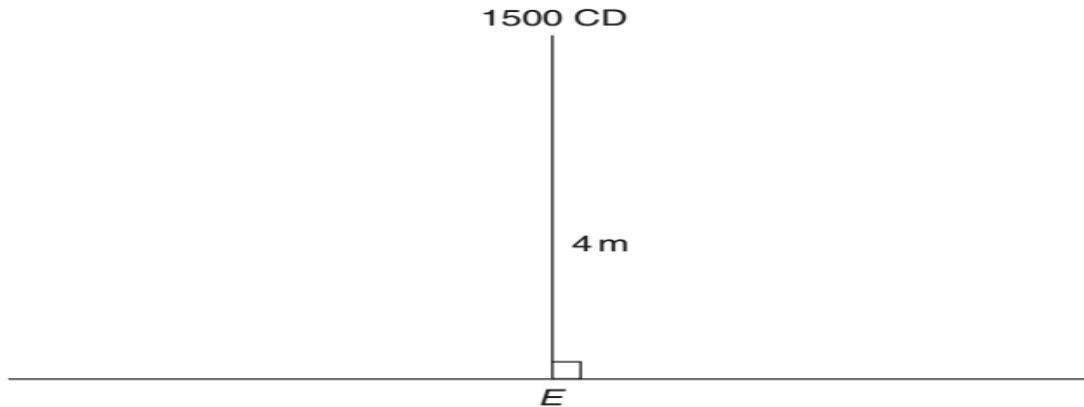


Figure 2.4 a luminaire that produces 1500 candela below the horizontal [7].

For instance, a luminaire producing a luminous intensity of 1500 candela in all directions below the horizontal, is suspended 4m above a surface. Let's calculate the illuminance produced on the surface immediately below the luminaire:

$$E = \frac{I}{d^2} = \frac{1500}{4^2} = 93.75 \text{ Lux}$$

So, as the calculation reveals, this luminaire emits 93.75lux toward the horizontal plane.

2.2.2 The cosine law of illuminance:

The law states that the illuminance at a point on a plane is proportional to the cosine of the angle of light incident (the angle between the direction of the incident light and the normal to the plane).

$$E = \frac{I_{\theta}}{x^2} \times \cos\theta \quad (2.2)$$

Where I_{θ} is the luminous intensity of the source in the direction of the illuminated point. θ is the angle between the normal to the plane containing the illuminated point and the line joining the source to the illuminated point. Whereas x is the distance to the illuminated point [7].

For example, a light source producing 1500 candela is suspended 2.2m above a horizontal surface. Let's calculate the illumination produced on the surface 2.5m away.

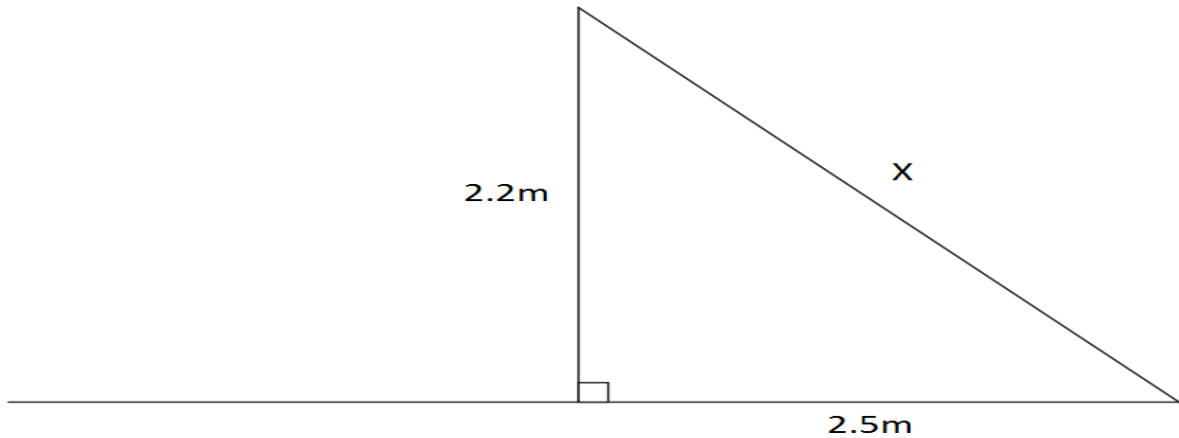


Figure 2.5 a luminaire that emits 89.26 lux, 2.5m away from the plane [7].

First of all, $\cos \theta$ must be calculated:

$$\cos \theta = \frac{2.2}{3.3} \cong 0.66$$

Then, using Pythagoras rule, x square can be calculated as follow:

$$x^2 = 2.2^2 + 2.5^2 = 11.09$$

Afterwards, applying the cosine law of illumination:

$$E = \frac{I_{\theta}}{x^2} \times \cos \theta = \frac{1500}{11.09} \times 0.66 = 89.26 \text{ Lux}$$

2.3 Lighting system design:

The lighting system design may involve so many aspects such as luminance, illuminance level measurements and so on. Indeed, all of these may differ from one lighting system to another, depending on whether the system is an indoor application or an outdoor one and then according to the specified task of the targeted application.

2.3.1 Indoor industrial areas:

To design an efficient lighting system for indoor applications, the following steps have to be respected [8]:

- Find the recommended level of illumination, extensive information on selecting appropriate illumination levels is contained in the SGS Lighting Handbook published by the Illuminating Engineering Society.
- Select the luminaire by choosing a lamp type and a lumen according to your application.
- Find the coefficient of utilization (CU) which is a very important factor in the lighting calculation. This CU is directly related to three major factors when considering interior lighting system:

- The efficiency and photometric distribution of the luminaire.
- The relative shape of the room.
- The reflectance of the room surfaces.

These factors are combined in a coefficient of utilization table for each different luminaire type [8].

- Determine the light loss factors (LLF), also called the maintenance factor. It is used to increase the initial illumination level to compensate for the normal deterioration of the lighting system in use. LLF values may be recommended by the luminaire manufacturer.
- Determine the number of luminaires N , using:

$$N = \frac{E \times A}{n \times LL \times CU \times LLF} \quad (2.3)$$

Where E , LL , A and n is the required level of illumination, the initial rate lamp lumens, the area of the space to be lighted and n is the number of lamps per luminaire respectively.

- Determine the luminaires distribution over the warehouse using these two equation:

$$N_L = \sqrt{\frac{N \times L}{W}} \quad , \quad N_W = \sqrt{\frac{N \times W}{L}} \quad (2.4, 2.5)$$

Where N_L , N_W are the number of columns and rows of the luminaires respectively distributed over the warehouse. Whereas L , W are the length and width of the warehouse respectively

- Finally, determine the final luminaire spacing. In addition to that the spacing between luminaires should be twice the distance of the spacing from the walls.

2.3.2 Outdoor industrial area:

Designing and installing a lighting system for an outdoor area differs somehow from an indoor area. For a proper lighting installation of an outdoor area, the following procedure has to be carried out:

- Determine the luminaire mounting height (MH), if possible, the luminaire mounting height should be at least one-half the width of the area being lighted. Lower mounting heights will reduce the utilization and uniformity.
- Calculate the aiming angle, maximum utilization is obtained when the aiming line bisects the angle drawn between the near and far side of the lighted area.
- Determine the utilization factor, the most difficult part of area-lighting design is determining the location of the edges of the lighted area in relation to the floodlight aiming line. This is needed to determine the lumens that will fall inside the area. This can be greatly simplified if the area is divided into a grid having the same scale as the floodlight mounting height.

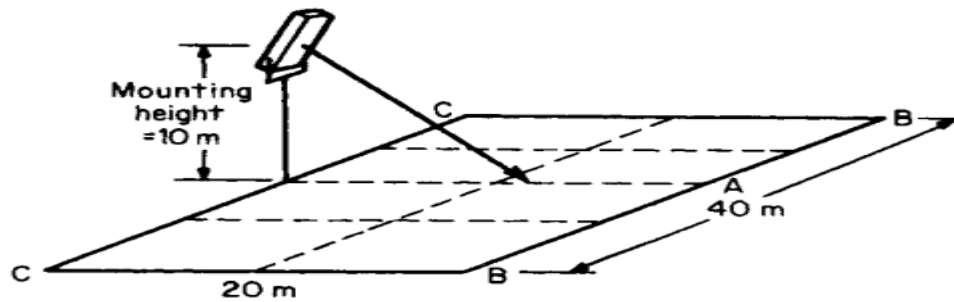


Figure 2.6 Layout for an outdoor area lighting design [8].

- Finally, calculate the level of illumination needed in this outdoor area:

$$\text{Average Lux} = \frac{LL \times CU \times LLF}{A} \quad (2.6)$$

Eventually, designing a lighting system must be as efficient as possible. This can be achieved by following the previous steps to the letter. No matter which lighting system is required, the norms must be well respected [8].

Apparently, we will be designing an indoor lighting system for the laying hen's farm. But which luminaire to choose is also a very important aspect in the process, this is why the upcoming section will technically compare between the available luminaires.

2.4 Light source selection:

Lights bulbs have seen tremendous development and significant improvement regarding efficiency, quality of light, density, and energy conservation. They are available in different shapes, sizes, voltages, and material.

The following section describes the most three common types of light bulbs along with their respective advantages and disadvantages.

2.4.1 Incandescent bulbs:

An incandescent bulb works on the principle of incandescence, a general term meaning light produced by heat. In these bulbs, an electric current is passed through a thin metal filament, heating this filament until it glows will produce light. These bulbs are made of tungsten filament due to its high melting point. A tungsten filament inside a light bulb can reach temperatures as high as 4,500 degrees Fahrenheit. A glass enclosure prevents the oxygen in the air from reaching the hot filament. Without this glass covering and the vacuum it helps create, the filament would overheat and oxidize in a matter of moments [9].

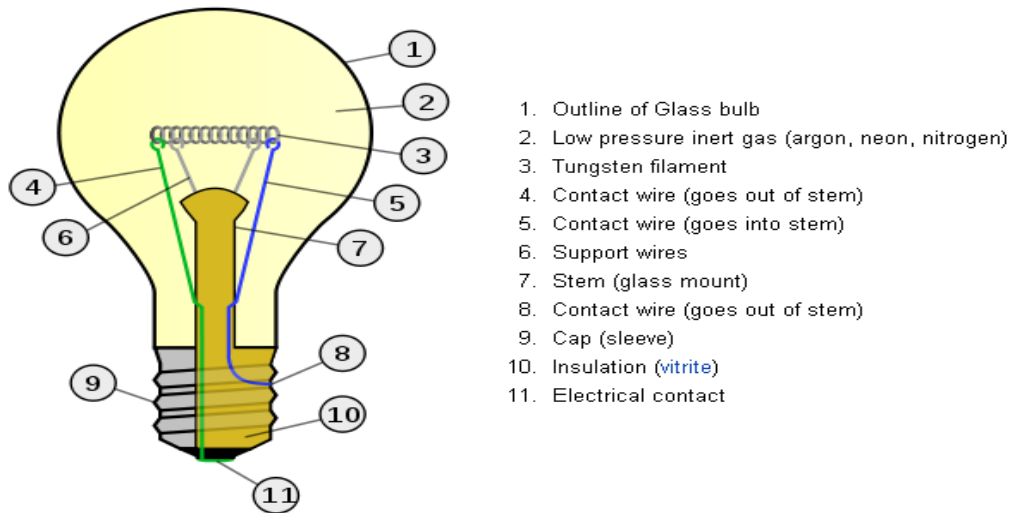


Figure 2.7 Incandescent light bulb’s different compositions [9].

After the electricity has made its way through the tungsten filament, it goes down another wire and out of the bulb via the metal portion at the side of the socket. It goes into the lamp or fixture and out a neutral wire.

This is an elegantly simple system and it works quite well at producing light. It’s perfect for a wide range of applications, cheap and easy to manufacture, and is compatible with either AC or DC current. **Table 2.1** gives more details about the advantages and disadvantages of the incandescent bulbs.

Table 2.1 Incandescent bulb’s shortcomings and benefits [6].

Luminaire type	Incandescent bulbs
Benefits	<ul style="list-style-type: none"> • Inexpensive • Good red spectrum output • Excellent light distribution • Quick to turn on • No difference in performance when used in cold or hot weather.
Shortcomings	<ul style="list-style-type: none"> • Short lifespan and must be frequently replaced. • Usually constructed of metal and glass and are prone to breakage <p>More than 90% of the energy used by the bulb goes to heat rather than light.</p> <ul style="list-style-type: none"> • Many types of incandescent bulbs do not comply with new energy efficiency standards.

2.4.2 Fluorescent tube lamp:

A fluorescent lamp is a low weight mercury vapor lamp that uses fluorescence to deliver visible light. An electric current in the gas energizes mercury vapor which delivers ultraviolet radiation through a discharge process and the ultraviolet radiation causes the phosphor coating of the lamp inner wall to radiate visible light [9]

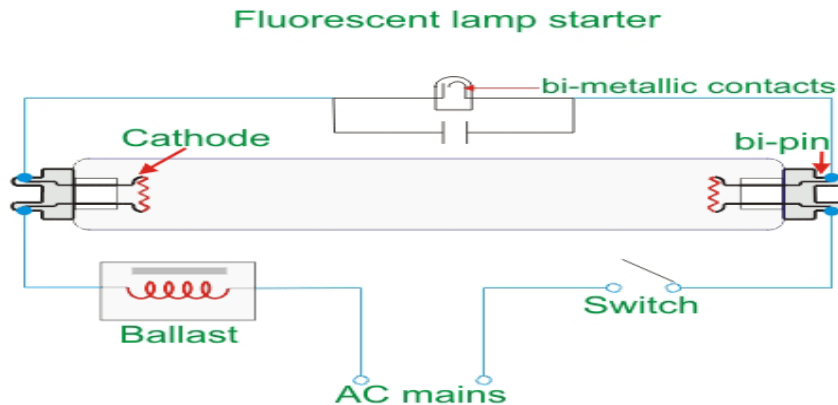


Figure 2.8 Construction of fluorescent tube bulb [9].

One ballast, a switch and a supply are all connected in series as shown in **Figure 2.8**. Then a fluorescent tube light and a starter are all connected together.

When the switch is ON, full voltage comes across the lamp as well as across the starter through the ballast. However at that instant, no discharge happens, i.e., no lumen output from the lamp because the applied AC voltage is not enough yet.

Indeed, at that full voltage the glow discharge is established in the starter. This is because the electrode gap in the neon bulb of starter is much lesser than that of the fluorescent lamp.

Then, a gas inside the starter gets ionized due to this full voltage and heats the bimetallic strip. That causes to bend the bimetallic strip to connect to the fixed contact. Now, current starts flowing through the starter. Although the ionization potential of the neon is more than that of the argon but still due to small electrode gap, a high voltage gradient appears in the neon bulb and hence glow discharge gets started first in the starter [9].

As soon as the current starts flowing through the touched contacts of the neon bulb of the starter, the voltage across the neon bulb gets reduced since the current, causes a voltage drop across the inductor (ballast). At reduced or no voltage across the neon bulb of the starter, there will be no more gas discharge taking place and hence the bimetallic strip gets cool and breaks away from the fixed contact.

At the time of breaking of the contacts in the neon bulb of the starter, the current gets interrupted, and hence at that moment, a large voltage surge comes across the inductor (ballast).

This high valued surge voltage comes across the fluorescent lamp (tube light) electrodes and strikes penning mixture (mixture argon gas and mercury vapor). Which leads to a gas discharge and hence current again gets a path to flow through the fluorescent lamp tube (tube light) itself. The discharge of mercury atoms produces ultraviolet radiation which in turn excites the phosphor powder coating to radiate visible light [9].

Table 2.2 Fluorescent bulbs’ shortcomings and benefits [6].

Luminaire type	Fluorescent Tube Light
Benefits	<ul style="list-style-type: none"> • Energy efficient. • Relatively inexpensive. • Similar color spectra as incandescent bulbs. • Available in both warm and cool spectra.
Shortcomings	<ul style="list-style-type: none"> • Contain mercury. • Uncovered spiral tubes may be difficult to clean. • Made out of metal and glass and are prone to breakage. • Bulbs require several minutes to reach maximum light intensity when turned on. • Poor performance in cold weather. • Not ideal in situations where light must be turned on and off multiple times per day. • Requires an electronic ballast to regulate current and voltage supplied to the lamp.

2.4.3 Light emitting diode bulbs (LED):

The LED is becoming the most energy efficient and rapidly developing lighting technologies. In the time being. Such lighting technology depends on the LEDs as their building blocks.

The Light emitting diode is a two-lead semiconductor light source. It is a special type of diode which they have similar electrical characteristics of a PN junction diode. Consequently, the LED allows the flow of current from the anode to the cathode only which is called the forward direction. In the other hand it blocks the current in the reverse direction [9].

When the diode is forward biased, then the electrons & holes are moving fast across the junction and they are combining constantly, removing one another out. Soon after the electrons are moving from the n-type to the p-type silicon, it combines with the holes, then it disappears. Hence it makes the complete atom more stable and it gives the little burst of energy in the form of a tiny packet or photon of light.

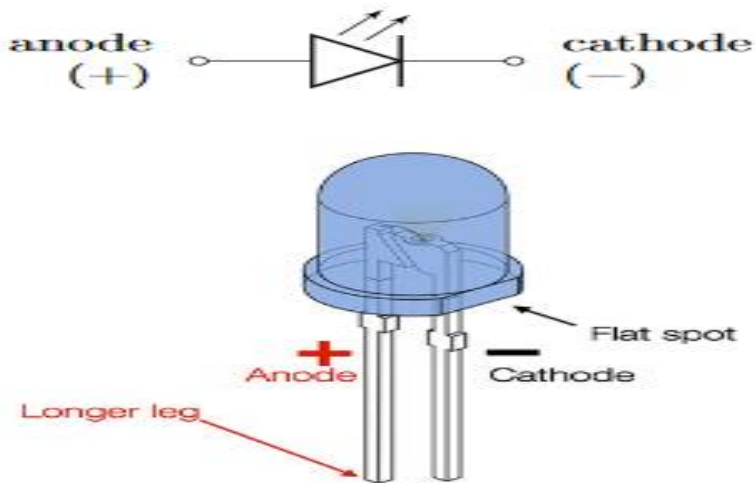


Figure 2.9 LED light bulb [9].

Simply, one can think of it this way, when power is applied to the p-n junction, the side lacking in electrons wants to be filled up with the charged electrons from the other side, and when power is applied the electrons get eager to move. Consequently, energy is emitted in the form of photons. **Table 2.3** shows the advantages and shortcomings related to LEDs.

Now, the question that comes in mind is which luminaire is the most efficient one depending on manufacturability and compatibility with the poultry farms. This will drive us to talk a little bit more about the lighting design in a poultry farm.

Table 2.3 LED bulbs' benefits and shortcomings [6].

Luminaire Type	Light Emitting Diode "LED"
<p>Benefits</p>	<ul style="list-style-type: none"> • The most efficient light bulb measured in lumens per watt. • They can be constructed out of non-glass materials that are waterproof and shatterproof. • Manufactured from non-toxic materials. • Can be designed to focus the light onto desired areas. • Color spectrum of the light can be adjusted depending on phosphors used. • Easier to dim than fluorescent bulbs. • Dimming can extend bulb's lifespan. • Very long lifespan – up to 10 years at 16 hours per day (50,000 – 60,000 hours) • Rapidly reaches peak light intensity after being turned on • Ideal for areas where lights are frequently turned on and off • Efficient in cold weather with no change in performance.

Shortcomings	<ul style="list-style-type: none"> • Expensive • LED light is directional and requires an appropriate lens to focus light, or appropriate diffusers to cover a broader area. • Lights may not burn out after expected lifespan but will be dimmed greater than 70% of original lumen output. <p>As a result, baseline lux testing in the house may be required to determine when bulbs should be changed.</p>
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2.5 Understanding poultry lighting:

Lighting in a poultry house is one of the significant factors affecting fowls' health, growth, behavior, productivity and overall costs. Birds have different spectral sensitivity compared to that of humans, which determines the need of specially designed luminaires.

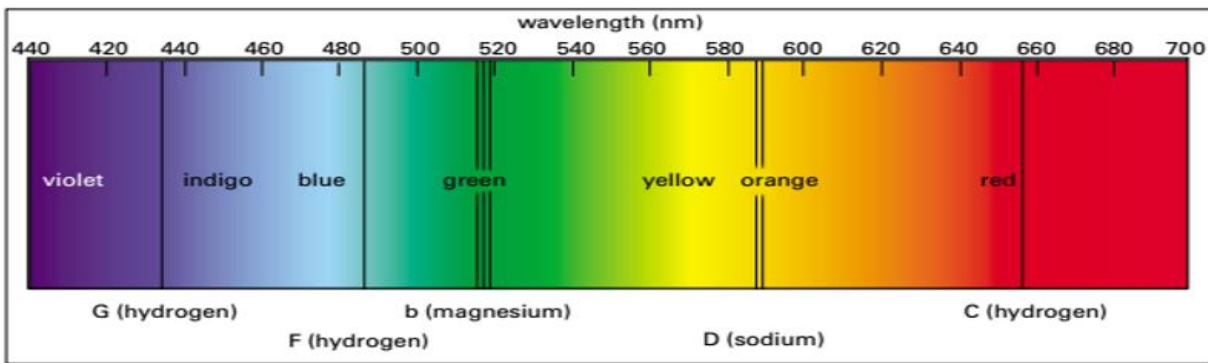


Figure 2.10 Visible light spectrum [6].

Understanding the impact light spectrum has on poultry production is critical for selecting the right bulb. In a matter of fact, laying hens are affected by the following three factors:

2.5.1 Duration:

As a general rule, decreasing light duration is utilized for growing pullets and increasing light duration is used to stimulate layers. Light stimulation has an immediate effect on the production of reproductive hormones. The standard level of light for maximum production is 16 hours. It is ideal to reach 16 hours of light by 30–35 weeks to help prolong peak production [6].

2.5.2 Spectrum:

Understanding the color spectrum given off by a light source will assist producers in selecting a light bulb which can deliver the proper amounts of red, green and blue light. Light bulb color can be expressed in degrees Kelvin (K) and color rendering index (CRI).

However, neither of these measurements expresses the spectral peak intensity in the red, green, and blue spectra that are important for poultry growth and production. Research on layer pullets indicates that LED lights with a greater portion of blue and green spectra result in better body weights and uniformity compared to other bulbs. Overall, laying hens should have lights with a sufficient red

spectrum (2700K - 3000K) [6]. Light bulb manufacturers usually provide information on degrees Kelvin, or a spectrometer can be used.



Figure 2.11 Color temperature's scale [9].

2.5.3 Intensity:

Light intensity, measured in lux or foot candles, is also important for poultry production. In general, light intensity below 5 lux is too dark to stimulate proper growth and production, while higher light intensity (above 50 lux) may cause nervousness and aberrant behavior. Laying hens should be kept at an average of 30 lux at the level of the feed through.

To measure light distribution in conventional cage or colony houses with manure belts, it is ideal to take a measurement at the feed through every 25 cm between lights and at every level. This will typically require between 30 and 100 light readings to accurately assess the light distribution. In floor houses, measure at the wall, at feeder and drinker lines beneath the lights and 2–3 times in between lights for a total of 10 to 50 measurements. In open-sided houses, use window shades and curtains to prevent direct sunlight from coming into the house. Even with these interventions, the light intensity in open houses can easily reach above 1000 lux [6].

Conclusion:

Light duration, spectrum and intensity are critical for optimum peaks and sustained egg production. While there are many choices in lighting available to the poultry producer. LED lights are becoming increasingly popular due to the combination of energy efficiency, reliability and long bulb life. Consequently, LED bulbs can and will be integrated in poultry warehouses, to prove or disapprove that a graphical user interface using app-designer in Mat-Lab has been carried to compare between a variety of luminaire bulbs and select which one is more efficient and economical. All of that will be fully explained in chapter three.

Part II: The ventilation system for egg production farms:

On average, 44% of the electricity consumption in a poultry operation is attributed to ventilation (Figure 2.12). This equates to 36,080 kWh for a 50,000 head broiler operation [10].

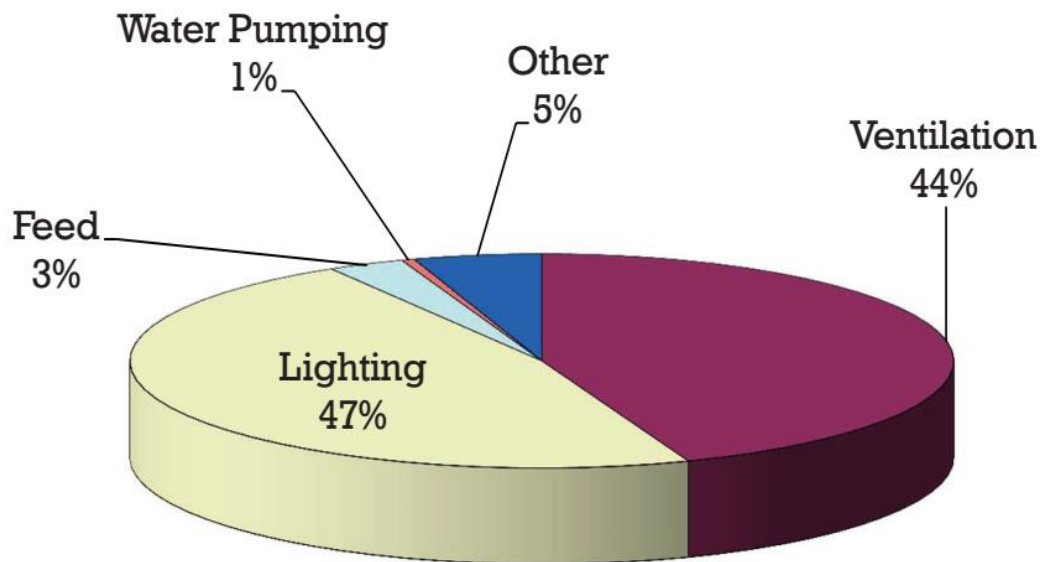


Figure 2.12 Electricity usage for laying hen's farm [10].

Proper sizing and selection of the number of fans are important for maintaining optimum barn conditions and high energy efficiency.

In this part, how to provide an optimum environment with minimum energy expenditure, is well educated through qualitzing and quantizing the used electrical fans.

2.6 Principles of ventilation:

If air is not replaced in an enclosed building where poultry are confined, the air composition changes. The concentration of carbon dioxide, ammonia and other harmful gases will increase to unacceptable levels which leads to the hens' mortality increase.

As the ventilation system exchanges the air in the building, it brings in the oxygen needed to sustain life and carries out the harmful gases, and undesirable odors caused by respiration and waste decomposition. There are usually two types of ventilation, natural and mechanical. Most poultry barns use mechanical ventilation which consume a large amount of energy.

Indeed, a variety of industrial mechanical ventilation systems are available [10]:

- **Negative pressure systems:** The exhaust fan(s) create a slight negative pressure or vacuum in the poultry house, which causes air to enter the barn through the designed inlets.
- **Positive pressure systems:** it does exactly the opposite of a negative pressure system. Fans blow air into the barn creating a positive pressure and air escapes through designed outlets.

This system is fairly uncommon, since it often causes building materials to deteriorate because moisture moves through the cracks in the building.

- **Multi speed fans:** such fans are usually equipped to have two speeds. The lower speed is 60% of the full speed.
- **Intermittent fans:** the installed fans are controlled by a timer or a thermostat so that they operate at certain times during a period.
- **Variable speed fans:** they can be adjusted down to 10% of the full fan speed. Speed is regulated by varying the root mean square (RMS) voltage or frequency to the motor by a variable transformer or a solid state control.

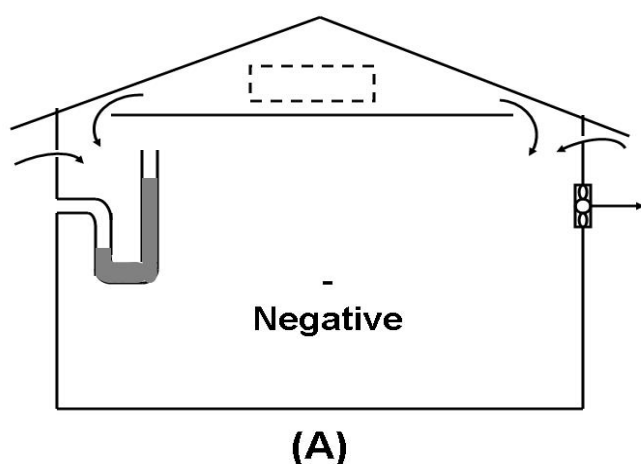


Figure 2.13 (a) Negative pressure system [11].

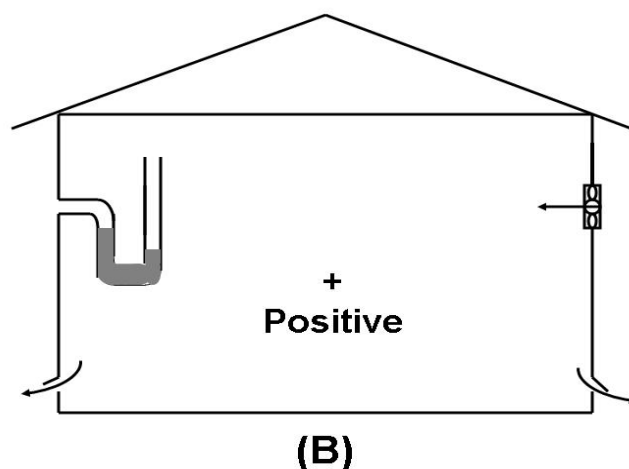


Figure 2.13 (b) Positive pressure system [11].

2.7 Ventilation modes:

Modern poultry house ventilation systems are typically set up to operate in three different modes, often referred to as minimum, transitional, and tunnel ventilation [12].

a. Minimum ventilation:

In this mode, fans draw air into the house through sidewall or ceiling air inlets, and in such a manner that incoming air does not directly flow over birds. Ventilation is regulated by a timer, not by thermostat or temperature sensor. The purpose is to maintain good air quality and exhaust excess moisture during cool weather. Many laying houses do not have sidewall air inlets for cooler weather ventilation, and instead try to utilize slightly opening or “cracking” the curtains to serve as air inlets. A cracked curtain is a very poor air inlet and will not direct air properly into the house. It is recommended that new houses be equipped with sidewall perimeter air inlets for cool weather operation [12].

b. Transitional ventilation:

This mode uses tunnel fans to bring air into the house through sidewall or ceiling air inlets, and is regulated by thermostat or temperature sensor. The primary purpose is temperature control.

This mode is used when excess heat must be exhausted from the house, but wind-chill cooling is not needed or wanted. Transitional ventilation is often called power mode ventilation [12].

c. Tunnel ventilation:

In this mode, tunnel fans bring air into the house through tunnel air inlets at the opposite end of the house. Ventilation is regulated by thermostat or temperature sensor. The purpose is to create a high velocity airflow which exhausts heat from the house at a higher rate and also flows over the birds to provide wind-chill cooling. Tunnel ventilation also provides a vehicle for evaporative cooling.

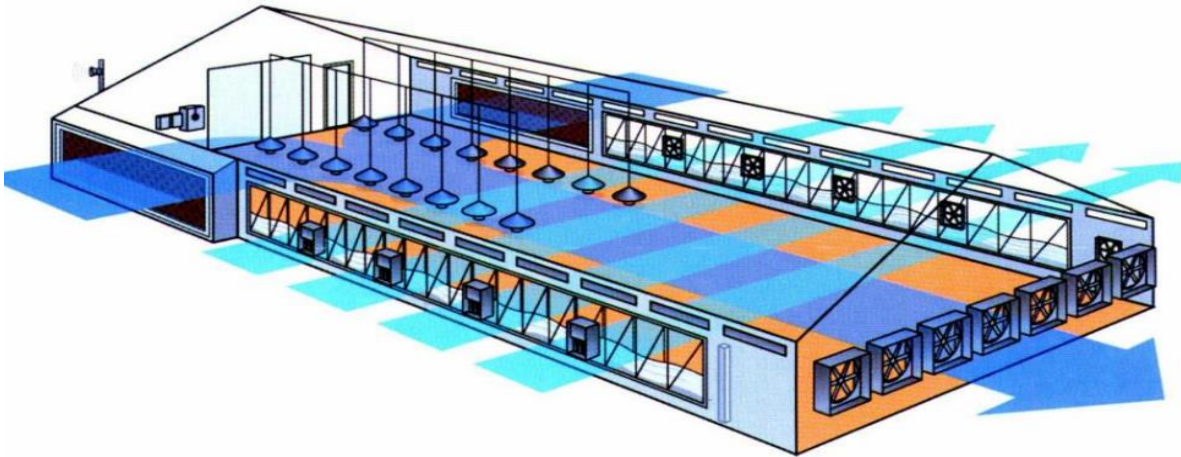


Figure 2.14 Tunnel Ventilation System [13].

2.8 Component of mechanical ventilation system:

Any ventilation system has three principal components [13]:

- The fans required to move the air through the warehouse.
- Air inlets and outlets which they have to meet a well-defined standards.
- A set of controllers (thermostats, sensors and timers) to regulate the operation of the fans.

However, to avoid being dragged too much into the mechanical system design, one can focus on selecting and sizing the electric fans.



Figure 2.15 Typical Fans Used in Poultry Farms [13].

a. Fan selection:

Do never choose a fan based strictly on its diameter. Also, never assume that two fans of equal size will always perform the same [14].

The following criteria will have a huge effect on a fan performance:

- **Static pressure (SP)** is the difference in pressure that a ventilation fan creates between the inside and outside of the chicken house..

It can be measured with a Magnehelic SP gauge and by the way, many poultry houses operate at a static pressure between 0.04 and 0.12 inch of water.

- **Fan efficiency (FE)** is the amount of air delivery that a fan will provide per unit of electric power used, usually given in cubic feet per minute per watt (cfm/W).
- **Air delivery (AD)** is the amount of air that a fan will move under different conditions. The term is expressed as volume of air movement per unit of time. The standard unit is cubic feet per minute (cfm). The largest amount of air is moved at 0.00 inch SP. As SP increases, a fan must work harder and the amount of air moved decreases.
- **Air flow ratio** is an indicator of how well a fan will hold up when static pressure increases. The air flow ratio is determined by dividing the amount of air a fan moves at 0.20 inch pressure by the amount of air a fan moves at 0.05 inch pressure. Air flow ratios usually vary from 0.50 to 0.85. A higher ratio indicates a better fan which means the fan is less affected by high static pressures.

b. Design technical concepts:

Integrators will specify a certain number of fans for new house construction or for retrofitting older houses. How do they come up with this number of fans?

- First of all, the required AD in the hen's farm must be well determined using this equation:

$$AD = W_t \times N_b \times \frac{(0.01, 0.097 \text{ or } 0.12)}{0.028} \quad (2.7)$$

Where AD is the air delivery required in the warehouse.

W_t , N_b is the hen's bodyweight in Kg and the total number of laying hens in the warehouse.

Minimum air requirement for the Bird is equal to 0.010 m³/min.Kg.

Maximum normal air flow for the Birds is equal to 0.097 m³/min.Kg.

Ventilation rate for hot conditions is equal to 0.120 m³/min.Kg.

- The next step is going to the market and seek for the available electric fans and their corresponding AD. The number of fans and sizes of the fans will depend on the minimum and maximum ventilation requirement as well as size and configuration of the facility.
- Thus after calculating the total AD required in the warehouse using the last equation, one can calculate the number of required fans:

$$\text{Number of fans} = 1.2 \times \frac{\text{Total AD for maximum ventilation}}{\text{fan AD}} \quad (2.8)$$

- Finally, to calculate which fan is more economical, the following equation can be used:

$$\text{EOCS} = \frac{\text{fan AD}}{\text{FE}} \times \text{AOH} \times \text{ER} \quad (2.9)$$

EOCS is the economical operating cost savings, the smaller EOCS the most economical is the fan [10].

AOH is the average operating hour per one trimester (h/Trimester) for a fan.

ER is the electricity rate charged by Sonelgaz (DA/Kwh).

2.9 Induction motor vs. brushless DC motor:

There are two types of electric motors, alternating current (AC) motors and direct current (DC). Most wall fans, as well as most household appliances, use AC motors since AC is the type of current distributed by power companies. This power source is what creates the moment of force required to rotate the motor's rotor [15].

However, since the PV system generates DC current, the idea of using brushless direct current (BLDC) fans may be applied.

a. Working principle of an Induction motor:

Unlike the BLDC motor, the induction motor (IM) is excited with three-phase supply, three-phase stator winding produce a rotating magnetic field with 120 displacements at constant magnitude which rotates at synchronous speed. This changing magnetic field cuts the rotor conductors and induces a current in them according to the principle of Faraday's laws of electromagnetic induction. As these rotor conductors are shorted, the current starts to flow through these conductors [15].

In the presence of magnetic field of stator, rotor conductors are placed, and therefore, according to the Lorenz force principle, a mechanical force acts on the rotor conductor. Thus, all the rotor conductors force, i.e., the sum of the mechanical forces produces torque in the rotor which tends to move it in the same direction of rotating magnetic field.

This rotor conductor's rotation can also be explained by Lenz's law which tells that the induced currents in the rotor oppose the cause for its production, here this opposition is the rotating magnetic field, so the rotor will rotate in the same direction to reduce the cause.

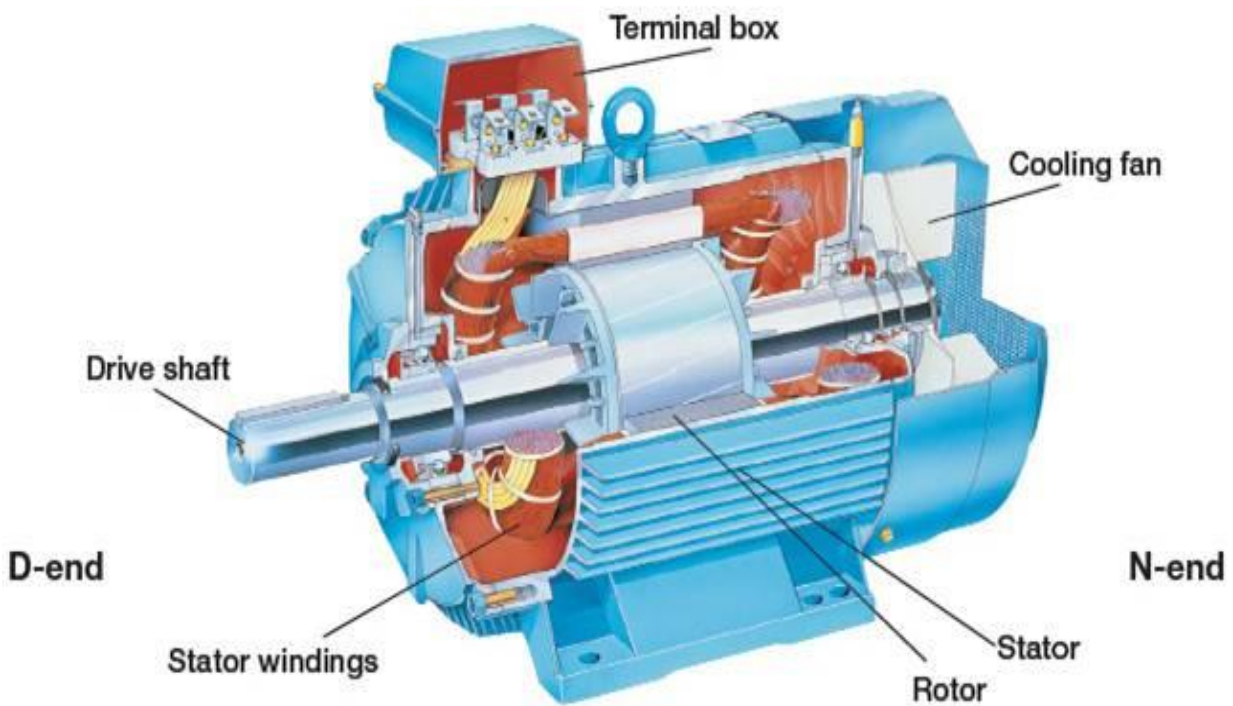


Figure 2.16 Induction motor's construction (listenlights.com)

Thus from the working principle of three phase induction motor, it may be observed that the rotor speed should not reach the synchronous speed produced by the stator. If the speeds become equal, there would be no such relative speed, so no Emf induced in the rotor, and no current would be flowing, and therefore no torque would be generated. Consequently, the rotor cannot reach the synchronous speed. The difference between the stator (synchronous speed) and rotor speeds is called the slip [15].

b. Working principle of BLDC motors:

A brushless DC motor (BLDC) is a permanent magnet synchronous electric motor which is driven by direct current (DC) and it accomplishes electronically controlled commutation system; commutation is the process of producing rotational torque in the motor by changing phase currents through it at appropriate times; instead of a mechanically commutation system. BLDC motors are also referred as trapezoidal permanent magnet motors [16].

BLDC motor employs electrical commutation with permanent magnet rotor and a stator with a sequence of coils. In this motor, permanent magnet (or field poles) rotates and current carrying conductors are fixed.

The armature coils are switched electronically by transistors or silicon controlled rectifiers at the correct rotor position in such a way that armature field is in space quadrature with the rotor field poles. Hence the force acting on the rotor causes it to rotate.

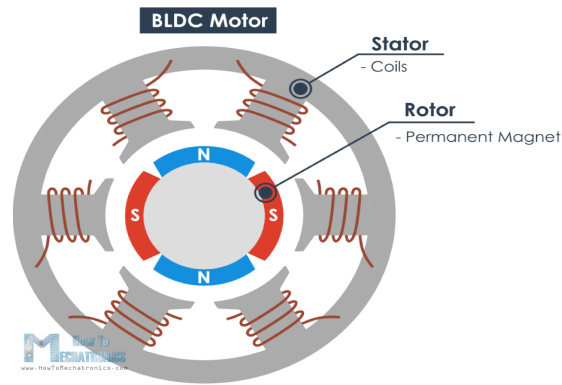


Figure 2.17 The Construction of BLDC motor [16].

Hall sensors or rotary encoders are most commonly used to sense the position of the rotor and are positioned around the stator. The rotor position feedback from the sensor helps to determine when to switch the armature current.

c. Brushless or Induction motor:

Both DC brushless and induction drives use motors having similar stators. Both drives use 3-phase modulating inverters. The only differences are the rotors and the inverter controls. And with digital controllers, the only control differences are with control code. (DC brushless drives require an absolute position sensor, while induction drives require only a speed sensor; these differences are relatively small.) [16].

One of the main differences is that much less rotor heat is generated with the DC brushless drive. Rotor cooling is easier and peak point efficiency is generally higher for this drive. The DC brushless drive can also operate at unity power factor, whereas the best power factor for the induction drive is about 85 percent. This means that the peak point energy efficiency for a DC brushless drive will typically be a few percentage points higher than for an induction drive.

In an ideal brushless drive, the strength of the magnetic field produced by the permanent magnets would be adjustable. When maximum torque is required, especially at low speeds, the magnetic field strength (B) should be maximum – so that inverter and motor currents are maintained at their lowest possible values. This minimizes the $I^2 R$ (current² resistance) losses and thereby optimizes efficiency. Likewise, when torque levels are low, the magnetic field should be reduced such that eddy and hysteresis losses due to magnetic are also reduced. Ideally, B should be adjusted such that the sum of the eddy, hysteresis, and I^2 losses is minimized. Unfortunately, there is no easy way of changing B with permanent magnets [16].]

In contrast, induction machines have no magnets and the magnetic fields are “adjustable,” since this last is proportionate to V/f (voltage to frequency). This means that at light loads the inverter can reduce voltage such that magnetic losses are reduced and efficiency is maximized. Thus, the induction machine when operated with a smart inverter has an advantage over a DC brushless machine – magnetic and conduction losses can be traded such that efficiency is optimized. This advantage becomes increasingly important as performance is increased. With DC brushless, as machine size grows, the magnetic losses increase proportionately and part load efficiency drops. With

induction, as machine size grows, losses do not necessarily grow. Thus, induction drives may be the favored approach where high-performance is desired; peak efficiency will be a little less than with DC brushless, but average efficiency may actually be better [16].

Permanent magnets are expensive – something like \$50 per kilogram. Permanent magnet (PM) rotors are also difficult to handle due to very large forces that come into play when anything ferromagnetic gets close to them. This means that induction motors will likely retain a cost advantage over PM machines. Also, due to the field weakening capabilities of induction machines, inverter ratings and costs appear to be lower, especially for high performance drives. Since spinning induction machines produce little or no voltage when de-excited, they are easier to protect. Induction machines are more difficult to control. The control laws are more complex and difficult to understand [16]

Achieving stability over the entire torque-speed range and over temperature is more difficult with induction than with DC brushless. This means added development costs, but likely little or no recurring costs [16].

Conclusion:

The ventilation system design plays very important role in keeping the laying hens healthy. However in the other side, the proper selection of the fans in terms of manufacturability and availability is super important.

Afterwards, talking about the induction motor and brushless DC motor and their electrical characteristics lead us to say that it is left to the engineer to decide which type of motor that is more suitable for a poultry warehouse in terms of efficiency. The choice of which one to install will be further discussed in the chapter that follows.

Chapter 3: Lighting and Ventilation System Simulation for Laying Hen's Farms

3.1 Case study:

After visiting three laying hen's farms, that contain 10000 birds each, in Douar Frikat, Ain Oulmene Setif.

Here is a resume concerning the installed lighting and ventilation system:

- All the three farms are still using the traditional incandescent bulbs that runs on 220v, 40 watts, E27 and 417 Lumens, dimmable. According to the standard dimensions of the poultry warehouses 30m length, 14m width and 4m height, 5*8 (rows *columns) incandescent bulbs are installed, 40 bulbs in total. The light is on for 16 hours in average per day.
- Concerning the cooling and ventilation system, some of the farms are using three AC electric fans, 380V and 1.5 Horse power (hp) each. Others use four AC fans with the same description as mentioned before. In all the visited farms, these fans are turned on and off automatically by using a set of thermostat sensors. A Tunnel ventilation mode is being employed with a negative pressure system.

Afterwards, the farms' daily load profiles were carefully observed and identified through held interviews with the owners of the farms who by the way provided us also with the annual average electricity bills.



Figure 3.1 Laying Hen's farm, Douar Frikat, Ain Oulmene, Setif

3.1.1 Scenarios considered:

In order to study the feasibility of the electrical installed system in a well selected farm, and seek for improvement, two scenarios were developed under the current electrical market and according to what the customer desire.

In case of retrofitting, the installed lighting system will be enhanced through seeking for alternative efficient bulbs. In addition to electrically upgrading the ventilation and cooling system.

However, In case the customer wants to go further with producing his own energy, a complete stand-alone PV system is well simulated using the BlueSol software.

3.2 Simulation, discussion and results:

This section covers all the aspects of the methodological procedure used to analyze both scenarios. It also includes the conducted calculations, simulations and results.

3.2.1 Lighting system design:

In order to assure installing the most efficient lighting system in a laying hen’s farm, the following criteria must be met:

- The installed light bulb should have a sufficient red spectrum (2700K - 3000K).
- Light intensity should be kept at an average of 30 lux at the level of the feed trough.
- Dimmable bulbs should be preferably chosen.

After a lot of documenting, here is a list of the potential light bulbs that might be used in a laying hen’s farm as shown in the **Table 3.1**.

Table 3.1 A List of the potential light bulbs that might be installed [19].

Manufacturer Name	Luminaire Type	Wattage (watts)	Lumens (Lm)	Color Temperature (K°)	Dimmable	Rows vs. columns
Stan 40W E27 230V A55 CL 2CT/12X5F	Incandescent	40	417	2700	Yes	5*8
Edison carbon filament bulb ST64	Incandescent	60	270	2700	Yes	6*11
LEDClassic P45 E27 WWCL DAU	LED	5	470	2700	Yes	5*7
Classic LEDbulb Filament Claire	LED	4	540	6500	No	5*6

As it is shown in the last column of **Table 3.1**, the bulbs’ distribution along the warehouse were well calculated and simulated using the DIALux software, this software is a professional lighting design simulation software, it can plan, calculate and visualize the lighting system for indoor and outdoor areas.

The performed simulation allows the farmer to know exactly how many bulbs are required, in addition to a detailed X, Y and Z coordination of each bulb. For instance, in case of installing a classic LED filament philips bulb of 5W, 470lm in a warehouse of 30m length, 14m width and 4m height , the obtained results were as folow:

Table 3.2 DIALux Simulation Results for an LED Classic Philips bulb (5w, 470Lm) [17].

Height of the working plane (m)	Ground area (m ²)	Number of bulbs	Total consumed power (w)	Total consumed energy (Kwh)
2.8	420	35 (5*7)	175	2.8

It is well understood from **Table 3.2** that the height of the working plane is 2.8m, which is a value that we have input into the simulation software. This value were recommended by a veterinarian doctor. The conducted simulation revealed also the total consumed power by the 35 bulbs per day which is 175w in this case.

Knowing that the light is on for 16 hours per day, then the total consumed energy can be calculated as well.

In addition to that, here were the obtained luminaire coordination list:

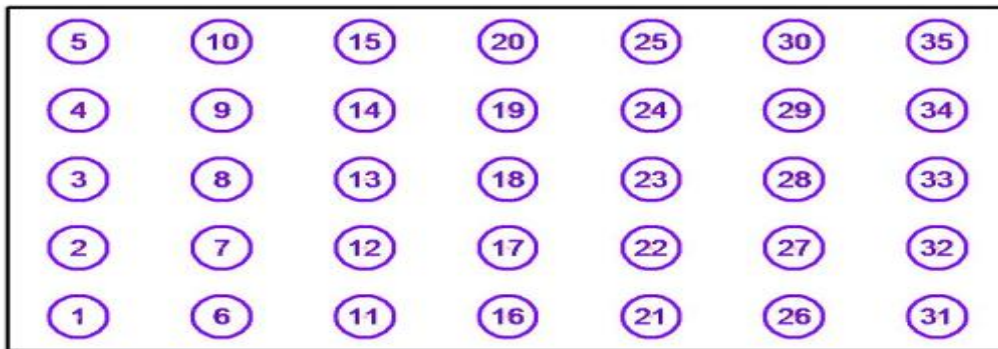


Figure 3.2 The 35 bulbs' distribution over the warehouse [17].

According to the performed simulation, the bulbs were automatically numbered from 1 to 35 and well distributed over the warehouse.

Furthermore, the space between each column or row is twice the spacing between the first and the last column or row compared to the side walls. Thus the spacing between each column is 4.29m. However, the spacing between each bulb of the same column is 2.8m.

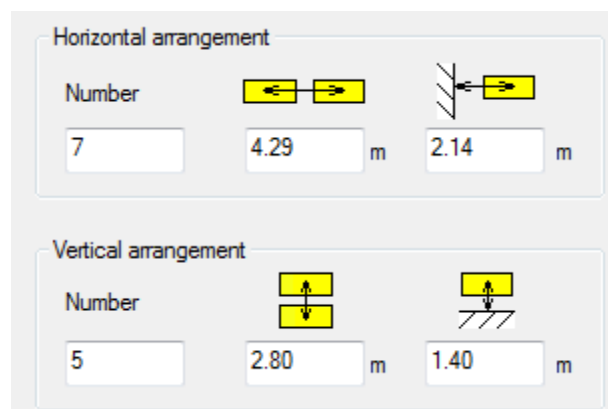


Figure 3.3 The Luminaire spacing in X and Y coordinates [17].

The DIALux gave all of that in a form of a table as it is shown below.

Table 3.3 The coordination list of the LED classic filament bulb (5w, 470Lm) [17].

No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	2.140	1.400	4.000	0.0	0.0	90.0
2	2.140	4.200	4.000	0.0	0.0	90.0
3	2.140	7.000	4.000	0.0	0.0	90.0
4	2.140	9.800	4.000	0.0	0.0	90.0
5	2.140	12.600	4.000	0.0	0.0	90.0
6	6.430	1.400	4.000	0.0	0.0	90.0
7	6.430	4.200	4.000	0.0	0.0	90.0
8	6.430	7.000	4.000	0.0	0.0	90.0
9	6.430	9.800	4.000	0.0	0.0	90.0
10	6.430	12.600	4.000	0.0	0.0	90.0
11	10.720	1.400	4.000	0.0	0.0	90.0
12	10.720	4.200	4.000	0.0	0.0	90.0
13	10.720	7.000	4.000	0.0	0.0	90.0
14	10.720	9.800	4.000	0.0	0.0	90.0
15	10.720	12.600	4.000	0.0	0.0	90.0
16	15.010	1.400	4.000	0.0	0.0	90.0
17	15.010	4.200	4.000	0.0	0.0	90.0
18	15.010	7.000	4.000	0.0	0.0	90.0
19	15.010	9.800	4.000	0.0	0.0	90.0
20	15.010	12.600	4.000	0.0	0.0	90.0
21	19.300	1.400	4.000	0.0	0.0	90.0
22	19.300	4.200	4.000	0.0	0.0	90.0
23	19.300	7.000	4.000	0.0	0.0	90.0
24	19.300	9.800	4.000	0.0	0.0	90.0
25	19.300	12.600	4.000	0.0	0.0	90.0
26	23.590	1.400	4.000	0.0	0.0	90.0
27	23.590	4.200	4.000	0.0	0.0	90.0
28	23.590	7.000	4.000	0.0	0.0	90.0
29	23.590	9.800	4.000	0.0	0.0	90.0
30	23.590	12.600	4.000	0.0	0.0	90.0
31	27.880	1.400	4.000	0.0	0.0	90.0
32	27.880	4.200	4.000	0.0	0.0	90.0
33	27.880	7.000	4.000	0.0	0.0	90.0
34	27.880	9.800	4.000	0.0	0.0	90.0
35	27.880	12.600	4.000	0.0	0.0	90.0

As a second example, the 40w, 417Lm incandescent bulb were also intended to be simulated in the DIALux software, but since the Illuminating Engineering Society (IES) file of such luminaire could not be found any where; because such incandescent bulbs ar super traditional; the simulation using the DIALux could not be carried out.

However, using Simulink which is a Mat-Lab based graphical programming environment for modeling and simulating dynamic problems, we were able to develop a model that can calculate the overall number of the required luminaires to be installed in the warehouse. All the equations used to develop such model were well explained in Chapter 2.

Moreover, this Simulink model suggest the light bulbs' distribution over the warehouse in addition to the spacing in between.

Indeed, all of that is possible only if the farmer provides the model with three inputs, which are the length, width of the warehouse and the luminous flux of the selected bulb.

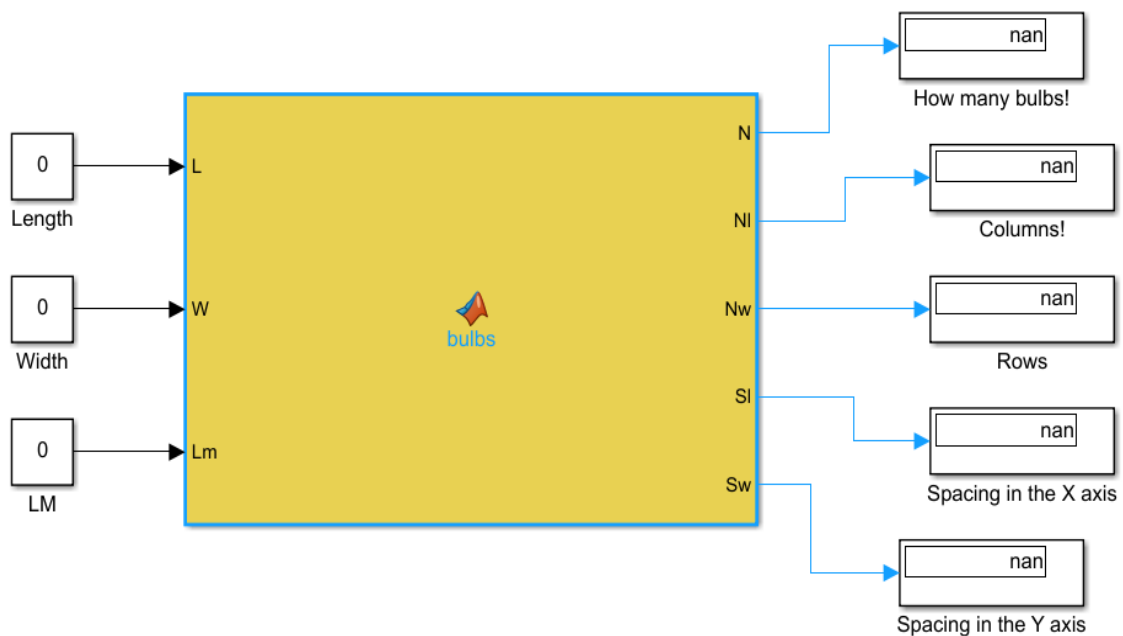


Figure 3.4 The Simulink model's Results when no inputs are provided.

Figure 3.4 shows clearly that this model has five outputs which are N, NI and Nw that represent the number of bulbs required, the number of columns and the number of rows respectively. The other two outputs Sl and Sw represents the horizontal and vertical spacing in meters respectively.

Now, before using this Simulink model to simulate the 40w, 417Lm incandescent bulb. This model were tested to ensure its validation.

The idea was to input the parameters of the LED classic filament bulb (5w, 470Lm) and then compare the obtained results with the ones found using the DIALux software.

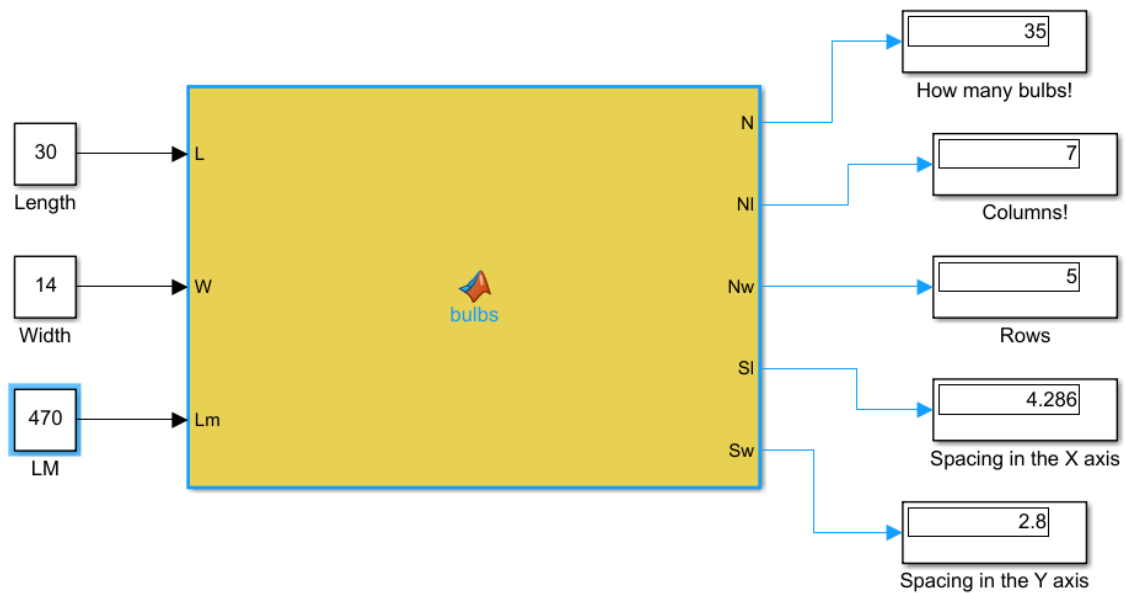


Figure 3.5 The Simulink model's results when the 5w, 470Lm LED is used.

Table 3.4 Results' Comparison between Simulink and DIALux for a LED bulb (5w, 470Lm)

Software used	Ground area (m ²)	Number of bulbs	Horizontal Spacing (m)	Vertical Spacing(m)
DIALux	420	35 (5*7)	4.29	2.8
Simulink	420	35 (5*7)	4.286	2.8

Based on the comparison given in **Table 3.4**, it was well ensured that the results generated by the developed Simulink model were highly matched with those given by the DIALux software.

Then, this model were used to simulate the lighting system with the 40w, 417Lm luminaire being selected as in input.

Table 3.5 Simulink model's Results for an Incandescent Bulb (40w, 417Lm)

Height of the working plane (m)	Ground area (m ²)	Number of bulbs	Total consumed power (w)	Total consumed energy (Kwh)
2.8	420	40 (5*8)	1600	25.6

It is well understood from **Table 3.5** that 5*8 bulbs are required. The conducted simulation revealed also the total consumed power by the 40 bulbs per day which is 1600w in this case.

Knowing that the light is on for 16 hours per day, then the total consumed energy can be calculated as well.

In addition to that, here is a capture of the results obtained from the Simulink model:

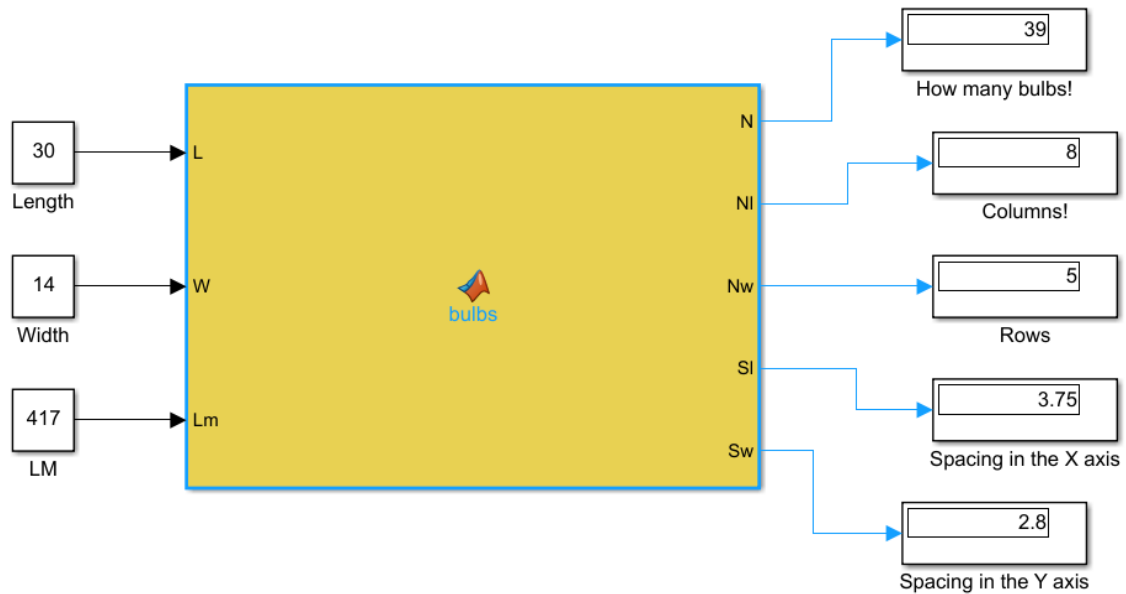


Figure 3.6 The Simulation Result of the 40w, 417Lm Incandescent bulb.

It is now super clear that 3.75m is the distance between each column, however the spacing between each bulb in the same column is 2.8m.

So far, so good. Now, among all the bulbs listed in **Table 3.1**, which one is more efficient and more economical!

To facilitate the answer to this question, a graphical user interface (GUI) application called “Light Cost Calculator” using the app_ designer in Mat-Lab were created.

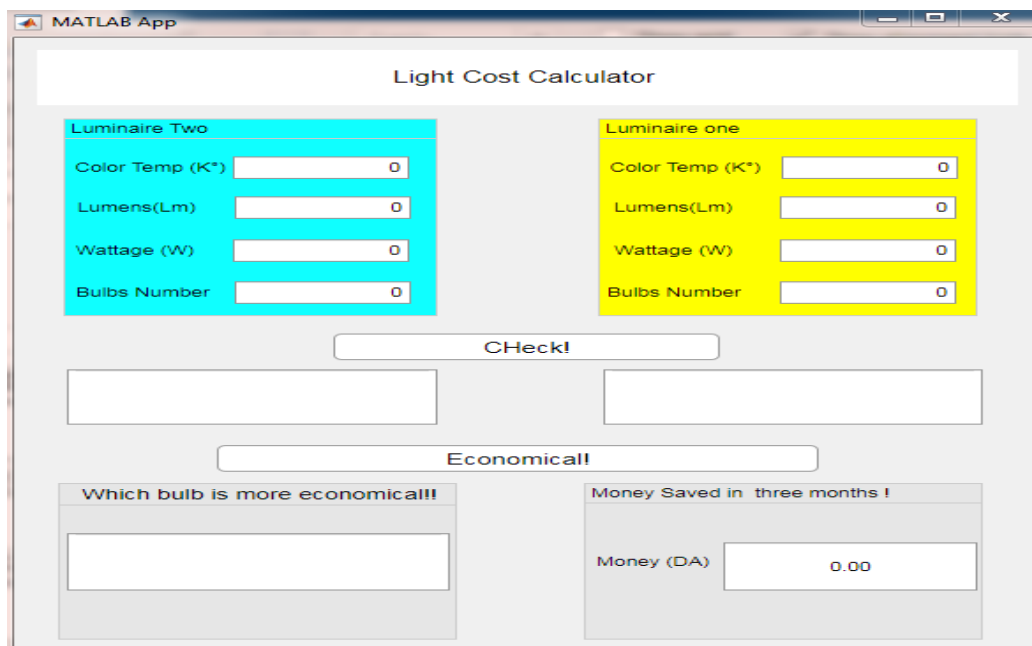


Figure 3.7 The light cost calculator application’s interface.

This application allows the farmer to know whether or not the selected bulb matches the physiological requirement of the laying birds and if it does or does not respect the lighting standards in a poultry farm. All of that can be achieved by clicking on the “Check!” button.

A flowchart, to describe the working process of this GUI application, has been established as shown in **Figure 3.9**

Briefly speaking and as the flowchart shows, this application calculate the amount of saved money in three months of all the running bulbs for each luminaire. It does that by calculating the total consumed energy over 16 hours/day in a three months period for each luminaire.

Afterwards, knowing that the electricity rate is 4 DA/Kwh, the Light Cost Calculator estimates the amount of the money saved when using one luminaire instead of the other, with a message to be displayed telling the farmer which luminaire is more economical. All of that happen, when clicking on the “Economical!” button.

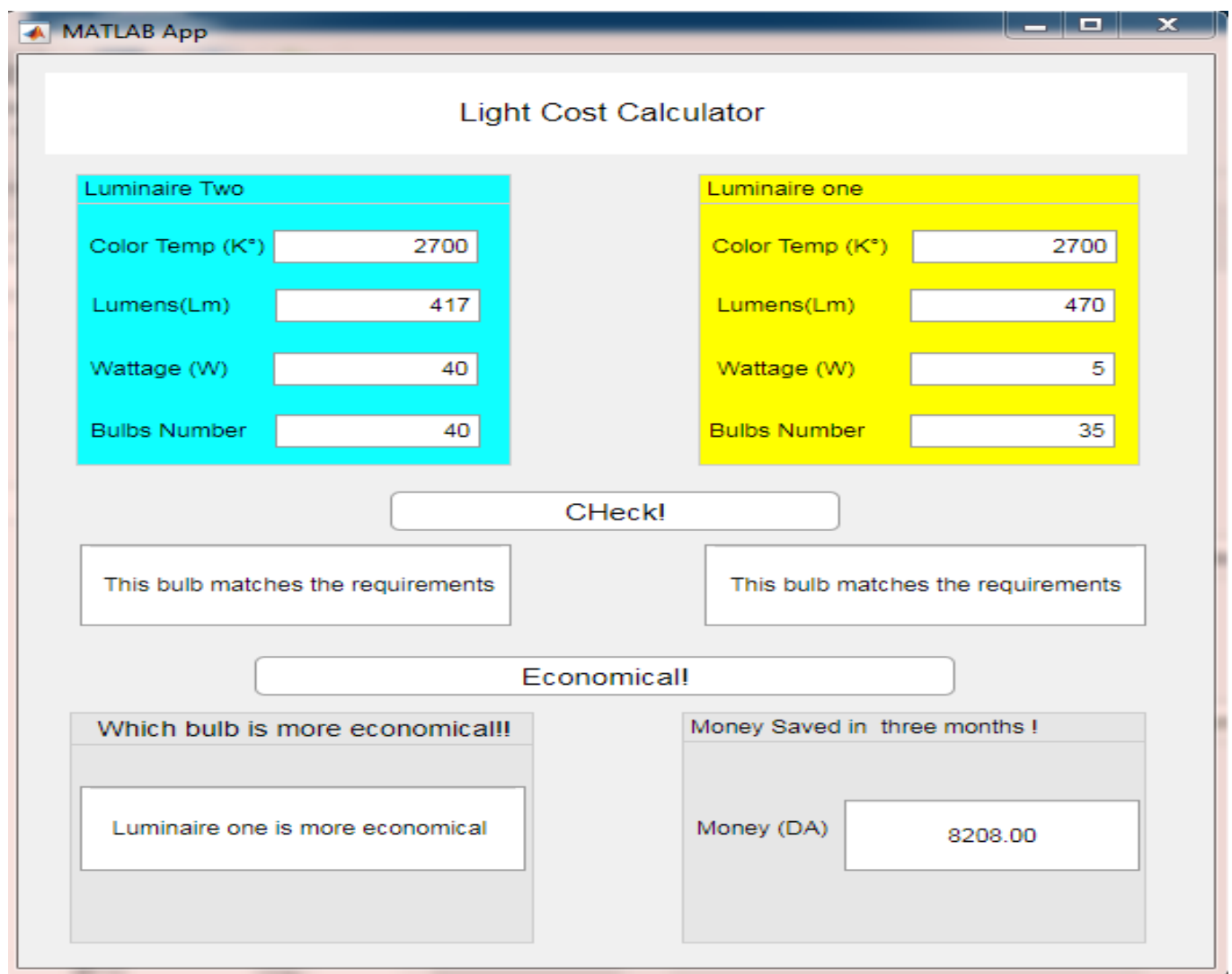


Figure 3.8 The 5w, 470Lm LED vs. The 40w incandescent bulb.

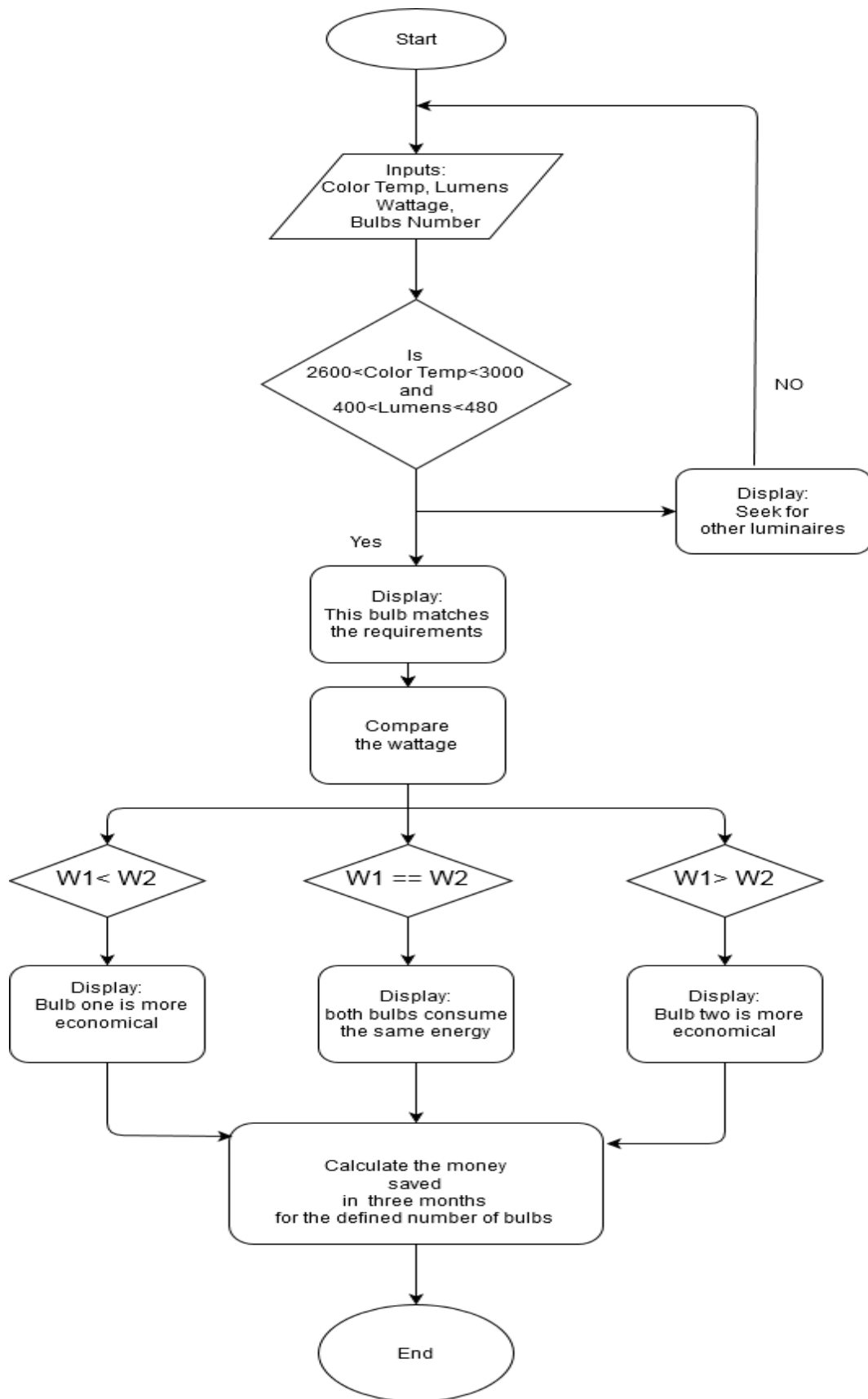


Figure 3.9 A flowchart that describes the working process of the light cost calculator application.

As **Figure 3.8** clearly shows, both luminaires are compatible and can be installed in a laying hen's farm. However, from an economical point of view, the LED saves up to 8208.00 DA/ 3months over the incandescent bulb, which is a very considerable amount of money that nearly represents 50 percent of the total amount of money paid by the farmer in 3 months. This can be well explained when comparing the total amount of energy consumed by the two luminaires from **Table 3.2 and 3.5**

From these two tables, the energy consumed by the 40w incandescent bulbs per day is nine times the one consumed by the 5w LEDs.

The other two luminaires listed in **Table3.1** were also compared to the 5w, 470 Lm LED classic filament bulb.

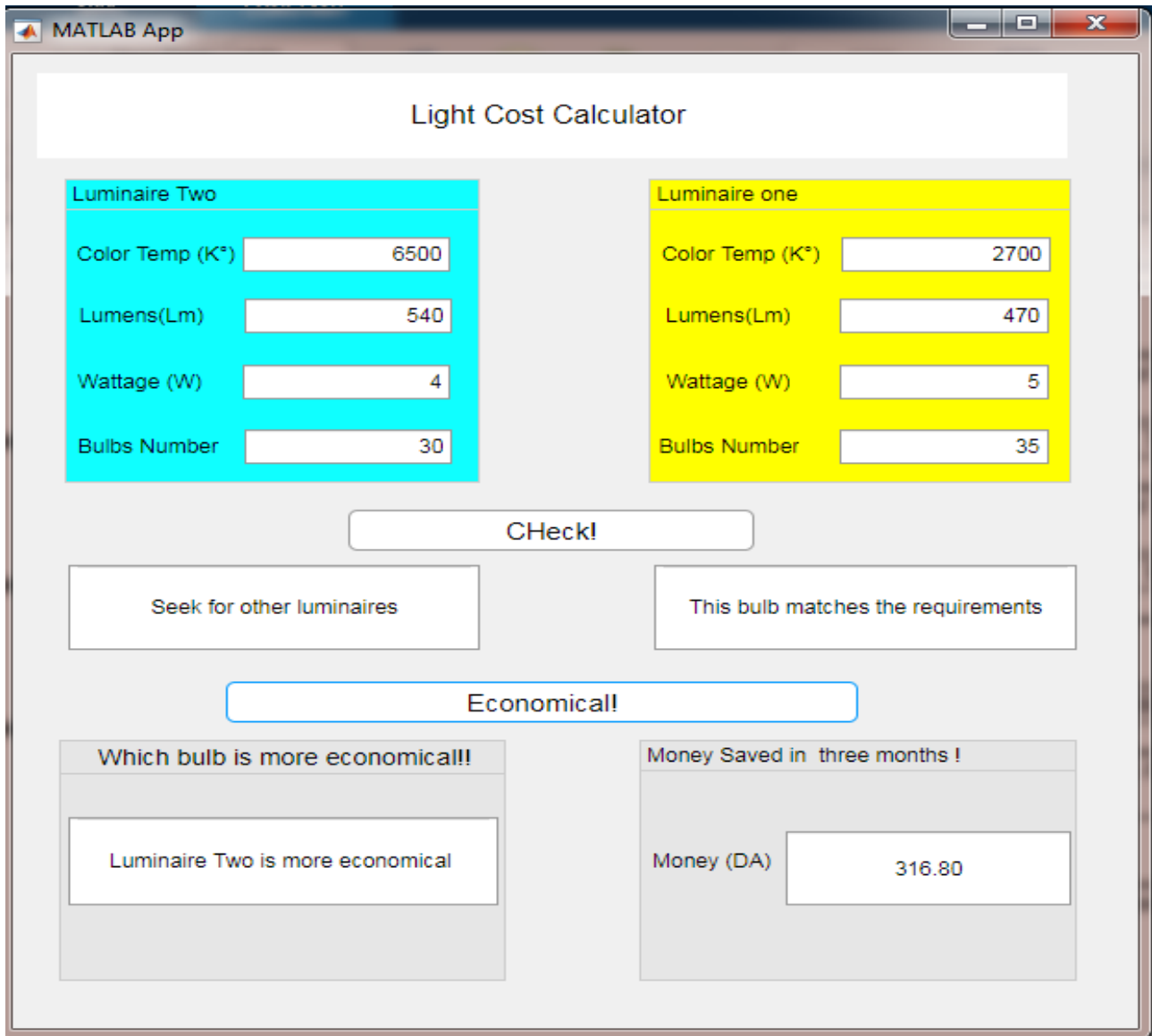


Figure 3.10 The Classic LED 5w, 470 Lm VS The 4w, 540Lm LED bulb

Even though the 4w, 540 Lm LED bulb is slightly more economical than the 5w, 470 Lm LED bulb, but the last one is much more preferable. This can be explained by the message displayed when clicking on the “Check!” button which indicated that Luminaire one (5w, 470 Lm) matched the requirements whereas luminaire two did not.



Figure 3.11 The classic LED 5w, 470 Lm VS The 60w, 270Lm incandescent bulb

In this case, it was crystal clear that the 5w, 470 Lm LED is much more efficient and economical over the 60w incandescent bulb. A 21801.30 DA/ 3months money will be lost if this incandescent bulb were used.

Conclusion:

Different luminaire types can be installed in a laying hen’s farm. But after conducting the right calculations, setting the right conditions and performing different simulations using either Simulink or DIALux, it has been well proofed that using the 5w, 470lm classic LED filament is the most efficient bulb; in terms of hens’ requirements and money saving; to be selected and installed instead of the traditional 40w incandescent bulbs.

3.2.2 Ventilation system design:

The importance of providing the birds with the correct environment is becoming overlooked, so the following recommendations must be taken into account:

- The proper selection and sizing of fans is super important for maintaining optimum barn conditions and high energy efficiency.
- Summer and winter design temperatures must be considered in sizing fans.
- The potential of using DC fans instead of AC ones may be more economical especially if the farmer decides to invest in solar energy.

A list of the potential electric fans that might be installed in a laying hen’s farm is shown in the table below:

Table 3.6 A list of a potential electric fans that might be used in a laying hen’s farm [18].

Manufacturer Name	Type	Wattage (watts)	AD (cfm)	Efficiency (%)	Number Of fans
24v solar fan	DC	370	900	2.86	68
SP-F-1000	AC	750	14715	23.07	5
SP-F1380	AC	1100	25898	27.68	3
SN2013022A	BLDC	380	17364	53.72	4

As it is shown in the last column of **Table 3.6**, the required number of fans were well determined using an interactive GUI Mat-lab application called the Fan_Selector.

This Mat-Lab application allows the farmer to well determine how many fans are required in a farm depending on the number of hens and their body weight.

Now to get the required number of fans, just click on “how many fans?” button, after inputting the required data. In addition to that, the Fan_Selector application recommends for the farmer which fan to choose based on the fan efficiency, which were carefully estimated using **equation (3.1)** as illustrated in **Table 3.6**.

Then, when clicked on the “money saved!” button, the amount of money saved in three months is estimated.

Figure 3.12 is the GUI of the application which visualize all of the above.

A flowchart were made to fully describe the working process of the Fan_Selector application which is shown in **Figure 3.13**.



Figure 3.12 Fan Selector GUI using App-designer in Mat-Lab

Briefly speaking and as the flowchart shows, the farmer needs to enter a set of inputs to the Fan Selector app, which are N_b , W_t , ER which are the total number of birds in the farm, the average body weight in Kg and the electricity rate in Kwh/DA. These inputs must be the same for all the tested fans in order to be able to test all the fans under the same conditions.

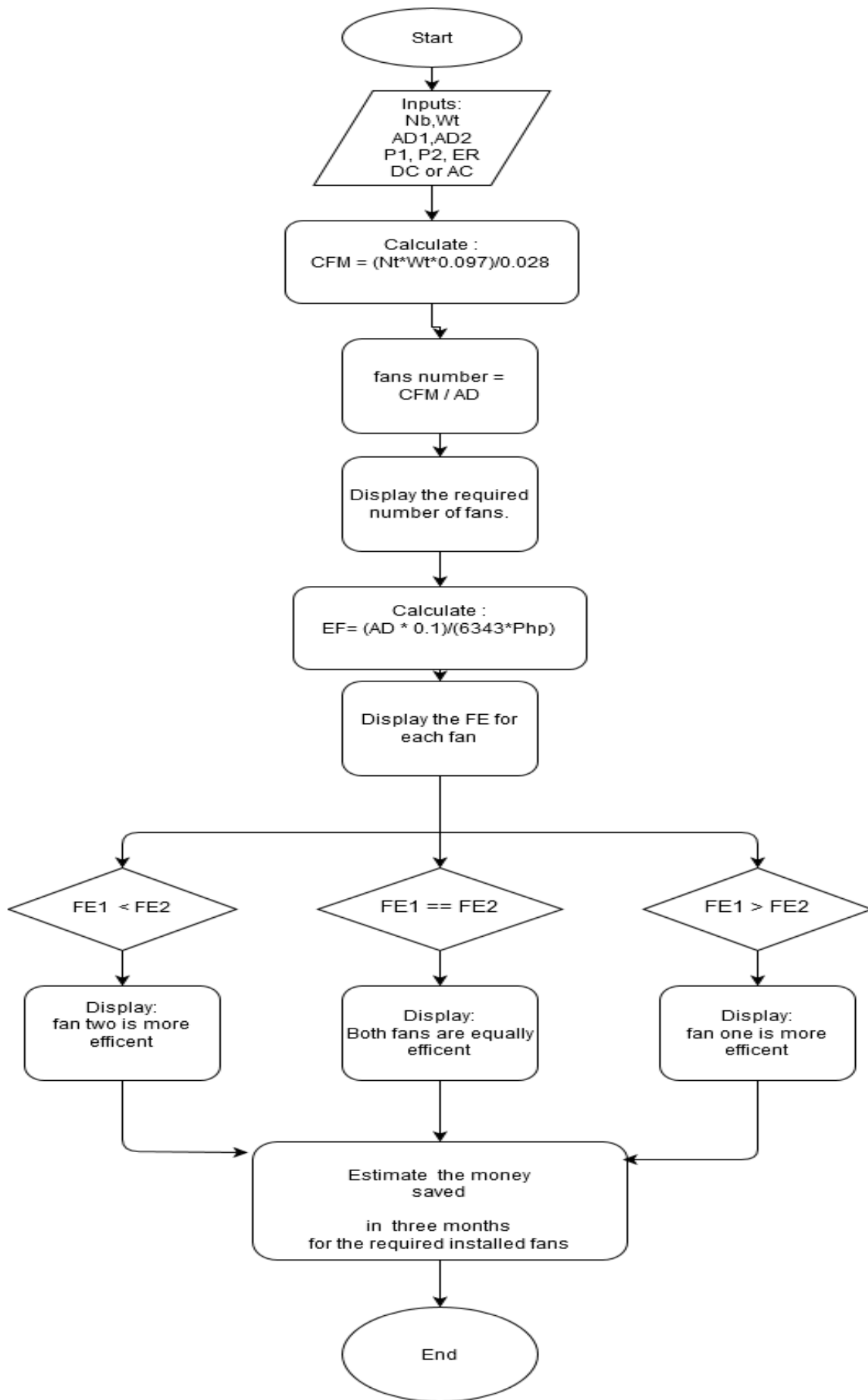


Figure 3.13 A flowchart that describes the working process of the Fan Selector application

Afterwards, the specifications of each fan, air delivery in cfm, the rating power in watts and whether the fan runs with AC or DC current, should all be inputted as well.

This GUI estimates the required number of fans by first calculating the total air delivery required in the warehouse in maximum conditions, then dividing it by the AD of each fan results in the number of fans needed to be installed.

However to calculate the fan efficiency in a SP of 0.1 inch water column (W.C), this equation were used [6]:

$$FE = \frac{AD \times 0.1}{6343 \times P_{hp}} \times 100\% \quad (3.1)$$

Where P_{hp} is the fan power input in Hp.

The higher the FE the better the performance of the fan.

As mentioned before, the SP-F1380 AC fan is the one installed in all the visited farms. So it was the first one to be simulated and then compared to all of the listed electric fans in **Table 3.6** in order to seek for the most efficient and economical fan that will be installed in future farms.

So the first simulation were between the SP-F1380 AC fan and the 24v solar fan as the below figure shows.

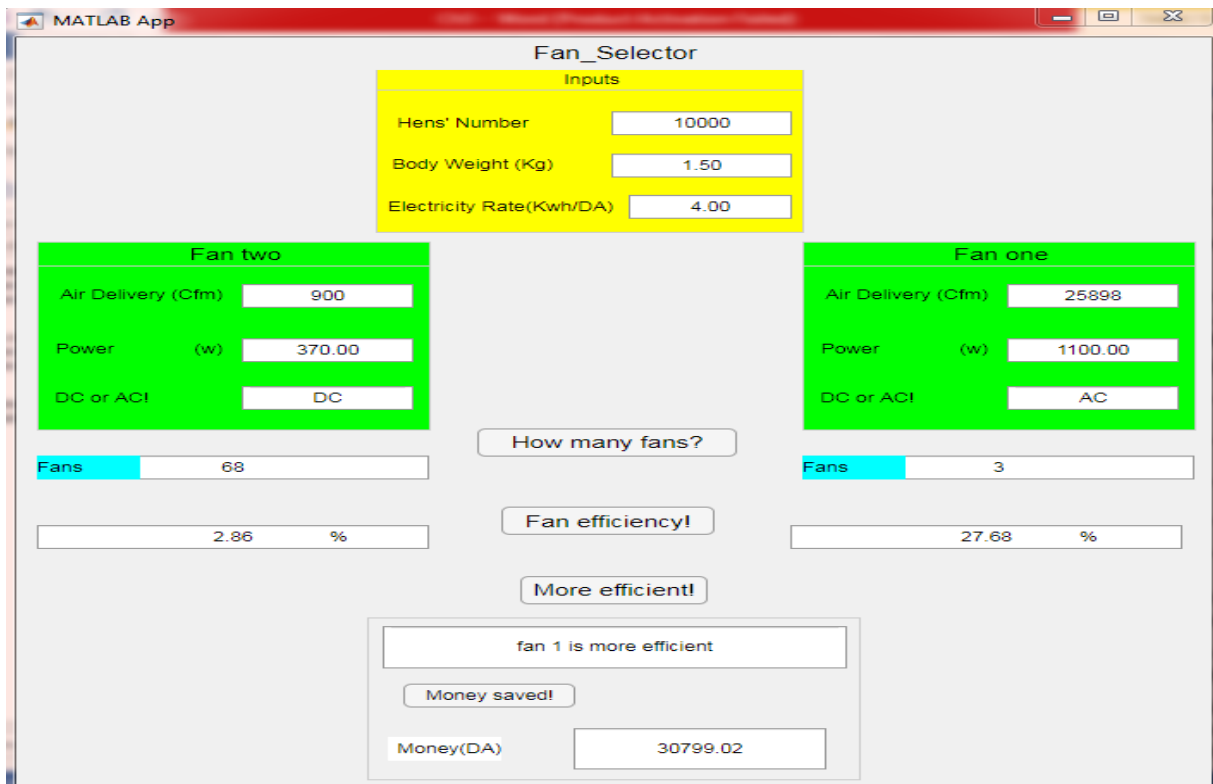


Figure 3.14 SP-F1380 versus the 24v solar fan Simulation Results.

As the simulation showed, The FE of the SP-F1380 is much higher than that one of the 24 DC fan. This last displayed a message that confirms that using the SP-F1380 AC fan is much more efficient.

In terms of money, 30799.02 DA will be saved each three months when using the SP-F1380 instead of the 24v solar fan, this double check that the SP-F1380 AC fan is the one to go with. Next, the SP-F-1000 AC fan were simulated versus the installed SP-F1380 AC fan.



Figure 3.15 SP-F1380 versus the SP-F-1000 AC fan Simulation Results.

As clearly shown in **Figure 3.15**, the FE of the SP-F-1000 AC fan is slightly less than that one of the SP-F1380 AC fan, 23.07 percent and 27.68 percent respectively. This yields to the need of installing five SP-F-1000 fans instead of just three of them in case of SP-F1380 fan. All of which confirms that the installed SP-F1380 AC fans are more efficient.

Economically speaking, 229.89 DA/3 months are saved when using the SP-F1380 AC fans.

Finally, the last fan listed in **Table 3.6** were carefully simulated versus the SP-F1380 AC fan.



Figure 3.16 SP-F1380 versus the SN2013022A BLDC fan Simulation Results.

In this time, all the odds were in favor of the BLDC fan.

Starting from the FE of the BLDC which is almost double that one of the SP-F1380 AC fan, 53.72 percent and 27.68 percent respectively. This confirms that using this BLDC fan is much more efficient even though four fans are required instead of just three usual SP-F1380 AC fans.

This simulation has also estimated the amount of money saved when using the SN2013022A BLDC fan which is 2815.77 DA/3 months.

Conclusion:

Numerous electric fans can be installed in a laying hen’s farm, either AC or DC. All of which may have different characteristics. After testing and simulating a list of a potential electric fans, it turned out that using the SN2013022A BLDC fan is the most efficient and economical fan that has to be installed in any typical farm that contains 10000 birds, 1.5 Kg each in average.

Chapter 04: Sizing of the PV Solar Plant

As mentioned in chapter three, the farmer may be willing to invest in solar energy. If this is the case, then a complete photovoltaic system design must be carried out.

In this chapter, the plant in matter will be well identified, project data as well. Furthermore, the characteristics of the materials used (photovoltaic modules, batteries, inverters) will be fully described, the design criteria of major components will be also covered. In addition to that, this chapter will cover the preliminary calculations and simulation needed to sizing the plant in question. Furthermore, a realistic view of the PV system is proposed, drawings including the single line circuit diagrams as well.

All of the calculations and simulation were carried out using the BlueSol software. This software is made for the design of photovoltaic systems in every country in the world. It allows the user to perform the entire process of designing a PV system, from the preliminary assessment of producibility to the realization of the project documentation. BlueSol is a product made with a standard Microsoft interface, very easy to use but at the same time manages every detail of the PV system.

4.1 Technical report:

The daily load profiles of the farm was carefully observed and identified through held interviews with the owners of the farms who by the way provided us also with the annual average electric bills. Thus, it was concluded that 50Kwh/day is the average consumed energy per day in a warehouse of 10000 birds.

After opening the BlueSol software and selecting the right geographical location, BlueSol gives the user the chance to select either a grid connected system or a standalone one. This last were chosen. Then a window pops up asking the user to input the average daily consumed energy. More details about how the simulation process will be explained in the upcoming sections.

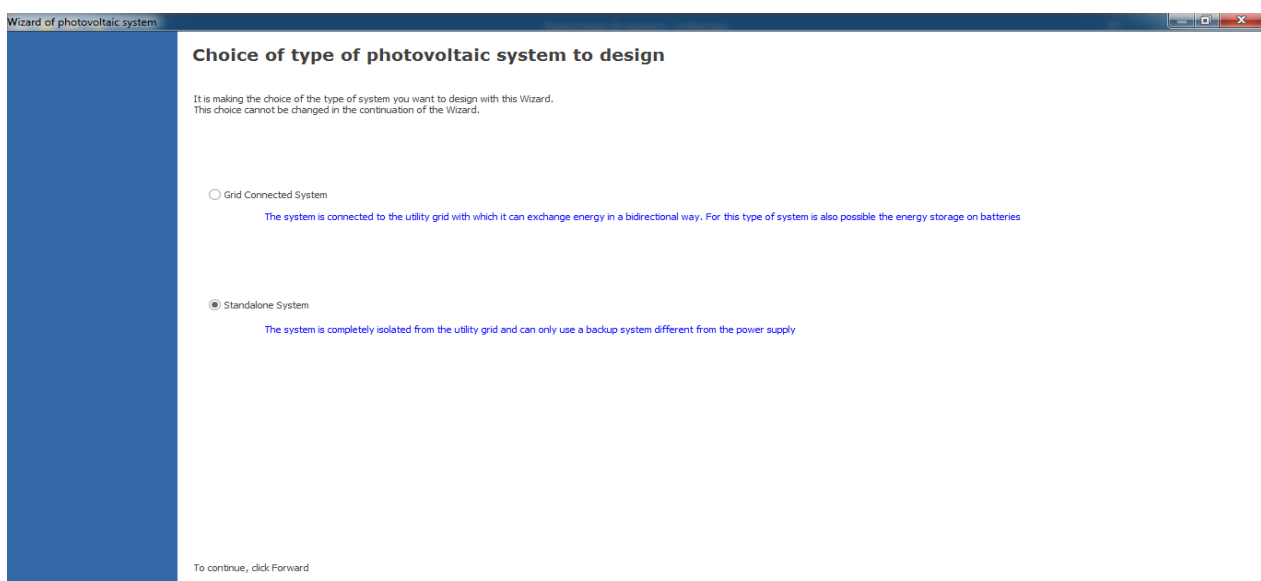


Figure 4.1 BlueSol asking the user to select the type of the PV system [20].

4.1.1 Project data:

As mentioned earlier, after choosing a standalone PV system, the next step were to accurately select the geographical coordinates where the farm is located, as seen in **Figure 4.2**.

The project data are reported below and relate to the customer, the installation site, the data on the electricity supply and the presence or absence of objects shading.

Table 4.1 Project Data of the installation Site [20].

Location	Ain Oulmene
Address	Douar Frikat
Latitude	35.92°
Longitude	5.30°
Maximum temperature	34.68 °C
Minimum temperature	3.03 °C
Global irradiation on a horizontal plane	1,741.05 kWh/m ²
Albedo	20%
Electricity Supply	Sonelgaz
Shading	No object shading

Albedo is the measure of the diffuse reflection of solar radiation out of the total solar radiation and measured on a scale from 0, corresponding to a black body that absorbs all incident radiation, to 1, corresponding to a body that reflects all incident radiation. The value 20 percent were set automatically by the used software [20].

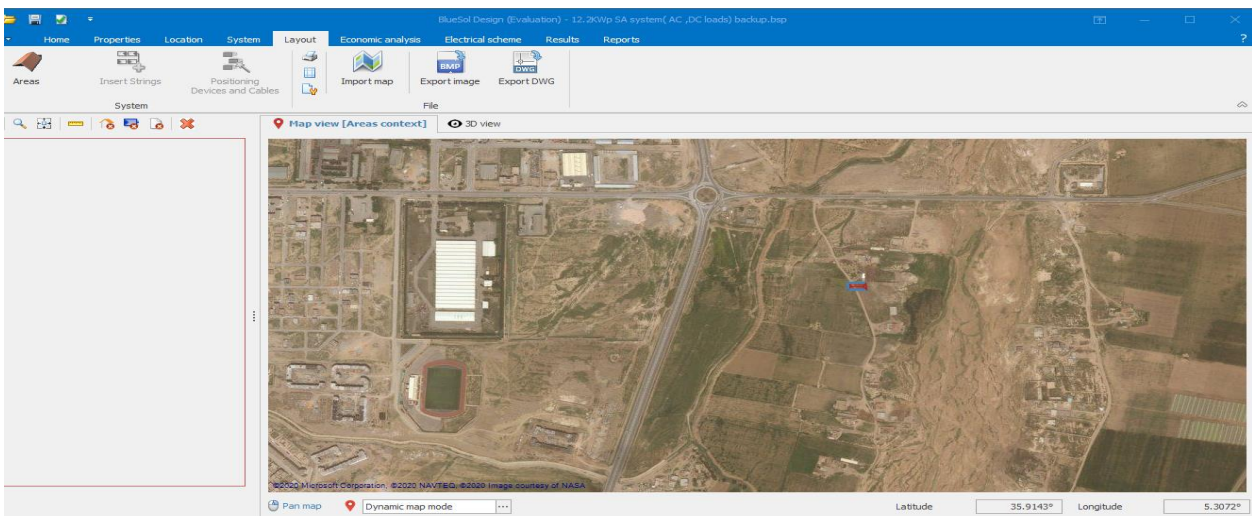


Figure 4.2 The Geographical coordinates of the Farm in matter [20].

4.1.2 Description of the photovoltaic system:

Afterwards, the total consumed energy which is 50 Kwh/day were set. As it shown in **Figure 4.3**, the type of electric loads were chosen to be AC and DC loads due to the reason that electric bulbs run brighter in DC, furthermore less DC power is converted to AC which yields in less inverter's power sizing.

Consequently, the software estimated that this photovoltaic system is of a nominal power of 12 kW, it will be located at Ain Oulmene, and it is not connected to the electricity distribution grid, therefore it is a stand-alone PV system.

This PV system is isolated and equipped with batteries bank for a total capacity of 245.00 Ah. After properly selecting which battery to use, PV panel and an inverter that fulfills the requirements, the characteristics of the photovoltaic system are summarized below:

- 8 strings of 6 modules connected in series.
- The group of conversion which is formed by 2 inverters single phase.
- The group of interface.
- The systems of measurement of energy.
- The battery bank.

Wizard of standalone system

Users consumption
You define the consumption of the system users, using the average daily consumption, or by specifying the detailed consumption profile

Type of electrical loads

Only AC loads AC and DC loads Only DC loads

Average electric consumption AC

AC daily average consumption: 25.0 kWh AC annual consumption: 9125.0 kWh

Maximum hourly AC consumption: 0.0 W

Specifies the details of electricity AC consumption Search the most unfavorable AC consumption period: 4 days

Detail of electricity consumption AC...

Average electric consumption DC

DC daily average consumption: 25.0 kWh DC annual consumption: 9125.0 kWh

Maximum hourly DC consumption: 0.0 W

Specifies the details of electricity DC consumption Search the most unfavorable DC consumption period: 4 days

Detail of electricity consumption DC...

Figure 4.3 Setting the AC and DC average daily consumption [20].

a. The photovoltaic generator:

The PV generator consists of the following:

- PV modules connected in series for the realization of the strings.
- Electric cables for connection between modules and between these towards electrical panels.

Below are the characteristics of photovoltaic generator and of its main components, namely strings and modules.

Table 4.2 Electrical Characteristics of the PV generator

Nominal power	12 kWp
Number of PV modules	48
Intercepting surface	78.72 m ²
Number of strings	8
Voltage at maximum power @STC (V _{mpp})	204V

In the case of the plant in question, the PV generator presents a single exposure which implies that the tilt angle, and azimuth angle are equal for all the PV modules, namely: the azimuth angle equals 183.623° and the tilt angle equals 30°.

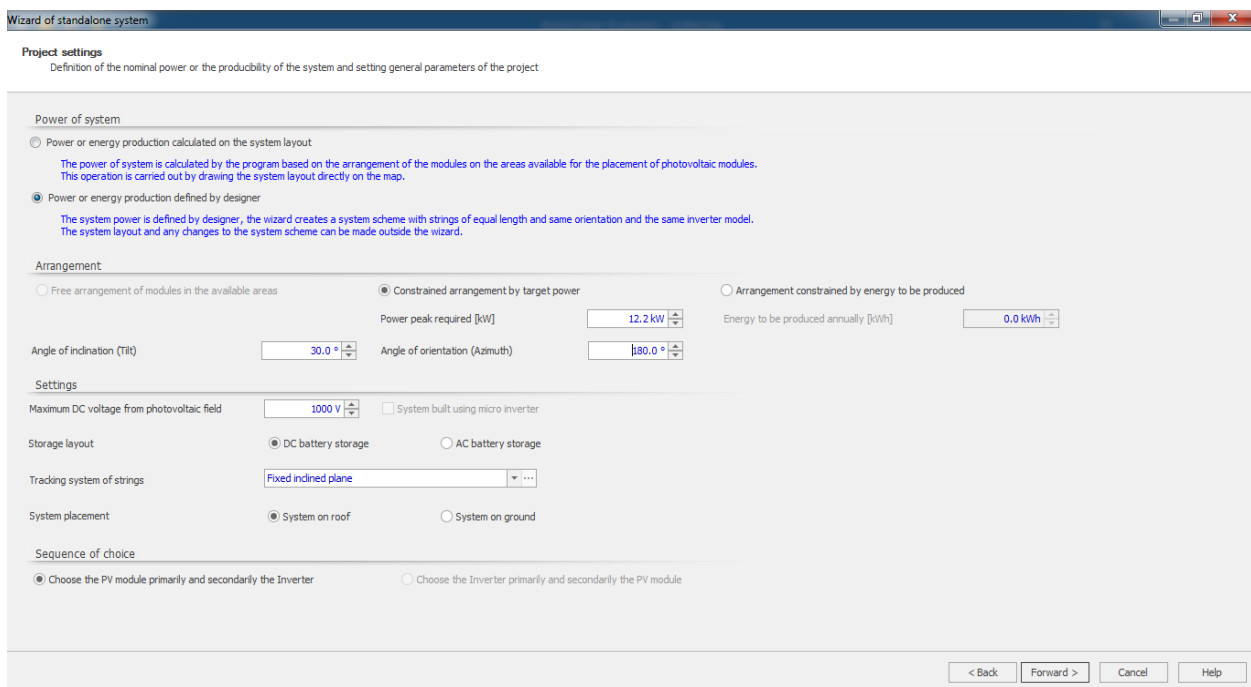


Figure 4.4 System installation on roof, fixed inclined plane with 30° tilt angle [20].

As mentioned earlier, this solar PV plant uses the series-parallel configuration and it will be divided into 8 strings of modules connected in series. The following table lists the compositions of the strings of the system.

Table 4.3 Electrical Characteristics of the Strings.

Number of PV modules in series	6
Nominal power	1.5 kW
Open circuit voltage (Voc)	240 V
Short circuit current (Isc)	8 A
Current at maximum power (Impp)	7.5 A

The “1 Soltech Inc” solar module is the one used in this simulation. Here is the electrical characteristics of the module tabulated in Table 4.4

Table 4.4 Electrical Characteristics of the “1 Soltech Inc” solar panel [20].

Manufacturer	1 Soltech Inc.
Model	M001
Technology	Si-Poly
Nominal power	250.00 W
Tolerance	3.00%
Open circuit voltage (Voc)	40.00 V
Voltage at maximum power (Vmpp)	34.00 V
Short circuit current (Isc)	8.00 A
Current at maximum power (Impp)	7.50 A
Area	1.64 m ²
Efficiency	15.2%

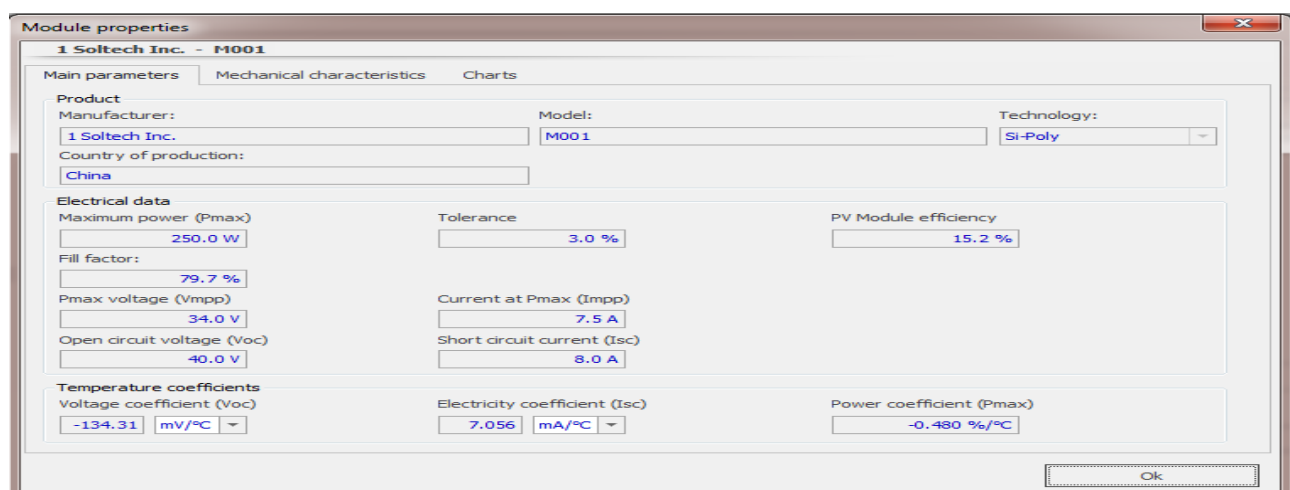


Figure 4.5 Photovoltaic Module Selection [20].

b. Group of conversion DC/AC:

The conversion group of the photovoltaic system responsible for converting the DC power into AC will consist of 2 inverters, single phase for a total output of about 12 kW.

The main technical characteristics of the inverter are summarized below.

Table 4.5 Electrical Characteristics of the Inverter [20].

Manufacturer	OutBack Power Systems
Model	Radian GS7048E3P
Nominal power	7.00 kW
Maximum power	9.00 kW
Maximum efficiency	93.00%
European efficiency	93.00%
Maximum voltage from PV	240.00 V
Number of MPPT	1
AC output voltage	220.00 V
Output	single-phase
Frequency	50 Hz

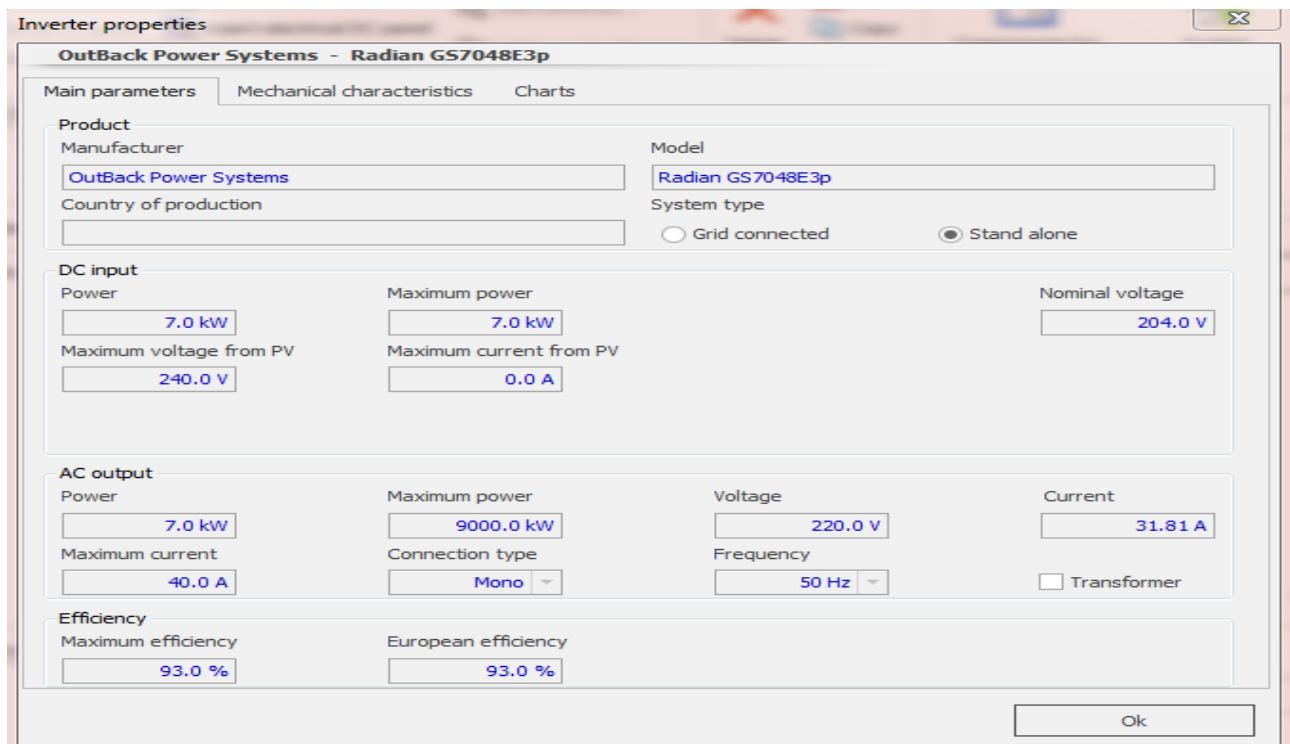


Figure 4.6 Electrical Characteristics of the Radian GS7048E3p inverter [20].

c. Battery bank:

The photovoltaic system is equipped with 2 battery banks for a total of 24 batteries. The main technical characteristics of the battery bank are tabulated below.

Table 4.6 a. Characteristics of the first Battery Bank

Battery manufacturer	INE
Battery model	Lithuim
Nr. Batteries in series	4
Nr. Batteries in parallel	3
Voltage	204.00 V
Capacity	123.00 Ah
Depth of discharge	75%
Charge Controller	Leonics SCB-48120

Table 4.6 b. Characteristics of the second Battery Bank

Battery manufacturer	INE
Battery model	Lithuim
Nr. Batteries in series	4
Nr. Batteries in parallel	3
Voltage	204.00 V
Capacity	123.00 Ah
Depth of discharge	75%
Charge Controller	Leonics SCB-48120

As it is shown in the last two tables, the PV system is equipped with two MPPT charge controllers where each MPPT is connected to a different battery bank. It was made sure that the Leonics SCB-48120 is compatible with the PV system in terms of minimum, maximum voltage sucked from the PV arrays and of course in terms of power capability.

The PV system were simulated such that the number of days a battery bank can provide to the appliances without a recharged by the solar panels to be 1 days.

4.2 Drawings:

BlueSol design simulates, via software, the behavior of the PV system in all its components. The schematic representation allows the designer to have a precise view of the operation.

4.2.1 Single-line circuit diagram:

In power engineering, a **single-line diagram** (SLD), also sometimes called **one-line diagram**, is a simplified notation for representing a three-phase power **system**. The **one-line diagram** has so many applications, one of which is representing the entire building of the PV system.

The overall diagram provides information on how the components connect and how the power flows through the system. A one-line diagram can represent an entire building system or a complicated component of the overall system.

Using the BlueSol software tools, the SLD of the photovoltaic system in matter were generated, as seen in **Figure 4.7**.

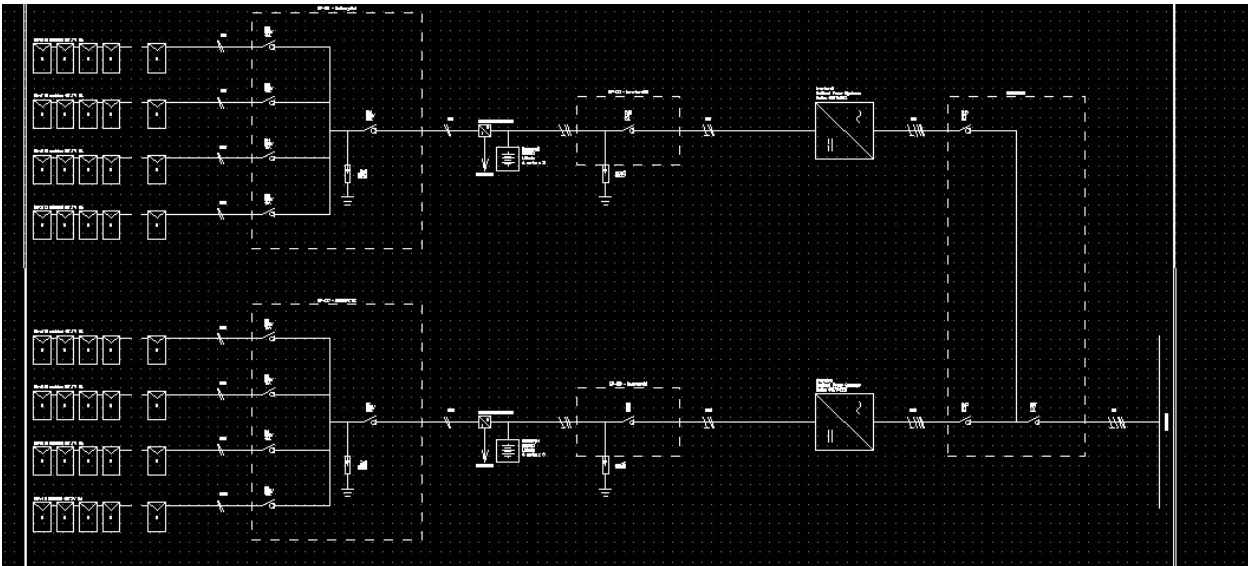


Figure 4.7 single-line circuit diagram of the PV system [20].

It is clearly visualized that the system in question is composed from two sub arrays, each one had its own battery bank, MPPT charge controller and a 7 Kw, two single phase inverters.

4.2.2 General layout of system:

Since the PV system will be mounted on the roof of a warehouse, then BlueSol allows the user to design the warehouse with real dimensions, furthermore a 3D view will be available as it is shown below in **Figure 4.8**.

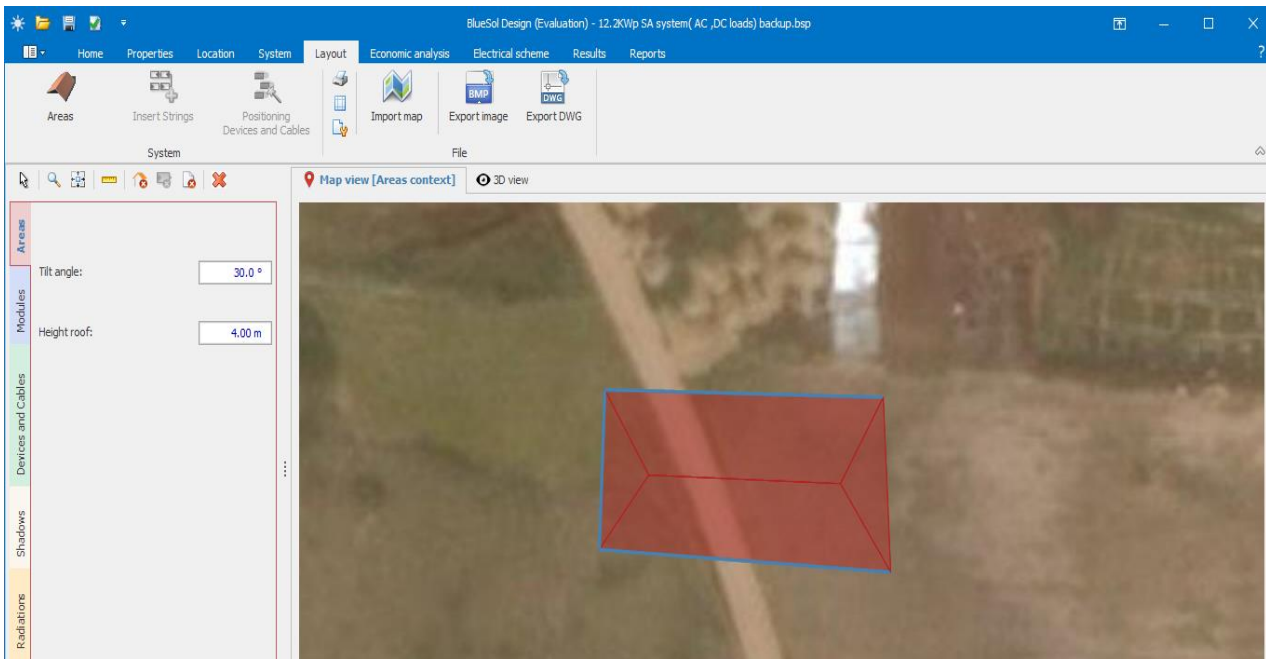


Figure 4.8 a. Map View of the designed warehouse [20].

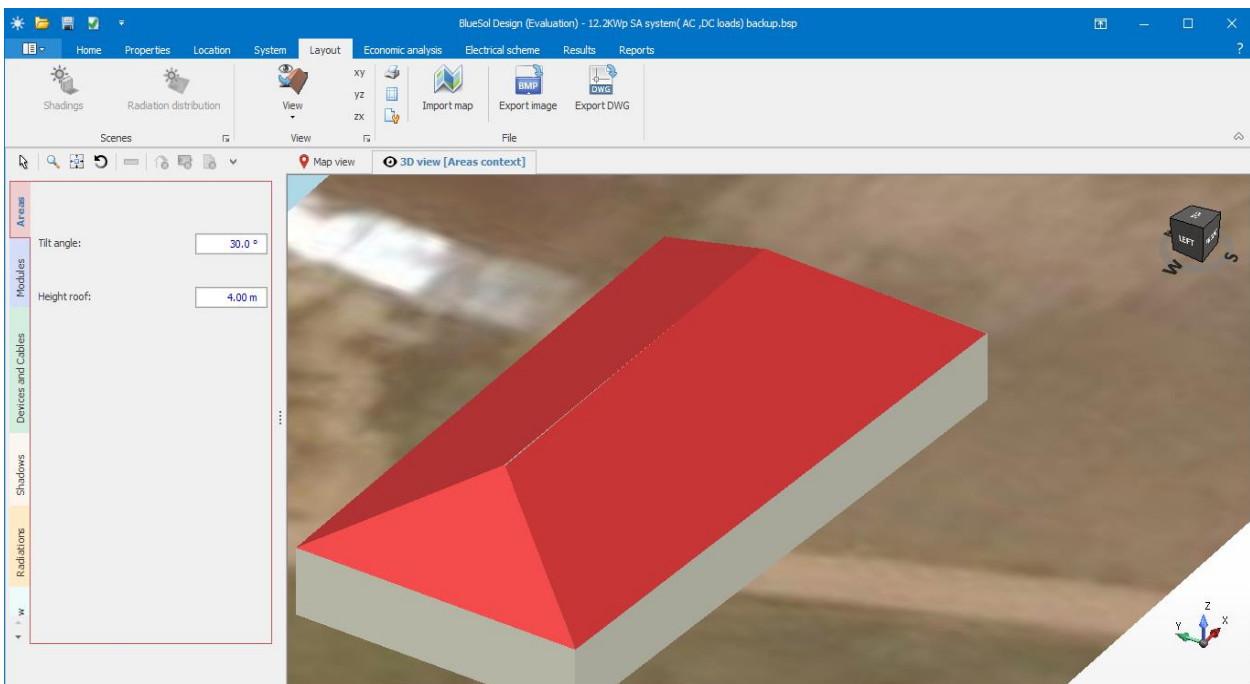


Figure 4.8 b. 3D View of the designed warehouse [20].

Using the “Insert String’ BlueSol tool, the Strings were placed in the highlighted area. To minimize the self-shading, 2.3m vertical spacing between each sub array were set and 1m spacing between each string. This all shown in the next figure.

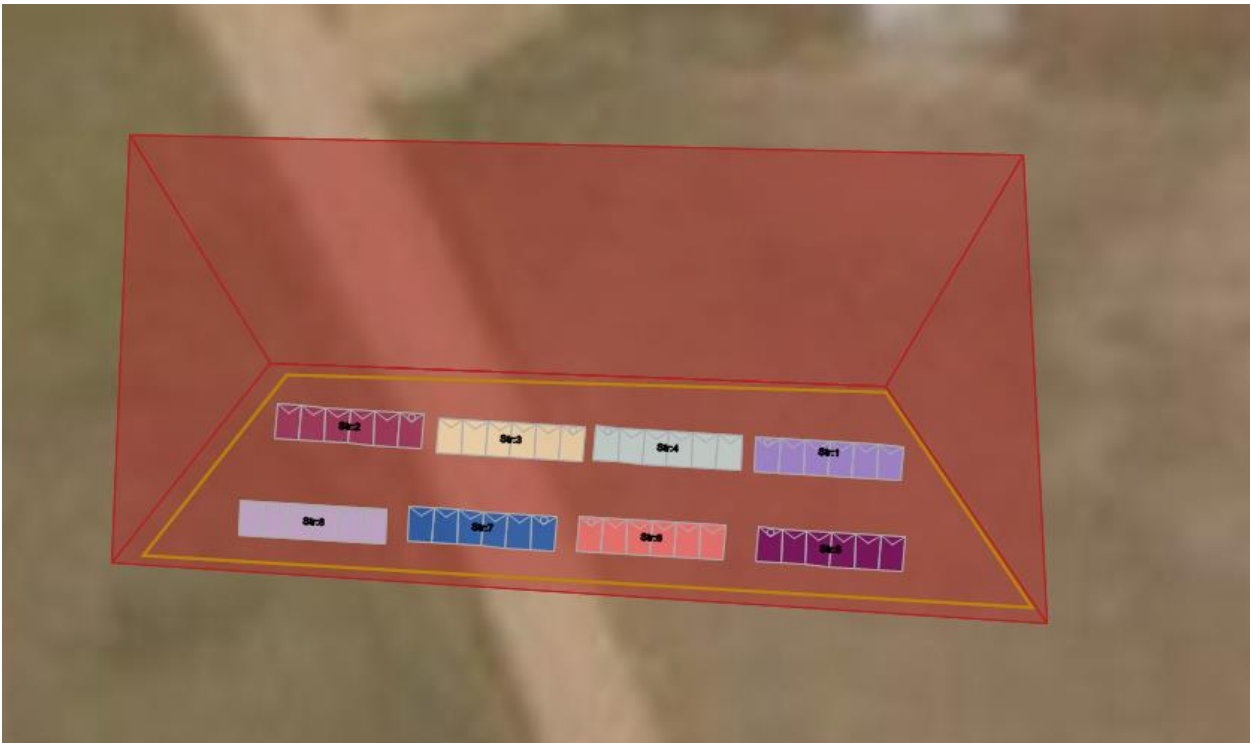


Figure 4.9 a. String Placement on the warehouse’s roof [20].

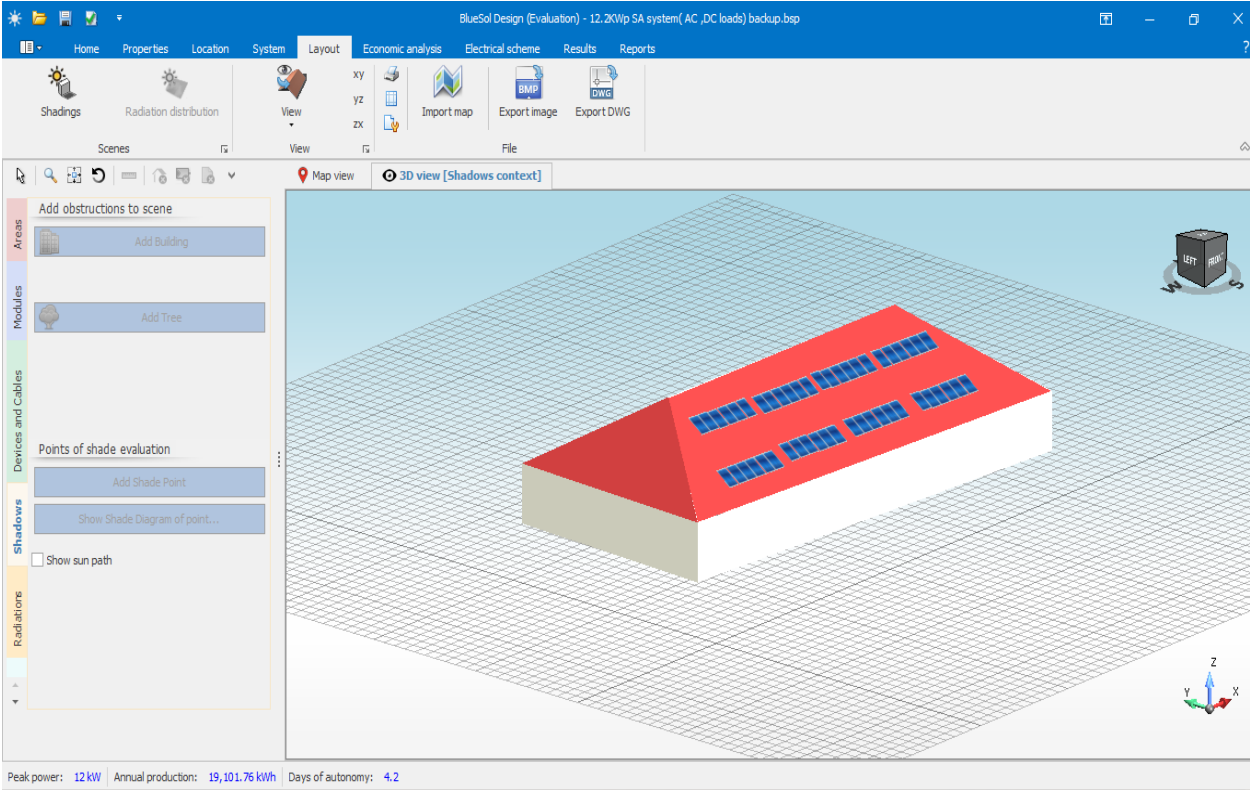


Figure 4.9 b. Realistic view of the system installation [20].

4.3 Electric pipes:

One of the advantages of the BlueSol is that it can even estimate the voltage drop across the pipe lines in order to better sizing the electric cables.

Knowing the length of the pipeline, type of cable and the maximum current on it, the calculation of the percentage voltage drop for a cable in DC current can be obtained with the relation [20]:

$$\Delta V\% = 2 \times \frac{R}{V_{nom}} \times I_{nom} \times \frac{L_p}{1000} \quad (4.1)$$

$\Delta V\%$ is the percentage voltage drop of the nominal voltage [20].

Where L_p is the length of the pipeline in meters, I_{nom} , V_{nom} are the current and voltage at standard test conditions.

R is the resistance per km of cable at a temperature of 80 °C.

However, the percentage drop voltage for the cable in alternating current is obtained with the relations:

For a single phase line:

$$\Delta V\% = 2 \times \frac{\sqrt{R^2 + X^2}}{V_{ac}} \times I_{nom} \times \frac{L_p}{1000} \quad (4.2)$$

For a three phase line:

$$\Delta V\% = 1.73 \times \frac{\sqrt{R^2 + X^2}}{V_{ac}} \times I_{nom} \times \frac{L_p}{1000} \quad (4.3)$$

Where V_{ac} is the RMS grid voltage.

R , X are the resistance and reactance of the line per km, at a temperature of 80 °C

A list of cables used in the system is shown in the table below.

Table 4.7 The Estimating of Losses in the simulated PV system [20].

Label	Description	Voltage drop	Length
C1	From: Main panel To: Users	0.00%	1.99 m
C2	From: Inverter:2 To: Main panel	0.53%	2.29 m
C3	From: EP-DC - Inverter:2:3 To: Inverter:2	0.00%	1.99 m

C4	From: Battery:2 To: EP-DC - Inverter:2:3	0.00%	1.99 m
C5	From: EP-DC - Battery:2:4 To: Battery:2	0.63%	2.05 m
C6	From: Str:8 To: EP-DC - Battery:2:4	0.93%	8 m
C7	String cable: Str:8	0.58%	4.96 m
C8	From: Str:7 To: EP-DC - Battery:2:4	0.13%	1.09 m
C9	String cable: Str:7	0.58%	4.97 m
C10	From: Str:6 To: EP-DC - Battery:2:4	0.11%	0.91 m
C11	String cable: Str:6	0.57%	4.9 m
C12	From: Str:5 To: EP-DC - Battery:2:4	0.96%	8.23 m
C13	String cable: Str:5	0.58%	4.97 m
C14	From: Inverter:1 To: Main panel	0.53%	2.29 m
C15	From: EP-DC - Inverter:1:1 To: Inverter:1	0.00%	1.99 m
C16	From: Battery:1 To: EP-DC - Inverter:1:1	0.00%	1.99 m
C17	From: EP-DC - Battery:1:2 To: Battery:1	0.62%	1.99 m
C18	From: Str:4 To: EP-DC - Battery:1:2	0.08%	0.73 m
C19	String cable: Str:4	0.58%	4.97 m
C20	From: Str:3 To: EP-DC - Battery:1:2	0.08%	0.72 m
C21	String cable: Str:3	0.58%	4.96 m
C22	From: Str:2 To: EP-DC - Battery:1:2	0.84%	7.2 m
C23	String cable: Str:2	0.58%	4.97 m
C24	From: Str:1 To: EP-DC - Battery:1:2	0.84%	7.26 m
C25	String cable: Str:1	1.03%	8.89 m

4.4 Preliminary calculations:

Preliminary calculations are of a most importance when designing PV systems, because a minor calculation error can lead to a wrong course of project development. Moreover, after the performed calculations, rigorous checks are imposed of how the system may function.

Using the BlueSol, monthly and average producibility calculations of the proposed system were carried out.

4.4.1 Annual producibility:

The plant will be installed in locations Ain Oulmene, Douar Frikat. At this location, the following monthly irradiation on a horizontal surface are obtained according to the source NASA-SSE.

Table 4.8 Monthly Solar Irradiation in Ain Oulmene, obtained from NASA-SSE [20].

Month	Diffuse daily [kWh/m ²]	Direct daily [kWh/m ²]	Global daily [kWh/m ²]
January	0.92	1.59	2.51
February	1.16	2.29	3.45
March	1.55	2.93	4.48
April	1.90	3.73	5.63
May	2.07	4.60	6.67
June	2.04	5.31	7.35
July	1.88	5.54	7.42
August	1.78	4.72	6.50
September	1.67	3.20	4.87
October	1.34	2.21	3.55
November	1.02	1.55	2.57
December	0.85	1.37	2.22
Yearly	551.15	1,189.90	1,741.05

Considering the monthly average daily irradiation and the number of days which make up the twelve months of the year, one can determine the value of the annual global irradiation on a horizontal surface. This value is equal to 1,741.05 [kWh/m²] as it is shown in the table. In the other hand, one of the very important tips when designing a PV system, the shading should be avoided because they cause a loss of power and therefore of energy produced.

However, limited phenomena can be permitted. In case of the plant in question, there may or may not be phenomena of shadowing. To know the answer to this question, a far object shadowing simulation were performed.

In particular, the figure that shows the profile of far objects shading seen by a hypothetical observer in the photovoltaic field, and the trend of monthly loss factor for shading.

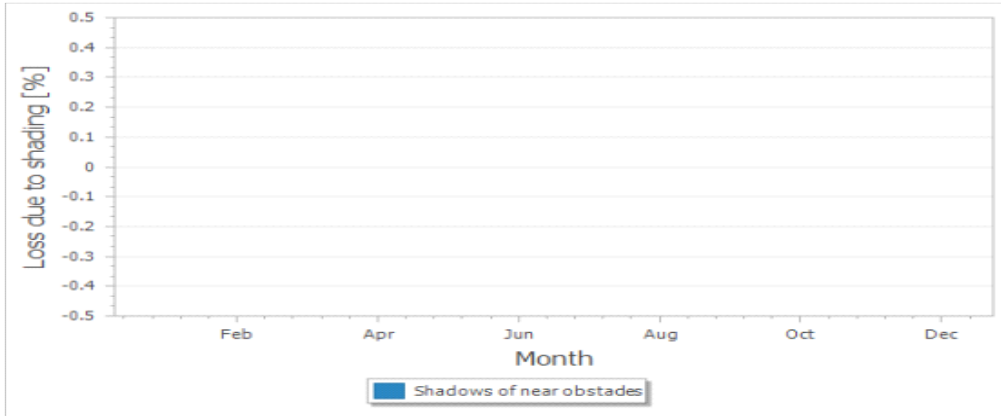


Figure 4.10 Shading losses per month [20].

Overall, on a yearly basis, the energy losses due to shading amount is about zero percent. This is because the warehouse is the only thing that were designed with neither near objects or far ones.

The producibility of the system was calculated on the basis of data derived from the source of climate data NASA-SSE, from the installation site relative to the average monthly global of solar radiation incident on horizontal surface.

The procedure for the calculation of the energy produced by the system takes into account the nominal power (12 kW), the angle of tilt and azimuth (30°, 183.623°) of the PV generator, the losses on the PV generator (resistive losses, losses due to difference in temperature of the modules, for reflection and for mismatching between strings), the efficiency of the inverter as well as the coefficient reflectance of the ground in front of the modules (Albedo).

Therefore, the energy produced by the system on an annual basis ($E_{p,y}$) is calculated as follows:

$$E_{p,y} = P_{nom} \times I_{rr} \times (1 - Losses) = 19101.76 \text{ kWh} \quad (4.4)$$

P_{nom} is the nominal power of the system which is 12 kW

I_{rr} is the annual irradiation on the surface of the modules which were estimated by 1913.90 kWh/m²

Losses were estimated to be 16.83 percent. These losses are due to various factors.

The table below lists these loss factors and their values assumed by the procedure for the calculation of system producibility.

Table 4.8 The Estimating of Losses in the simulated PV system [20]

Temperature losses	3.00 %
Mismatching losses	2.00 %
Resistive losses	4.00 %
Losses for DC/AC conversion	7.00 %
Other losses	2.00 %
Shading losses	0.00 %
Total losses	16.83 %

The graph below shows the trend of monthly production of energy expected during the year.

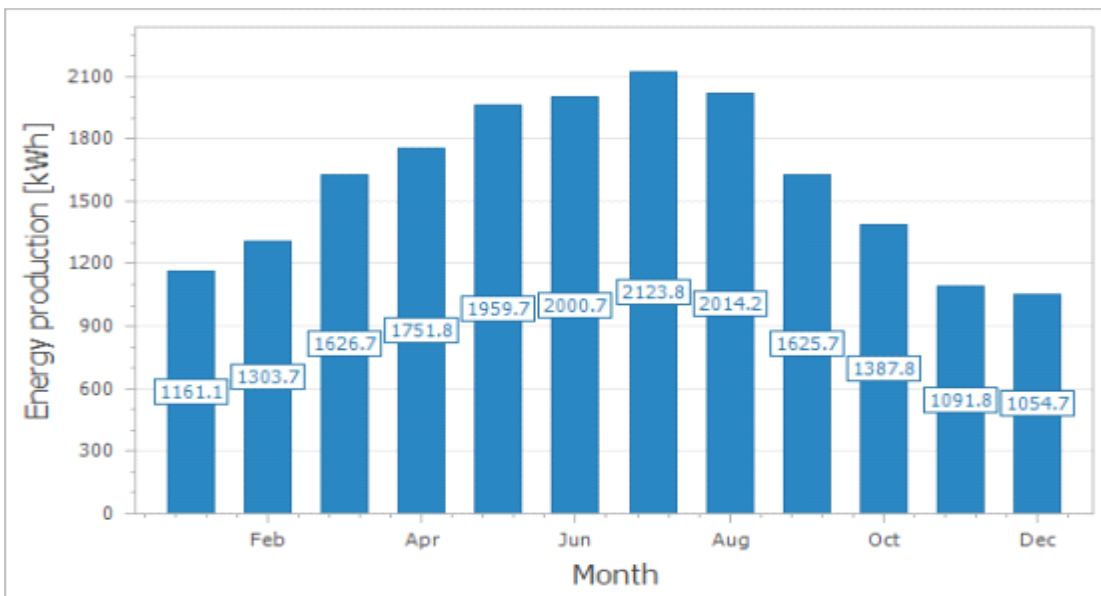


Figure 4.11 The monthly Energy production during a year [20].

Conclusion:

As we know the energy consumption for such farms is very high, there is substantial benefit that could be realized. With the aid of BlueSol software, we were able to conduct and perform a real detailed PV system simulation starting from setting the right geographical coordinates and finishing by estimating the annual energy production. We concluded that installing 12 kw photovoltaic system would be so beneficial as an alternate electricity source by excluding the grid consumption every month to zero.

The return of investment (ROI) results indicated about seven to ten years for cost recuperation, which is fairly good, relative to a life expectancy of 25 years.

General conclusion:

So far and after so many held interviews with farmers who are currently investing in egg production farms. They are dramatically complaining about the massive electricity bills which they are paying for. So the first intension we thought of as an electrical engineer was to invest in solar energy. However as this thesis indicated, a 12 Kw peak stand-alone PV system must be installed with two battery banks of 1500 Ah capacity combined together. Furthermore this system need approximately a roof area of 80 m².

Such investment for a farmer is very costly and at least needs 7 to 10 years for the farmer to fully recover his or her money. Therefore, alternative options must be proposed. To do so, the electricity usage consumption were carefully observed. As this thesis indicated, 50 percent of the daily energy is consumed by the incandescent bulbs which have a very low inefficient. Moreover, the installed AC electric fans are less efficient which are energy consumers by the way.

The idea was to develop two different applications, friendly user and flexible. The light Cost Calculator proved that replacing the 40 watts traditional incandescent bulbs with 5 watt classic LED filament bulbs is super-efficient and much more economical. One more feature of this application is that it allows the user to well determine the required number of bulbs and their distribution over the warehouse. The second application is named the Fan Selector, as explained in chapter three, this application helps the user to select the most efficient fan available in the market, plus how many of them. It is concluded that using three BLDC fans is twice efficient comparing to the AC installed ones, which implies less electricity consumption.

Combing the results of these two applications together will yield in a tremendous minimization of the electricity consumption that will certainly reach 50 percent of the current total consumed energy. If this is the case and the retrofitting of the bulbs and fans is carried out, then the situation now is more suitable for investing in solar energy than it was before. A standalone PV system of just 7 Kw peak will be enough for these farms, which yields to say that the system is more cost effective and 3 to 4 years are enough for the farmer to fully recover his or her money.

Future perspectives:

In this thesis, we addressed a specific sector of the agriculture domain which is the integration of PV solar energy in poultry warehouse. However, investing in solar energy in much more applications such as water pumping and freezer farm's facilities. Moreover, extending our system into hybrid multisource source system to improve its efficiency, reliability and cost will fall under the scope of our interests and concerns.

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