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Faculty of Technology

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Graduation Project

To obtain master's degree in Renewable Energies

Photovoltaic conversion

Study of the integration of PV installation in the air treatment at the CANASTEL Hospital

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presented to the jury composed of:

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With deepest appreciation and love,

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Abstract

العربية

الهدف من هذا المشروع هو تحديد الأبعاد المناسبة للنظام الكهروضوئي الهجين الذي سيوفر الطاقة لوحدات معالجة الهواء في مستشفى كاناستيل في وهران ، الجزائر. سيتم تحقيق ذلك من خلال مجموعة من الحسابات اليدوية ، واستخدام برنامج PVsyst لمحاكاة تحجيم النظام ، واستخدام برنامج HOMER pro لتقييم التكلفة المالية للنظام.

خلصنا إلى أن زرع الأنظمة الكهروضوئية في وحدات معالجة الهواء هو حل قابل للانصهار لتوفير الطاقة في المستشفيات.

French

L'objectif de ce projet est de déterminer les dimensions appropriées d'un système photovoltaïque hybride qui alimentera les unités de traitement de l'air de l'hôpital CANASTEL d'Oran, en Algérie. Cet objectif sera atteint par une combinaison de calculs manuels, l'utilisation du logiciel PVsyst pour les simulations de dimensionnement du système, et l'utilisation du logiciel HOMER pro pour évaluer le coût financier du système.

Nous avons conclu que l'implantation de systèmes photovoltaïques dans les unités de traitement de l'air est une solution viable pour économiser l'énergie dans les hôpitaux.

English

The aim of this project is to determine the appropriate dimensions for a hybrid photovoltaic system that will supply power to the air treatment units at CANASTEL hospital in Oran, Algeria. This will be achieved through a combination of manual calculations, utilization of PVsyst software for system sizing simulations, and the utilization of HOMER pro software to assess the financial cost of the system.

We concluded that implanting photovoltaic systems in air treatment units is a fusible solution to save energy in the hospitals.

Summary

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In recent years, the world has witnessed a growing concern about sustainable development and the need to minimize energy consumption in various sectors. One area of significant energy usage is the operation of hospitals, which require constant heating, cooling, and ventilation to ensure a comfortable and healthy environment for patients, staff, and visitors. Consequently, finding innovative and eco-friendly solutions to reduce energy consumption in healthcare facilities has become imperative.

In the context of the CANASTEL Hospital in Oran, Algeria, this thesis focuses on studying the integration of photovoltaic (PV) systems in air treatment units. The aim is to harness the power of solar energy to offset the energy demand for air conditioning and ventilation within the hospital, thereby reducing its overall energy consumption.

Algeria, a country abundant in sunlight, presents an ideal environment for the implementation of solar energy technologies. By exploiting this renewable energy source, hospitals like CANASTEL can not only achieve significant cost savings but also contribute to a greener and more sustainable future. The integration of PV systems in air treatment units offers a promising approach to address energy efficiency and environmental challenges simultaneously.

The primary objective of this thesis is to conduct a comprehensive analysis of the potential benefits and challenges associated with integrating PV systems in the air treatment units of CANASTEL Hospital. The study will encompass various aspects, including system design, technical feasibility, economic viability, and environmental impact assessment.

By investigating the potential energy savings, financial implications, and environmental advantages of this integration, the research will provide valuable insights for decision-makers, facility managers, and energy professionals in the healthcare sector. The findings and recommendations derived from this study can serve as a foundation for future initiatives aiming to promote renewable energy adoption in hospitals not only in Oran but also in other regions with similar energy consumption patterns.

In conclusion, this thesis aims to contribute to the understanding of the integration of PV systems in air treatment units to reduce energy consumption in healthcare facilities, using CANASTEL Hospital in Oran, Algeria, as a case study. By addressing the technical, economic, and environmental aspects, this research will shed light on the feasibility and potential benefits of adopting solar energy technologies in the context of air conditioning and ventilation systems.

Ultimately, it aspires to pave the way for sustainable energy practices in hospitals, fostering a greener and more resilient healthcare infrastructure.

Chapter 1
Problematic of the project

Introduction

Chapter 1 provides an overview of the key topics that will be discussed in this thesis, focusing on the CANSTEL hospital and the energy situation in Algeria. The chapter begins by introducing the CANSTEL hospital and highlighting its importance in the context of healthcare. It then identifies the problematic issues associated with the hospital's air handling unit and emphasizes the need for a hygienic solution. Moving on, the chapter explores the energy landscape in Algeria, including the country's energy providers, electrification rate, and electricity production. Finally, it delves into the renewable energy potential in Algeria, specifically focusing on solar energy, wind power, geothermal energy, and hydraulic potential. This chapter sets the stage for the subsequent discussions on improving energy efficiency and implementing renewable energy solutions in the CANSTEL hospital.

1.1 CANSTEL hospital

1.1.1 Description

Hospital Pediatric of Canstel is located in Oran 31130 ،Algeria, it Takes care of children referred or transferred from the 58 wilaya of the national territory, in several pediatric specialties, surgical and exploration.

The hospital specialized in pediatrics Canastel, named professor Boukhrofa Abdelkader is functional since March 1999, it has 22 hospital services between medical surgical and technical platforms, according to the following respective description: Service Capacity of beds: Gastroenterology nutrition 20 beds, Hematology 20 beds, Pneumo-phthisiology allergology 20beds, Cardiac surgery 20 beds, Nephrology transplantation of organs 20 beds, a unit of hemodialysis of 6-bed , multipurpose resuscitation unit 12 bed ,orthopedic surgery 25-bed, urological surgery25 beds, Visceral surgery 30 beds, Neurosurgery 30 beds, Anesthesia resuscitation 14 beds, With 9 operating rooms old building, With 8 operating rooms new building

Ophthalmology 16 beds Infectious diseases 20 beds, ENT 30 beds UMC 30 beds, Central Laboratory 3 Units: microbiology, hemobiology, and biochemistry SEMEP and Prevention services, Functional rehabilitation 19 beds medical imaging 3 units: conventional radiology, scanner and MRIMRI Anapathology, Blood transfusion station (PTS), Pharmacy and sterilization. A careful study shows the following facts:

1- the 4th floor (technical platform: operating room with 5 operating rooms, central sterilization and resuscitation) has 6 ATU (Air Treatment Unit) and an ice water group.

2-the UMC (Medical and surgical emergencies 1st, 2nd and 3rd floor) have 4 ATUs and a chilled water production unit.

These AHU installations have a total power consumption of 470.94 kW. On the other hand, it should be noted that the average monthly consumption of our establishment is: [max power reached = 225 kW for a power made available 650 kW] For an average monthly expenditure of 500 000 DA

Figure 1-1 Canastel PEDIATRIC Hospital location (35.7385°N, - 0.5733°W)

Figure 1-2 Canastel Pediatric Hospital logo

1.1.2 Problematic

Due to the exorbitant energy bill of CANASTEL Hospital's pediatrics facility, the hospital was forced to halt the use of its air handling units. This decision had severe consequences for the patients, as many of them developed respiratory diseases due to the lack of proper ventilation. As a result, the hospital had to increase its spending on antibiotics and other medications to treat these new conditions, further exacerbating the financial strain on the institution. The hospital is now exploring solutions to reduce its energy consumption while maintaining the necessary air quality standards for patient care. So, we are proposing a PV hybrid system that ensures a proper operation of the air treatment unit as well as reduce the electricity consumption

1.1.3 Why use a hygienic air handling unit in the CANSTEL hospital?

The new building has a technical platform with two operating theatres, resuscitation and sterilization. In terms of hygienic air treatment, these premises must comply with:

The essential standard for air treatment in operating theatres the NFS 90-351 which specifies the health safety requirements for the design, construction, operation, maintenance, control and use of air treatment and control facilities in health establishments.

The ISO 14644-1 standard: specifies the classification of the cleanliness of the air of clean rooms, clean areas in terms of concentration of particles in suspension in the air only are taken into account the populations of particles presenting a granulometric distribution cumulated in the lower threshold is in the range of 0,1 µm to 5µm, the establishment must ensure a good asepsis of these premises with the aim of reducing the consumption of antibiotics generated by nosocomial infections. The parameters that have a direct influence on the hygienic quality of the rooms are: ventilation, air diffusion, overpressure of the room and air filtration. To do this, the hospital uses an installation known as an "air handling unit".

1.2 Energy in Algeria

1.2.1 Energy provider in Algeria

In Algeria, the national company Sonelgaz is responsible for the production, transmission, and distribution of electricity and gas. It is the main energy provider in the country.

According to the company's website, Sonelgaz was created in 1969 and is a public industrial and commercial company with a capital of 100 billion dinars. The company's main activities include:

- Electricity production: Sonelgaz has several power plants across the country, including thermal, hydraulic, and combined cycle power plants. The company also has several renewable energy projects underway, including wind, solar, and geothermal energy.
- Electricity transmission: Sonelgaz operates a high-voltage transmission network that covers the entire country. The network has a total length of 14,500 km and operates at voltages up to 400 kV.
- Electricity distribution: Sonelgaz is responsible for distributing electricity to customers across the country. The company operates a low-voltage distribution network that covers more than 1.6 million km. [1]

1.2.2 Electrification rate in Algeria

Sonelgaz is the main electricity and gas company in Algeria and is responsible for the production, transmission, and distribution of electricity and gas across the country. The company has played a crucial role in achieving high electrification rates in Algeria, which was reported at 99.5% for 10,983,538 customers as of 2019. [1]

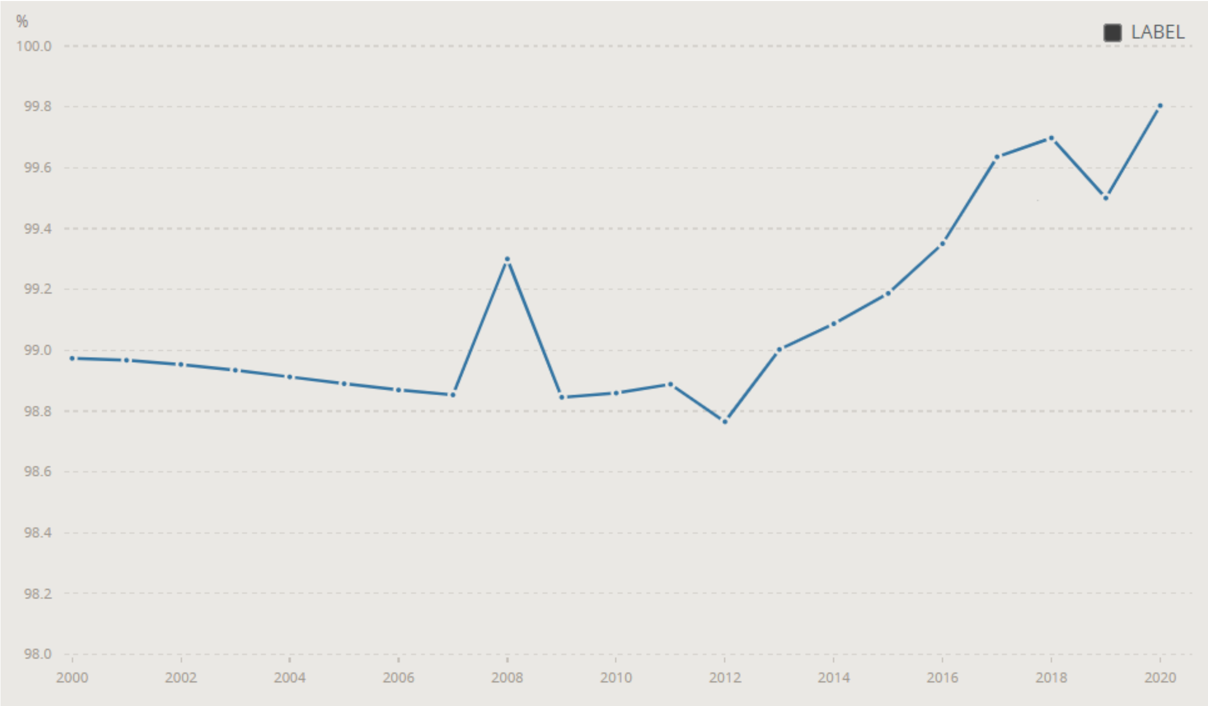

Figure 1-3 Access to electricity (% of population) – Algeria [2]

1.2.3 Productions of electricity

The national production fleet is made up of the power plants of the Algerian Electricity Production Society (SPE), and of "Shariket Kahraba wa Taket Moutadjadida" (SKTM), which are a subsidiary of Sonelgaz, as well as companies in partnership with Sonelgaz.

1.2.3.1 Electricity Production Society SPE

This branch is responsible for the production of electricity through the operation of thermal, hydraulic, and combined cycle power plants across the country. As of 2020, the Production Company has a total installed capacity of 24561 MW. [1]

In 2022, Sonelgaz operates and maintains 59 power plants in various power generation sectors:

05 Steam power plants (TV), 14 TV groups;

30 Gas-fired thermal power plants (TG), 83 fixed TG groups;

14 Mobile Gas Turbine (GMT) Plants, 50 Mobile GT Unit ;

02 Combined Cycle (CC) single shaft (01TV+01TG) power plants, six (06) DC bands;

04 Multi-shaft (02TG+01TV) Combined Cycle (DC) power plants with eight (08) DC bands;

04 Power plants Hydraulic turbines (TH), 09 TH groups.

In addition to these plants, our company has been operating and maintaining Sonatrach's Hassi Berkine Gas Turbine Plant (4 x 110 MW) since 2001. (SPE, 2020)

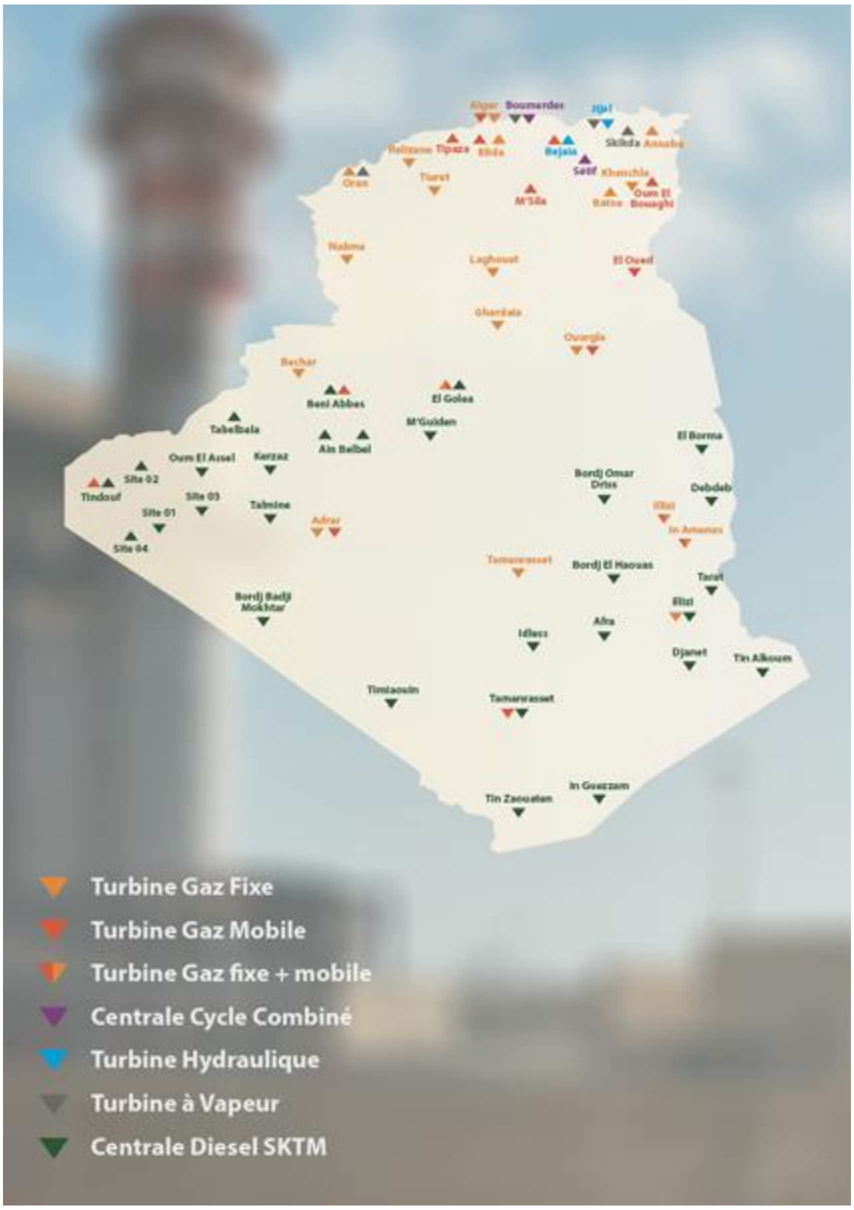

Figure 1-4 Map of power plants [1]

1.2.3.2 SKTM

Electricity & Renewable Energy Company (SKTM) is a power generation company, which is a subsidiary of the national electricity and Gas Company (Sonelgaz group). It was created on April 07th, 2013 for implementing the renewable energy program of in Algeria. The head office is located in Ghardaïa province ("Electricity & Renewable Energy Company (SKTM)," n.d.). SKTM is mainly responsible for:

- The exploitation of isolated electricity networks in the south (conventional electricity generation) and renewable energies.
- Development of the national network electrical infrastructures, production of isolated Southern Networks, engineering, maintenance and management of power plants under its jurisdiction.
- The marketing of the energy produced for the distribution subsidiaries.

Installed capacity

Photovoltaic power plant: 356.1 MWC

Wind power plant: 10.2 MW

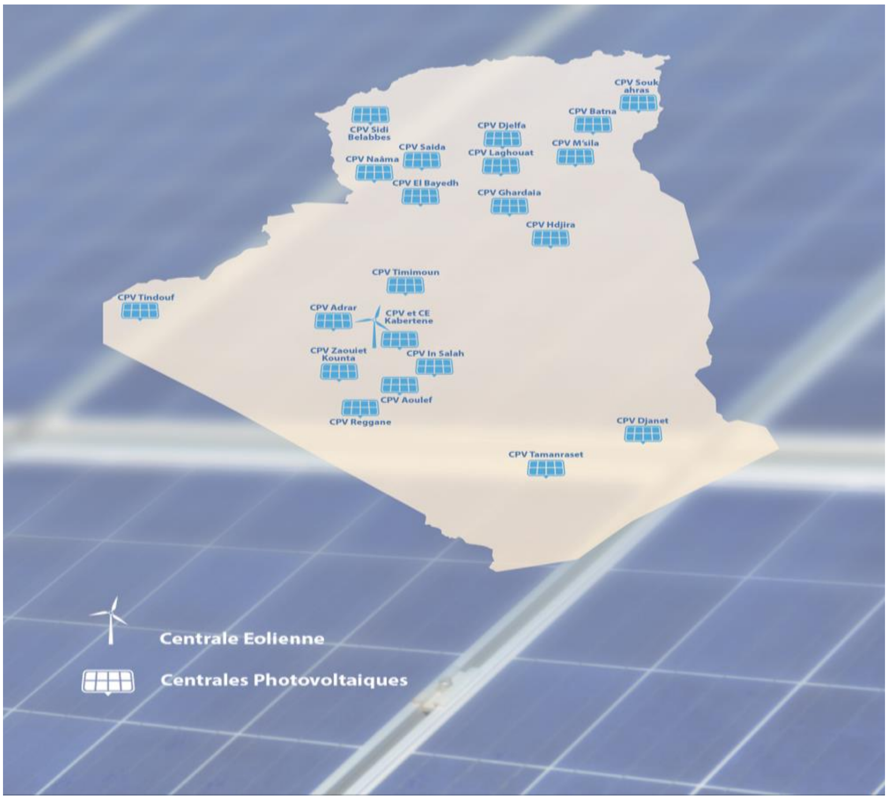

Figure 1-5 Photovoltaic and wind power plants [1]

1.2.3.3 Algeria energy balance

Table 1-1 Evolution of installed power 1980-2017 by producer (MW) [3]

	1980	1990	2006	2010	2016	2017
SPE	1 837	4 686	6 736	8 446	12 702	13 039
SKTM	-	-	-	-	1 007	1 133
Other producers	-	-	1 170	3 036	5 412	5 414
Total	1 837	4 686	7 906	11 482	19 121	19 586

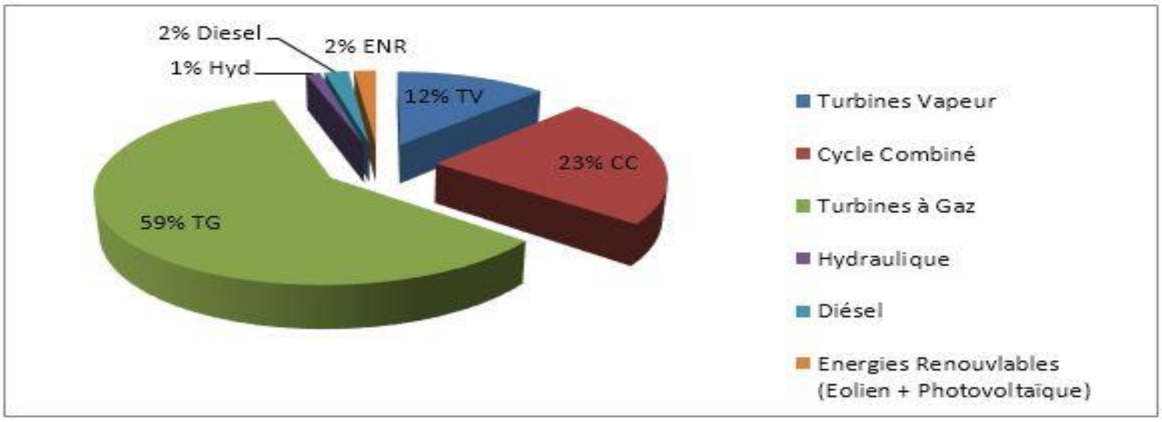

Figure 1-6 Installed power by type of equipment at the end of 2017 [3]

1.3 Renewable energy potential in Algeria

1.3.1 Solar energy

Given its geographical location, Algeria has one of the highest solar deposits in the world. The duration of insolation on almost the entire national territory exceeds 2000 hours annually and can reach 3900 hours (highlands and Sahara).

The energy received annually on a horizontal surface of 1m² is nearly 3 kWh/m² in the North and exceeds 5.6 kWh/m² in the Great South. [4]

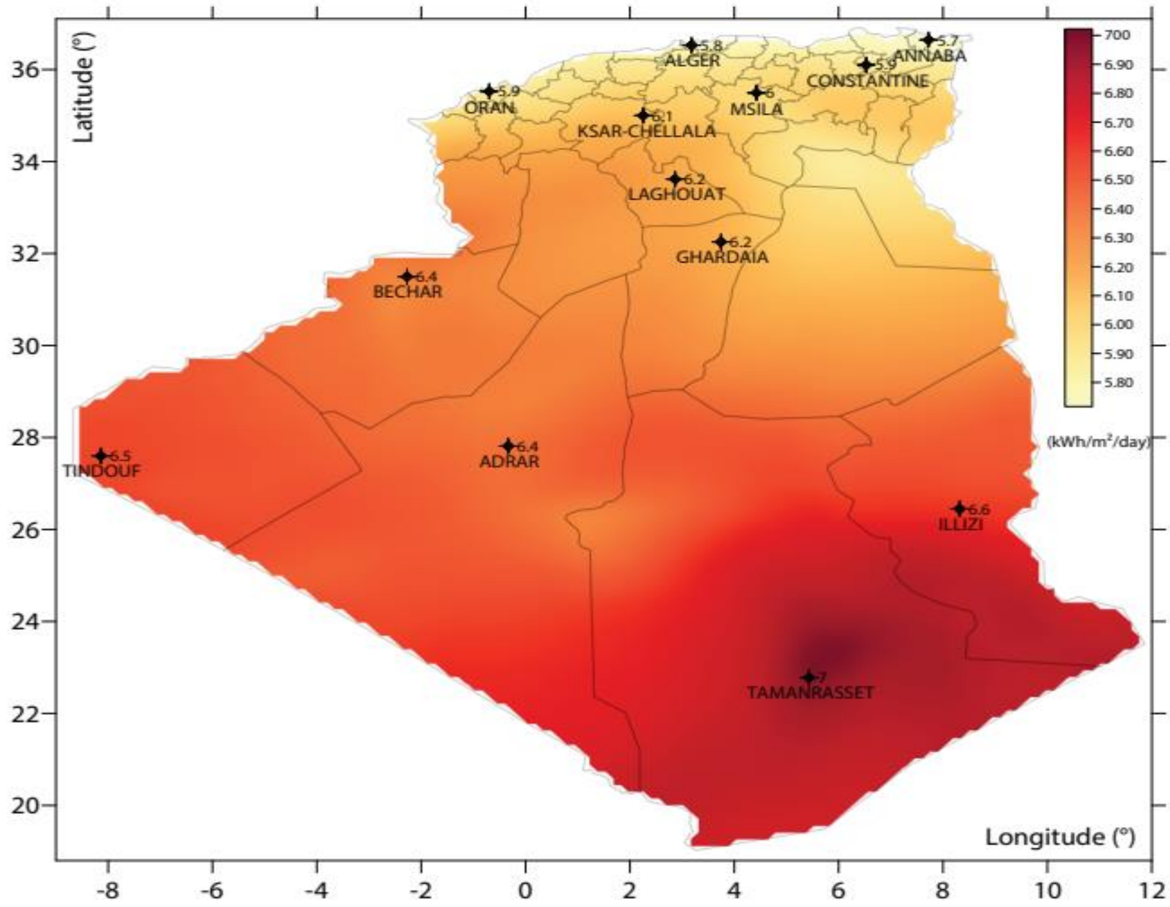

Figure 1-7 Clear sky global Irradiation map [5]

1.3.2 Wind Power Potential:

Algeria has diverse wind resources due to its varied topography and climate. The country is divided into two main geographical regions: the Mediterranean North and the South. The North, characterized by a 1200 km coastline and mountainous relief, experiences lower average wind speeds. However, there are microclimates with speeds ranging from 6 to 7 m/s along the coastal sites of Oran, Bejaia, and Annaba, as well as in highland areas like Tebessa, Biskra, M'sila, and El Bayadh. The South, with a Saharan climate, exhibits higher wind speeds, particularly in the South-East where speeds exceed 7 m/s and reach values exceeding 8 m/s around Tamanrasset (In Amguel). [4]

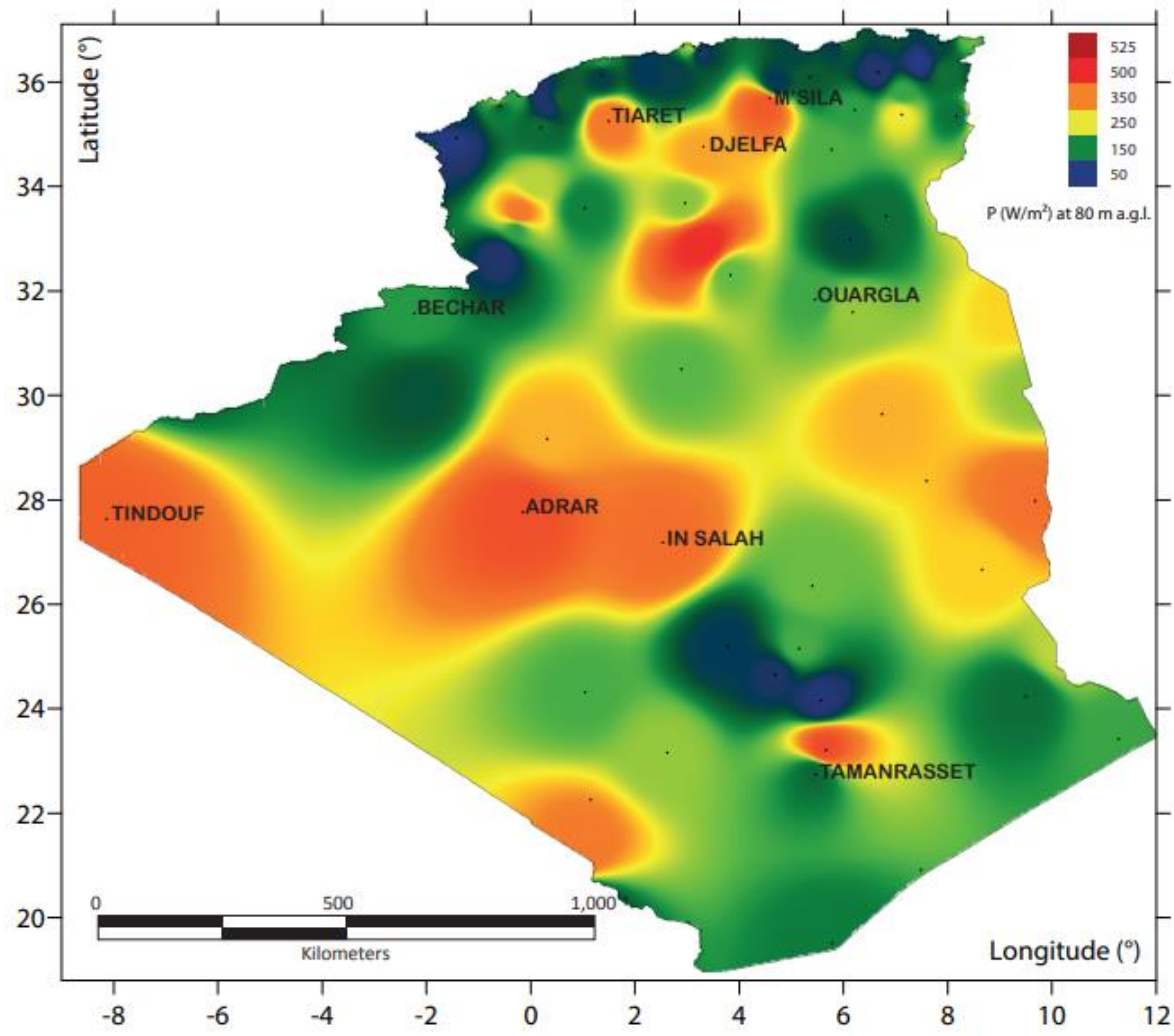

Figure 1-8 wind power density map [5]

1.3.3 Geothermal energy potential

The compilation of geological, geochemical and geophysical data has identified more than two hundred (200) hot springs that have been inventoried in the northern part of the country. About one third (33%) of them have temperatures above 45°C. There are high temperature springs that can reach 118°C in Biskra.

Studies on the thermal gradient have identified three areas where the gradient exceeds 5°C/100m [4].

Zone of Relizane and Mascara

Aïne Boucif and Sidi Aïssa area

Zone of Guelma and Djebel El Onk

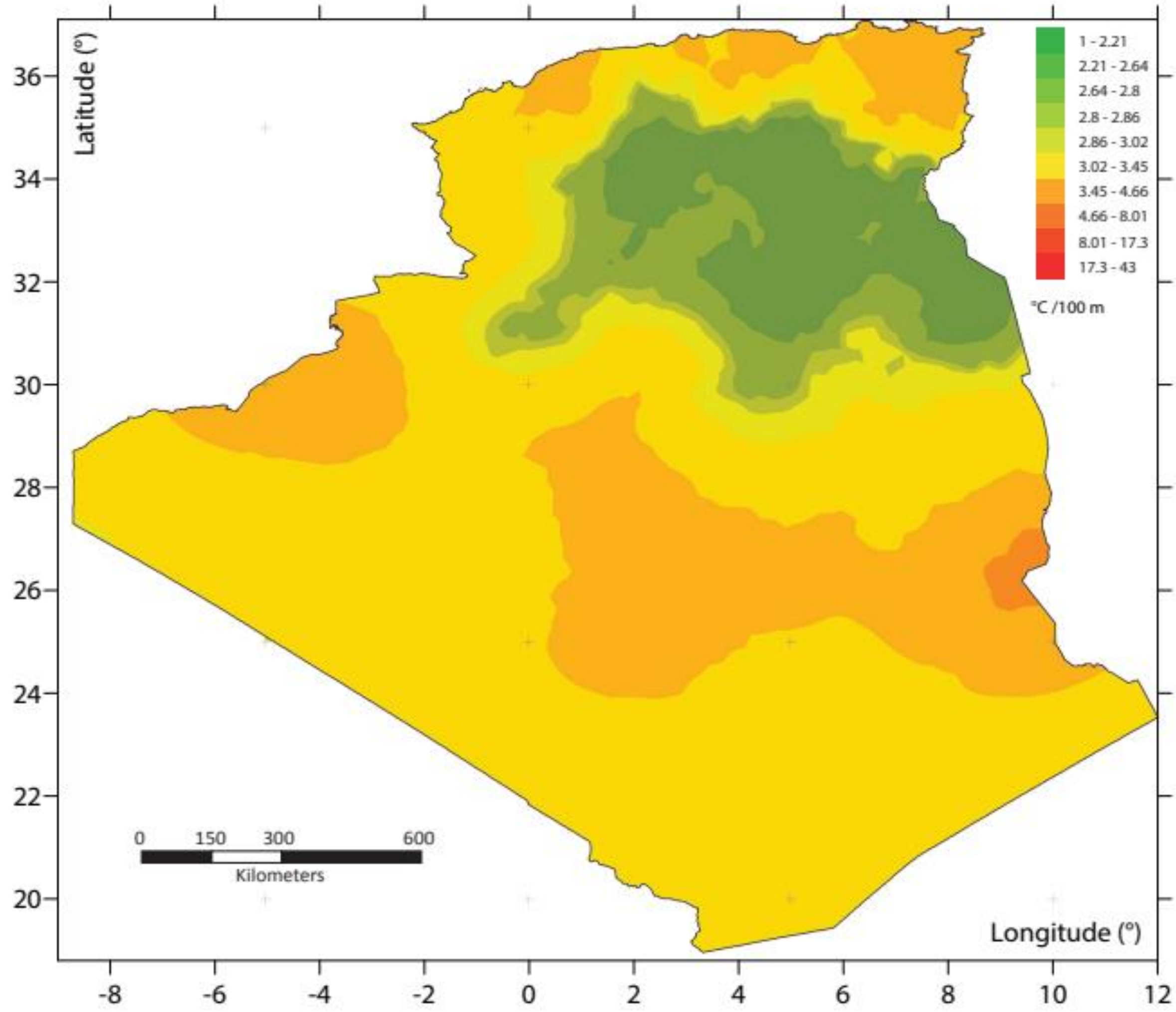

Figure 1-9 Geothermal gradient map [5]

1.3.4 Hydraulic potential

The global quantities falling on the Algerian territory are important and estimated at 65 billion m3, but finally benefit little to the country: reduced number of days of precipitation, concentration on limited spaces, strong evaporation, rapid evacuation towards the sea.

Schematically, the surface resources decrease from north to south. The useful and renewable resources are currently estimated at about 25 billion m3, of which about 2/3 are surface resources.

103 dam sites have been identified. More than 50 dams are currently in operation. [4]

1.3.5 Renewable energy development program

Through this program of renewable energy, Algeria intends to position itself as a major player in the production of electricity from photovoltaic and wind energy, integrating biomass, cogeneration, geothermal and beyond 2021, solar thermal. These energy sources will be the driving force behind sustainable economic development and will be able to drive a new model of economic growth.

37% of the installed capacity by 2030 and 27% of the electricity production for national consumption will be of renewable origin.

The national potential in renewable energies is strongly dominated by solar energy, Algeria considers this energy as an opportunity and a lever for economic and social development, particularly through the establishment of industries that create wealth and jobs.

This does not exclude the launch of many projects to build wind farms and the implementation of experimental projects in biomass, geothermal and cogeneration.

The RE projects of electricity production dedicated to the national market will be conducted in two stages:

- First phase 2015 - 2020: This phase will see the realization of a power of 4010 MW, between photovoltaic and wind, as well as 515 MW, between biomass, cogeneration and geothermal.
- Second phase 2021 - 2030: The development of the electrical interconnection between the North and the Sahara (Adrar), will allow the installation of large renewable energy plants in the regions of In Salah, Adrar, Timimoune and Bechar and their integration in the national energy system. By this time, solar thermal could be economically viable.

The strategy of Algeria in this area aims to develop a real industry of renewable energy associated with a training program and capitalization of knowledge, which will eventually employ the local Algerian engineering, especially in engineering and project management. The RE program, for the electricity needs of the national market, will create several thousand direct and indirect jobs. [4]

Algeria aims to produce 27 percent of its electricity from renewable resources by 2035, mostly from solar power. To reignite the country’s energy transition, in 2021, the Algerian government made a new push to develop strategic partnerships in the field of renewable energies with multiple countries, including China, Germany, and the United States. More specifically, the government seeks to forge relationships with foreign suppliers in engineering services, storage systems, solar-tracking technologies, universal certification solutions, and solar application kits for agriculture. Towards this end, Algeria launched a tender for a one-gigawatt solar energy project in 2021, comprised of building five power generation sites ranging from 50 to 300 MW each. Sonatrach, Algeria's national oil company, is also launching sizeable solar power projects to transition from oil and gas power generation for its off-grid oil and gas surface processing facilities. [6]

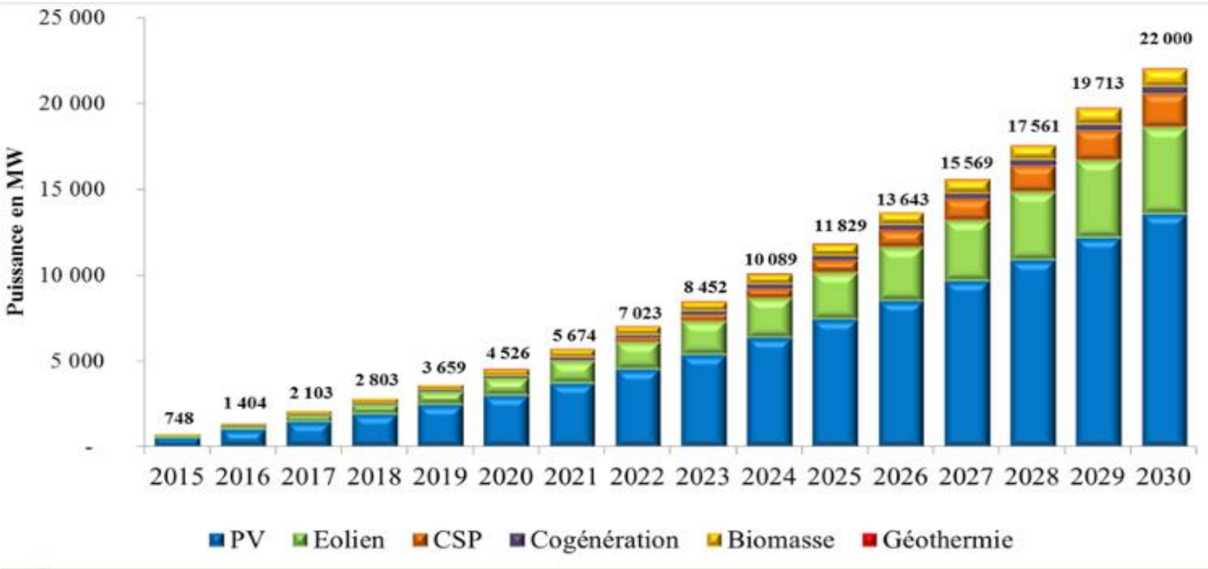

Figure 1-10 Power generated by different types of renewable energy (2015-2030) [4]

1.3.5.1 Why use solar energy:

Photovoltaic (PV) systems are generally preferred over other renewable energy sources for the following reasons.

availability: Sunlight is available almost everywhere, making solar power readily available in most places

Environmentally friendly: PV systems generate clean electricity without emitting polluting greenhouse gases, helping to combat climate change.

Lower operating costs: Once installed, PV systems are cost-effective because they do not require fuel, reducing operating costs.

Scalability and modularity: PV systems are easily modified to meet different energy needs, allowing flexibility in design and operation.

Grid applications: PV systems can operate independently from the grid, making them suitable for remote locations and increasing energy efficiency

Durability: Solar panels are designed to withstand a variety of weather conditions and can last for decades with proper maintenance.

Quiet operation: Solar panels operate quietly, preventing noise pollution, making them suitable for residential or noisy environments.

Versatility: Solar panels can be installed in existing buildings and installed in different locations, making them suitable for different uses

1.4 State of the art

2018 Mohd Shah and al Has developed and implanted a solar powered ventilation system in Melaka Malaysia an innovative ventilation system to regulate the temperature inside a car using solar power. The system features a ventilator or fan that draws fresh air from the environment and expels hot air outside, thereby stabilizing the thermal conditions inside the car on sunny days. To optimize performance, the ventilation system is equipped with a PIC Microcontroller, which controls the system automatically, making it more efficient. Test results showed that the system significantly reduces heat gain inside the car, resulting in a 12% reduction in temperature. [7]

2019 Basrawi and al developed an efficient and cost-effective solar-powered attic ventilation system. This system is designed to enhance the ventilation process in hot attic spaces of buildings. The system utilizes solar energy to power its operations, and its efficiency is maintained through the use of solar panels, resulting in improved performance for both systems simultaneously. This solar-powered attic ventilation system is less expensive to install and operate compared to other commercially available ventilation systems such as the turbine ventilator or mechanical assisted ventilation systems. The developed system has been subjected to experimental testing, which has provided evidence of its performance, working conditions, and functionality. The results of the testing indicate that the developed system can reduce the temperature of the attic space by 2.9°C and maintain temperature differences between the ambient temperature and indoor temperature of the attic space within the range of 0.1–0.4°C. In addition, it can increase the PV (photovoltaic) efficiency by 17% if there is cooling effect from the outflow of the ventilation system beneath the surface of the PV module. [8]

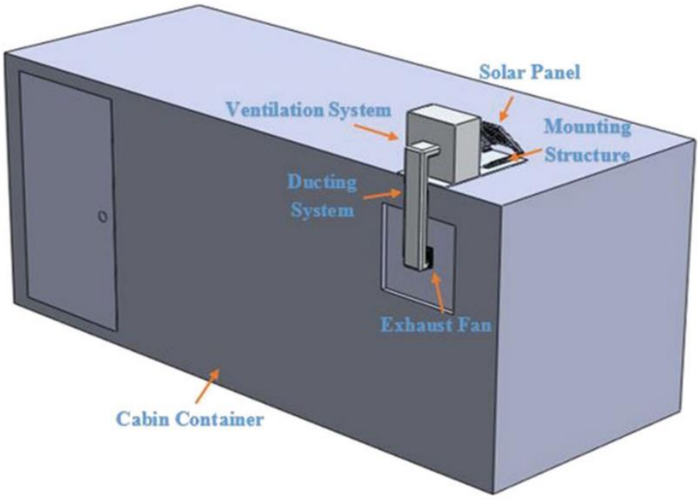

Figure 1-11 view of the solar-powered ventilation system and its component [8]

2019- Roselli et al analyzed a solar electric heating and cooling system consisting of a photovoltaic plant and an air handling unit equipped with desiccant wheel. that serves a university classroom of 63.5 m2 located in Benevento, Italy. compared to conventional HVAC systems. The system is fully electric-driven and uses solar PV electricity for heating and cooling. Four peak powers of the PV system were simulated, ranging from 9-18 kW, with four alternative solutions considered: single-axis (vertical, horizontal, and polar axis tracking) and bi-axial tracking systems. The study found that the renewable-based system achieved a maximum primary energy saving (PES) and percent reduction in equivalent CO_2 emissions (ΔCO_2) of about 79% compared to conventional systems, and the highest performance was achieved with the two-axis tracking system and 18 kW PV peak power. The study also found that effective solar tracking is necessary to achieve positive PES during summer weekdays and that the amount of electricity required for the innovative system is very high, suggesting that a full-electric configuration may be more interesting. The study concludes that the innovative solar-based air conditioning system with desiccant wheel is a promising alternative to conventional HVAC systems. [9]

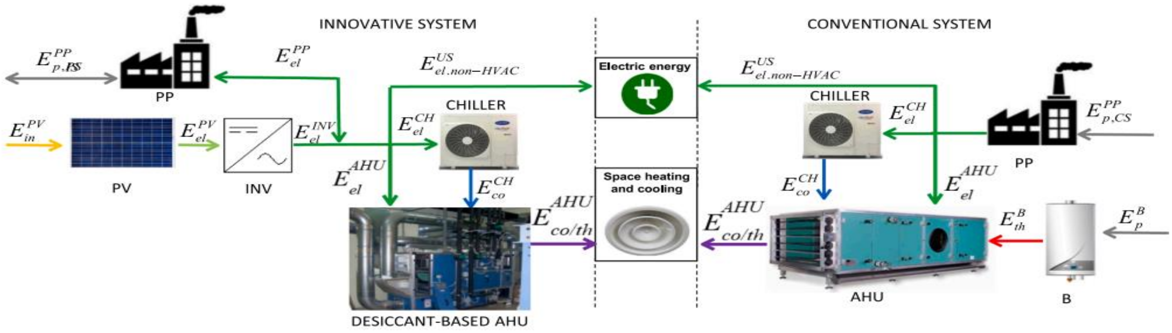

Figure 1-12 Scheme of the innovative and conventional systems. [9]

2019- Birtürk et al did a study examined the feasibility of a solar-powered mechanical ventilation system with heat recovery for a 70m² residency in two different cities: Izmir, Turkey, and Bucharest, Romania. The mechanical ventilation unit used in the study was a counter-flow heat exchanger with a thermal efficiency of 90.5% and a maximum ventilation rate of 370 m3/h. The unit was energized by a solar photovoltaic system, with the option to connect to the national electricity grid when solar energy was not available. The results showed that the system was not economically feasible for Izmir with the current electricity prices but was feasible for Bucharest, with an amortization period of 10 years. The authors noted that the economic feasibility of such systems depends on factors such as electricity prices, solar energy potential, and initial investment cost. They suggest that future research could explore ways to improve the efficiency and cost-effectiveness of solar-powered mechanical ventilation systems. [10]

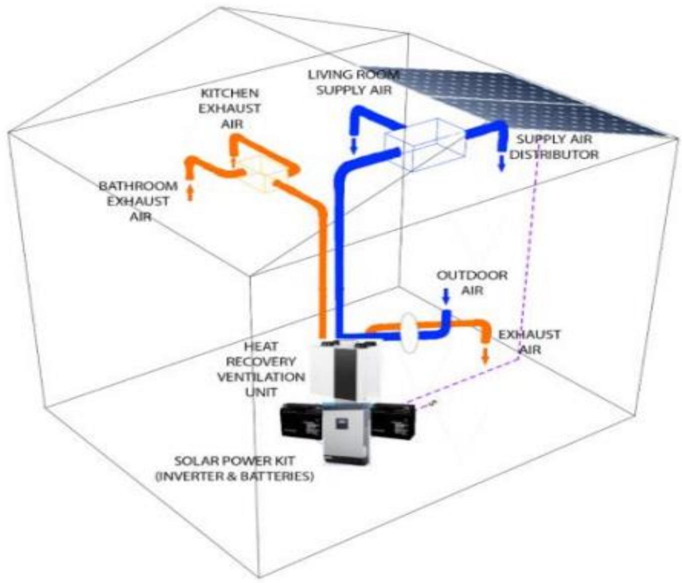

Figure 1-13 Basic diagram of the experimental system [10]

2020 Riahi and al aimed in this study to propose a MATLAB/Simulink simulated dynamic model for experimental validation, along with the development of a fuzzy controller for smart control of indoor temperature and humidity of an agricultural greenhouse powered by a supporting PV system, The greenhouse is a small, semi-insulated Capel and occupies an area equal to 14.8 m2, with a volume of 36 m3. The fuzzy controller was designed to increase indoor air temperature overnight to 15°C and decrease it during the day to 24°C, while maintaining a constant relative humidity of 70% during the day and 80% at night. The control system is powered by an 800 W photovoltaic system to significantly reduce grid utility usage and lower agricultural costs. The fuzzy vector control was designed to regulate ventilation speed, with simulation results demonstrating the efficiency and robustness of the fuzzy controller in maintaining a maximum ventilation speed of 450 RPM. Additionally, the constraints of the fuzzy logic controller can be adjusted to accommodate other greenhouse characteristics and cultivations. [11]

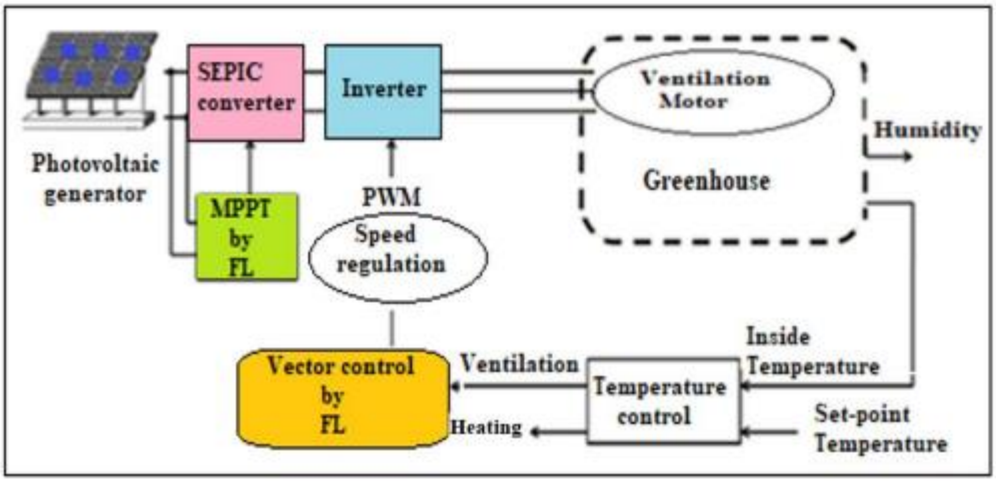

Figure 1-14 Photovoltaic (PV)-based ventilation system. [11]

1.5 Suggested solution

Utilizing solar photovoltaic (PV) power can effectively address a hospital's energy consumption challenges. By installing solar panels on the hospital's rooftop or nearby areas, the facility can generate clean and sustainable electricity from sunlight. This reduces the hospital's reliance on traditional energy sources, such as fossil fuels, thereby lowering carbon emissions and mitigating environmental impact. Solar PV systems also offer financial benefits, as they can significantly reduce operational costs in the long run. Moreover, the energy independence provided by solar power ensures uninterrupted medical services during grid outages or emergencies. Overall, adopting solar photovoltaic power empowers hospitals to become more environmentally conscious, financially efficient, and resilient in their energy supply.

1.6 conclusion

Chapter 1 lays the groundwork for the research presented in this thesis. It has provided an introduction to the CANSTEL hospital, identifying the problematic issues related to its air handling unit and emphasizing the significance of implementing a hygienic solution. The chapter has also shed light on the energy landscape in Algeria, including the country's energy providers, electrification rate, and electricity production. Furthermore, it has explored the vast renewable energy potential in Algeria, highlighting the possibilities offered by solar energy, wind power, geothermal energy, and hydraulic potential. By establishing this foundation of knowledge, the subsequent chapters will delve deeper into improving energy efficiency and integrating renewable energy sources in the CANSTEL hospital. Through these efforts, it is hoped that this thesis will contribute to the sustainable development of the hospital and the broader energy sector in Algeria.

Chapter 2

Air treatment units

2.1 Introduction

This chapter focuses on air treatment units and their critical role in maintaining clean and healthy indoor air quality, particularly in hospital environments. Hospitals require a specialized approach to air treatment due to the unique challenges they face in terms of infection control and patient well-being. In this chapter, we will explore the definition of air treatment units and discuss the different types specifically designed for hospital applications. By understanding the specific requirements and considerations for air treatment in hospitals, healthcare professionals can ensure a safe and conducive environment for patients, staff, and visitors.

2.2 Air treatment units

2.2.1 Definition

Air treatment units are devices or systems that are designed to improve the quality of indoor air by removing impurities and contaminants. These units typically use a combination of filters, purifiers, and other technologies to remove particles, allergens, volatile organic compounds (VOCs), and other pollutants from the air.

The specific components and design of air treatment units can vary depending on the intended application and the types of pollutants that are present in the air. Some common types of air treatment units include mechanical filters, electrostatic precipitators, UV germicidal irradiation systems, and air purifiers.

Overall, the goal of air treatment units is to improve indoor air quality, which can have significant benefits for health and well-being. This is particularly important in settings where people spend a lot of time indoors, such as homes, offices, schools, and healthcare facilities. [12]

2.2.2 Types of air treatment units

We will see three types of air handling units:

1.The single flow AHU, it is either all fresh air, or all return air or a mixture of the two flows

2.The double flow air handling unit, it allows all possible combinations between the air return, the new air, the rejected air, the treated air according to the configuration.

3.The air handling unit with constant air supply. [12]

2.2.2.1 Details of a single flow air handling unit

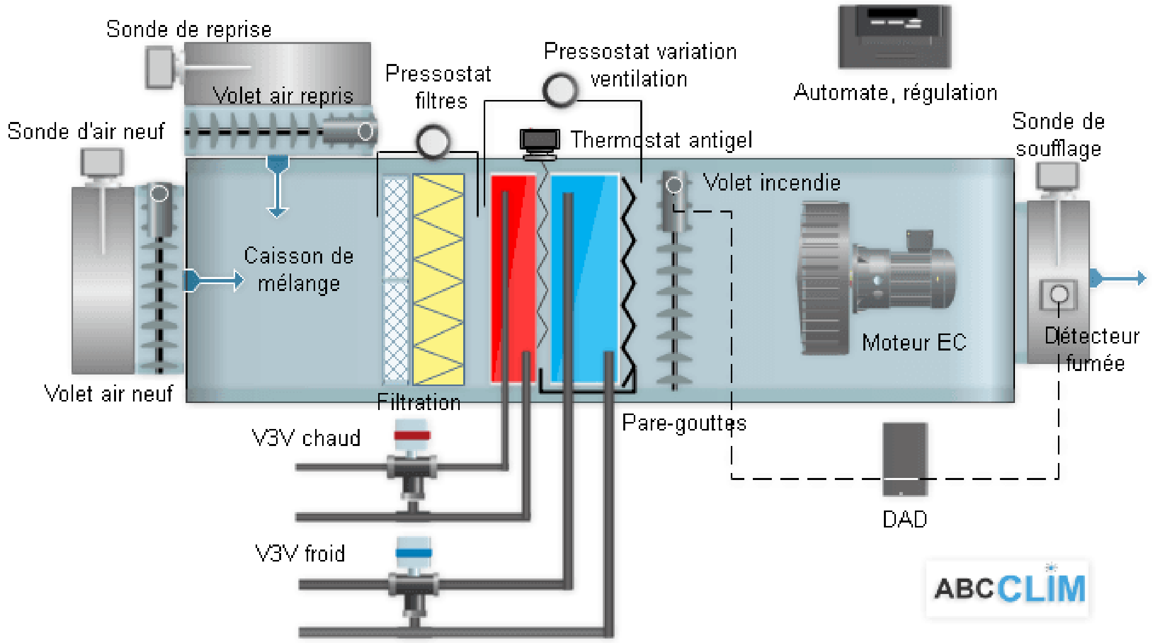

Figure 2-1 Single flow air handling unit [12]

Role of the various elements:

Fresh air damper: This motorized damper regulates the flow of fresh air according to the regulation; it also has an anti-freeze function.

Return air damper: It regulates the admission of the return air in the room to be treated, works in parallel with the fresh air damper.

- Mixing box: Allows the mixing of the fresh air and the return air. The return air and fresh air dampers are synchronized by a set of linkage or by independent motors.
- Filter pressure switch: Detection of clogged filters, alarm only.
- Ventilation variation pressure switch: Transducer type sensor that allows to modify the motor rotation speed according to the filter clogging.
- Filtration: Filtration protects the AHU from dust and various harmful particles. There can be several levels of filtration from medium to high efficiency.
- Hot coil: Copper coil where the hot water circulates with aluminum fins to promote exchange with the air, water and air circulate in counter-current.
- Chilled coil: The chilled coil can be direct expansion (refrigerant) or chilled water (identical configuration to the hot water coil).

- Humidifier: Humidification is carried out by water run-off on a galvanized steel wire mat or by steam injection (not shown).

Droplet barrier: Prevents water droplets from being carried away.

Fire shutter: Limits the propagation of smoke by compartmentalization.

DAD: Autonomous detector trigger, fire protection, controls the fire shutter.

Smoke detector: Smoke detection which allows the DAD to act on the fire shutter.

Fan unit: The fan can be action or reaction, belt driven, direct or electronically commutated (EC).

[12]

2.2.2.2 Double flow air handling units

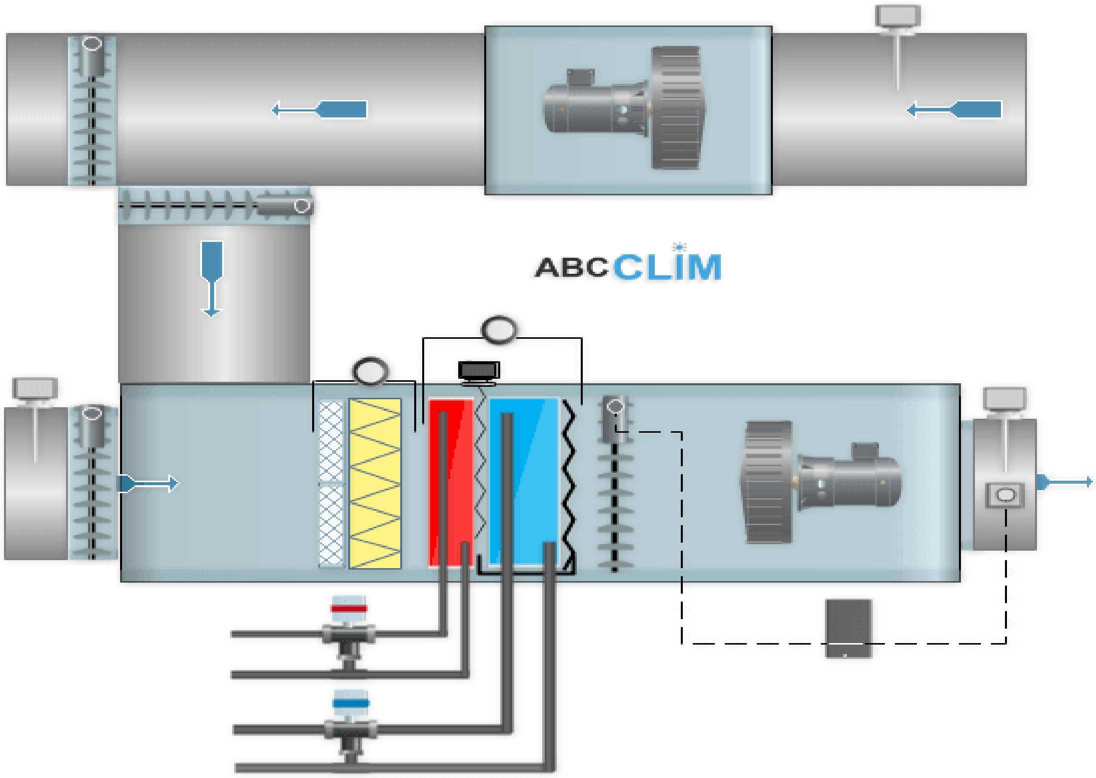

Figure 2-2 Double flow air handling units [12]

A double flow air handling unit can operate:

Partial recycling: part of the air taken back in the room is rejected, and it is replaced by fresh air.

Total recirculation: without any fresh air supply, the air treatment is done only on the return air.

All fresh air: Here the unit operates with all fresh air [12].

2.2.2.3 All fresh air unit with constant supply:

Here we choose a regulation of the supply temperature by action on mixed valve. A probe placed at the air handling unit's supply measures the temperature and regulates the opening or closing of the three-way valve via an automaton.

This mixed valve delivers cold water in summer and hot water in winter via an air/water heat pump for example. The summer/winter inversion of the three-way valve is controlled either by changeover on the water pipe, or by a simple switch.

As it is an all-new air handling unit, an anti-freeze thermostat protects the battery from freezing in case of low outside temperature by [12]:

- Opening the valve to 100% (warm),
- Closing the fresh air damper,
- Stopping of the fan by limit switch of the fresh air damper;

Usage:

- Supply of fresh air in a building or in recovery on other AHUs
- Air compensation of a hood in the kitchens of a restaurant.
- Overpressure of a room (laboratory, etc...)

2.2.3 Different AHU systems:

2.2.3.1 Dual Duct Air Handling Unit

This system is a dual duct air handling unit designed to deliver both cold and warm air through separate main supply ducts to dual-duct Variable Air Volume (VAV) mixing boxes. These mixing boxes combine the cold and warm air to achieve the desired temperature for the specific space.

The air handling unit supplies air simultaneously over the cooling and heating coils. The dual-duct mixing boxes play a crucial role in determining the appropriate amount of each air stream to open based on the temperature requirements indicated by the room temperature sensor. In other words, the mixing boxes adjust the proportions of cooling and heating based on the specific needs of each room.

To clarify further, one dual-duct mixing box may be responsible for providing cooling, while another box is simultaneously delivering heating, depending on the temperature demands of each individual space. This arrangement allows for precise temperature control and ensures that each room receives the appropriate mixture of cold and warm air. [13]

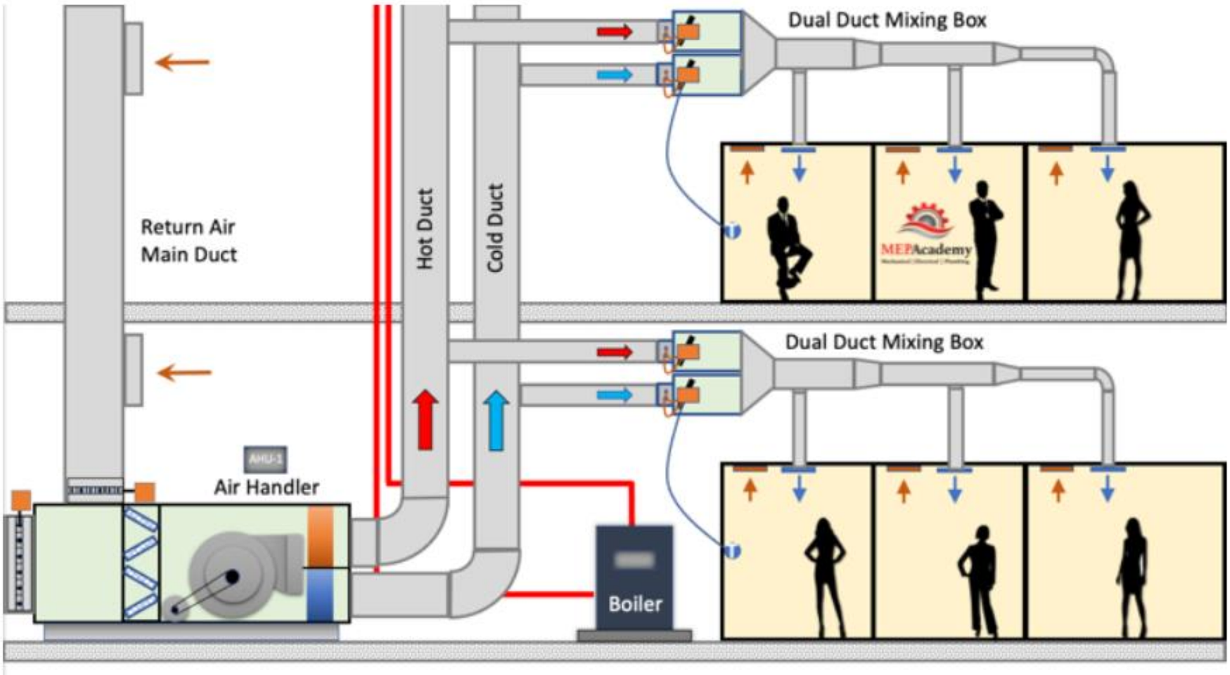

Figure 2-3 Dual-Duct Air Handling Unit with Mixing Boxes [13]

2.2.3.2 Multi-Zone Air Handling Unit

This air handling unit consists of multiple zones, and each zone is equipped with separate hot and cold deck dampers at the air handler unit. It is distinct from the dual duct air handler we previously demonstrated. Additionally, each zone has its own supply air damper located at both the heating coil and cooling coil. [13]

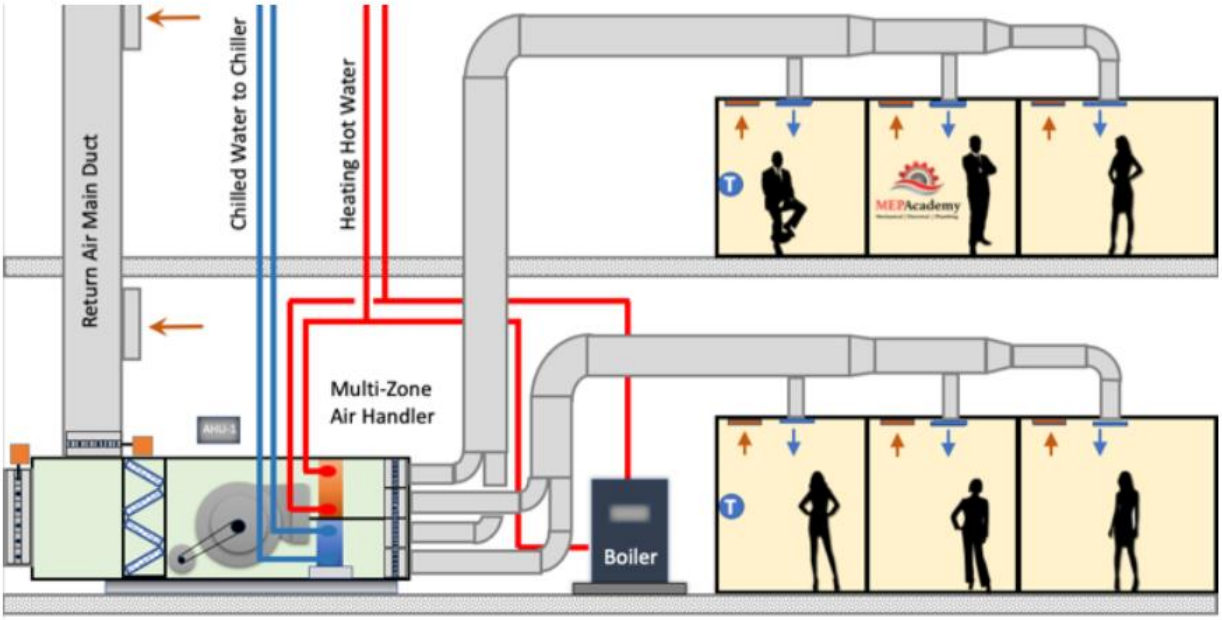

Figure 2-4 Multi-Zone Dual-Duct Air Handling unit [13]

This air handler has a mixing box that allows for return air and outside to mix. The outside air damper will modulate to maintain the minimum amount of ventilation air as required by code. It's possible to control the outside air using a CO sensor in the space being served by this air handler, to allow for energy conservation.

This is another version of the multi-zone air handler, except instead of a dual duct system with two coils in the air handler, this unit uses only a cooling coil. The heating if required is provided by an in-duct reheat coil.[13]

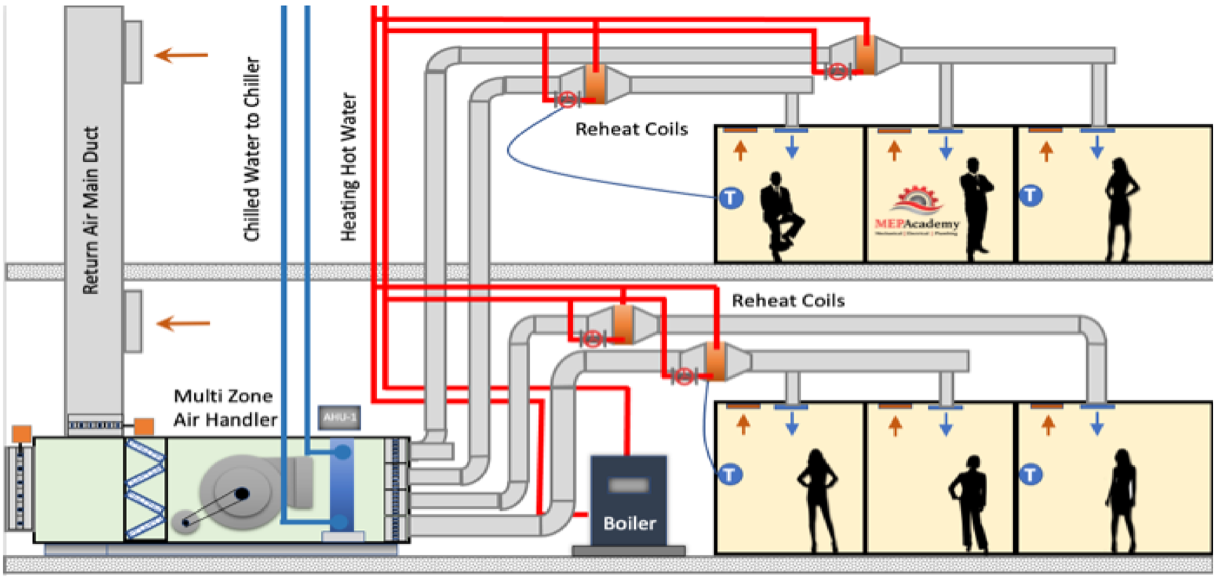

Figure 2-5 Multi-Zone Air Handling Unit [13]

2.2.3.3 VAV Air Handling Unit

Presented here is a rooftop-mounted Variable Air Volume (VAV) Air Handler, which is widely utilized in medium to large commercial buildings. This customized air handler is designed with several components. The air initially passes through the return air section and subsequently reaches the return air fans. From there, it enters the economizer, which provides the option to either exhaust the air from the building or reintroduce it into the system. The outside air dampers, working in conjunction with the economizer, enable the intake of ventilation air as mandated by building codes. When the outside air damper opens to allow increased ventilation air, the exhaust damper opens by approximately the same degree to facilitate air outflow. Economizers contribute to energy conservation by utilizing outside air to cool the building when its temperature is lower than the return temperature or a predetermined value. [13]

Afterwards, the air flows into the filter section, where the air is purified. Different types of filters can be employed based on the air's cleanliness requirements. Subsequently, the air passes through a humidifier, which adds moisture to the air stream before entering the coil section. Finally, the air is propelled by the supply fan through the ductwork to the VAV boxes located in each zone. These VAV boxes regulate the opening and closing of their dampers to maintain the desired temperature within their respective spaces. [13]

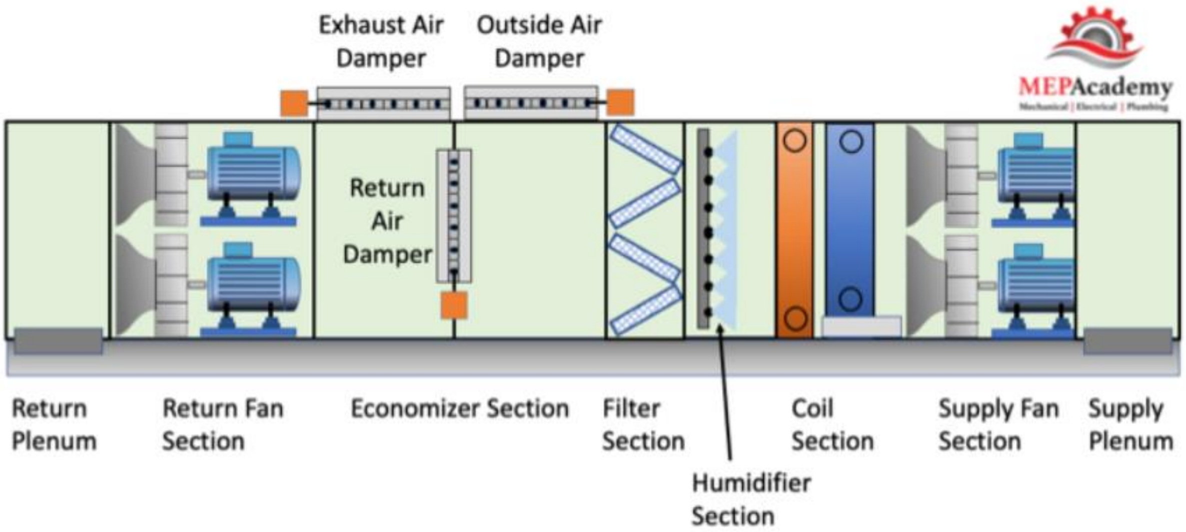

Figure 2-6 Typical Custom Air Handling Unit [13]

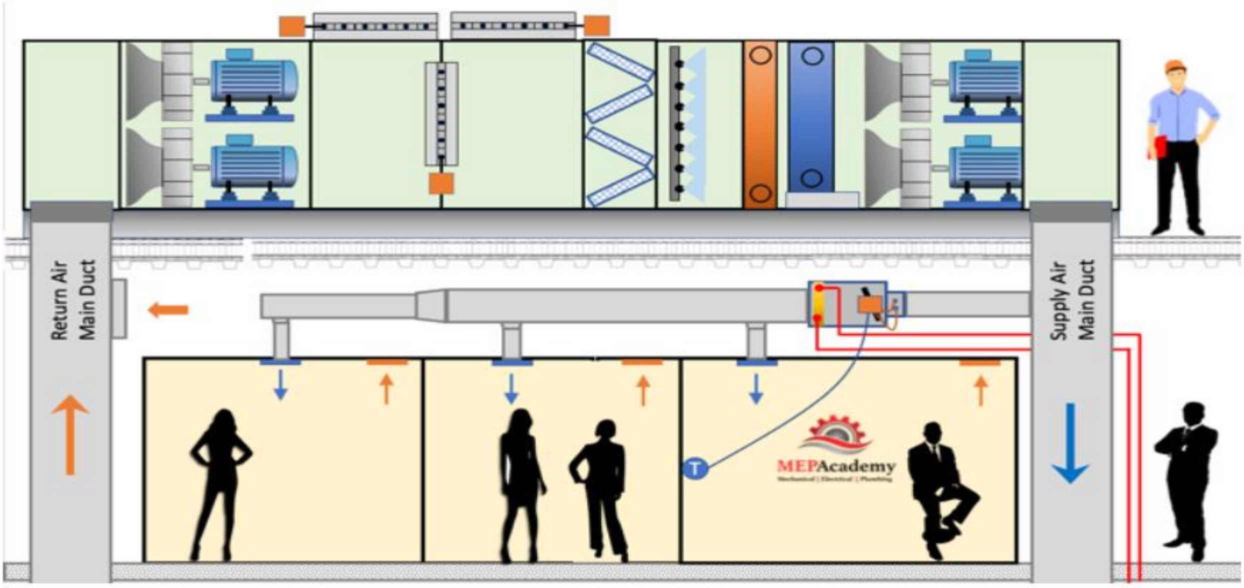

Figure 2-7 VAV Air Handling Unit [13]

2.3 Energy Conservation

- Monitoring & Control Automation:

Implement a comprehensive monitoring and control system for the hospital's energy management. This system will utilize advanced automation technologies to continuously monitor and analyze energy consumption patterns, enabling real-time adjustments and optimizations. Continuous monitoring of the system can lead to saving up to 10 to 15% in their annual energy bills [14].

- Improve control and utilization of outside air:

Enhance the hospital's HVAC system by incorporating advanced controls to efficiently utilize outside air for ventilation. By leveraging sensors and intelligent algorithms, the system will automatically adjust the intake of outside air based on factors such as outdoor temperature, humidity levels, and air quality, ensuring optimal indoor air quality while minimizing energy consumption [15].

- Reduce HVAC system operating hours (night, weekend):

Utilize automation capabilities to optimize the operating hours of the HVAC system, specifically during nights and weekends when the building occupancy and thermal load are typically lower. By adjusting the system settings and implementing scheduling algorithms, the

HVAC system will be automatically adjusted to reduce unnecessary operation, resulting in energy savings without compromising occupant comfort [15].

- Optimize ventilation:

Employ intelligent ventilation control algorithms to optimize the airflow within the hospital building. By considering factors such as occupancy levels, pollutant concentrations, and outdoor air conditions, the ventilation system will dynamically adjust the ventilation rates in different areas of the hospital to ensure a healthy and comfortable indoor environment while minimizing energy waste [14].

- Seal all leaks around coils:

Conduct a thorough inspection of the HVAC system's coils and sealing components. Identify and rectify any air leakage around the coils, ducts, and connections to prevent unnecessary energy losses and ensure efficient heat transfer within the system. Implement sealing measures such as gaskets, caulking, and insulation materials to create a tightly sealed HVAC system [14].

- Replacing lighting with LED or other energy-saving light bulbs:

Undertake a comprehensive lighting upgrade by replacing traditional light bulbs with energy-efficient alternatives such as LED (Light-Emitting Diode) lights. LEDs consume significantly less energy, have longer lifespans, and offer enhanced control capabilities. By implementing intelligent lighting controls, such as occupancy sensors and daylight harvesting systems, A smart lighting system can reduce hours of lighting operation and intensity with 24 to 38% energy savings [15].

- Building automation systems

Hospitals often have older, pneumatic control systems that can be recalibrated or replaced with electronic systems. These newer systems can save much more energy than older systems [16].

BASs, which typically include building energy management systems (EMSs), can control the HVAC, lighting, security, and other systems from one central location. This can increase efficiency and allow for easier monitoring of these various systems. When you use a BAS to monitor things like occupancy, temperature, lighting, and pressure, you can run the different systems as efficiently as possible and only when they’re needed [16].

- A BAS saves energy costs by:
  - Running systems only when they’re needed
  - Ensuring that systems are running at sufficient capacity
  - Decreasing peak demand by reducing power to certain systems, like lighting, when the power draw of a building reaches a set level (with minimal impact on occupant comfort)

2.4 Conclusion

In conclusion, air treatment units are crucial in maintaining clean and healthy indoor air quality, particularly in hospital settings. This chapter has highlighted the specific requirements and considerations for air treatment in hospitals. By implementing appropriate air treatment units, hospitals can effectively control airborne contaminants, ensure patient safety, and create a conducive environment for healthcare workers. Optimizing energy efficiency in these units also leads to significant cost savings and reduced environmental impact.

Chapter 3

Photovoltaic system

3.1 Introduction

This chapter introduces the photovoltaic systems and their significance in harnessing solar energy. Photovoltaic technology, based on the photovoltaic effect, has revolutionized the renewable energy sector by providing a clean and sustainable source of electricity. In this chapter, we will explore the photovoltaic effect and the fundamental components of a solar cell. Furthermore, we will discuss different types of solar cells, their electrical characteristics, and the influence of external factors such as light intensity and temperature on their performance. Additionally, we will examine the various components of a photovoltaic system, including smart meters, mounting structures, combiner boxes, wiring and cables, and protection equipment, providing readers with a comprehensive understanding of this rapidly evolving field.

3.2 Photovoltaic

3.2.1 Photovoltaic effect in solar energy

The photovoltaic effect was discovered for the first time by E. Becquerel in 1839, using an electrochemical cell. The process of conversion of light to electricity is called the photovoltaic effect. It simply means the production of DC current from sunlight as depicted in. A basic structure of a solar cell comprises two layers of semiconductors (P and N); the junction between P and N acts as a diode allowing electrons to move from N to P. So, when photons with sufficient energy hit the cell, they create a movement (from N to P only) causing excess electrons in the N layer and a shortage in the P layer. [17]

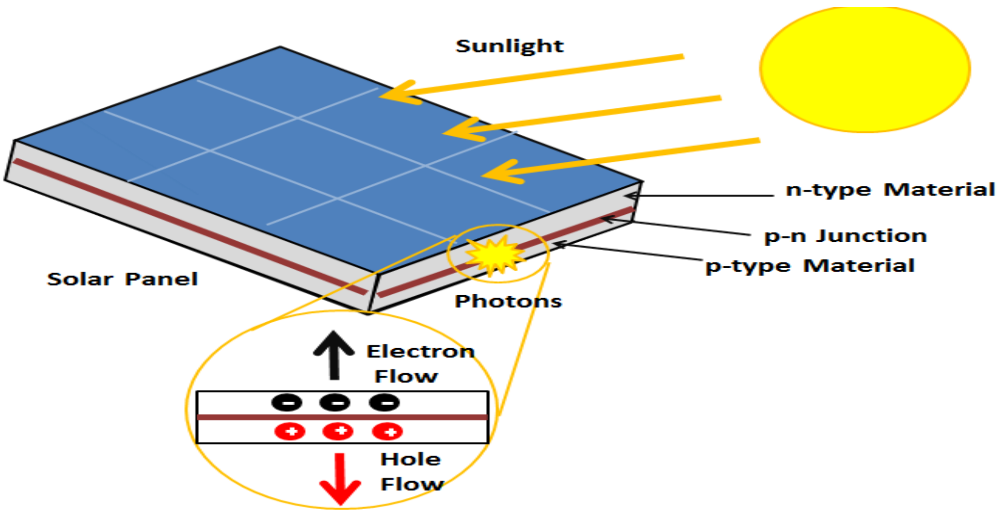

Figure 3-1 A diagram showing the photovoltaic effect. [18]

3.2.2 Solar cell

A photovoltaic (PV) cell is an energy harvesting technology that converts solar energy into useful electricity through a process called the photovoltaic effect. There are several different types of PV cells, which all use semiconductors to interact with incoming photons from the Sun in order to generate an electric current. A photovoltaic cell is comprised of many layers of materials, each with a specific purpose. The most important layer of a photovoltaic cell is the specially treated semiconductor layer, which is comprised of two distinct layers (p-type and n-type) and is what actually converts the Sun's energy into electricity. By joining these two types of semiconductors together, a p-n junction is created, which is the basis for the photovoltaic effect [17].

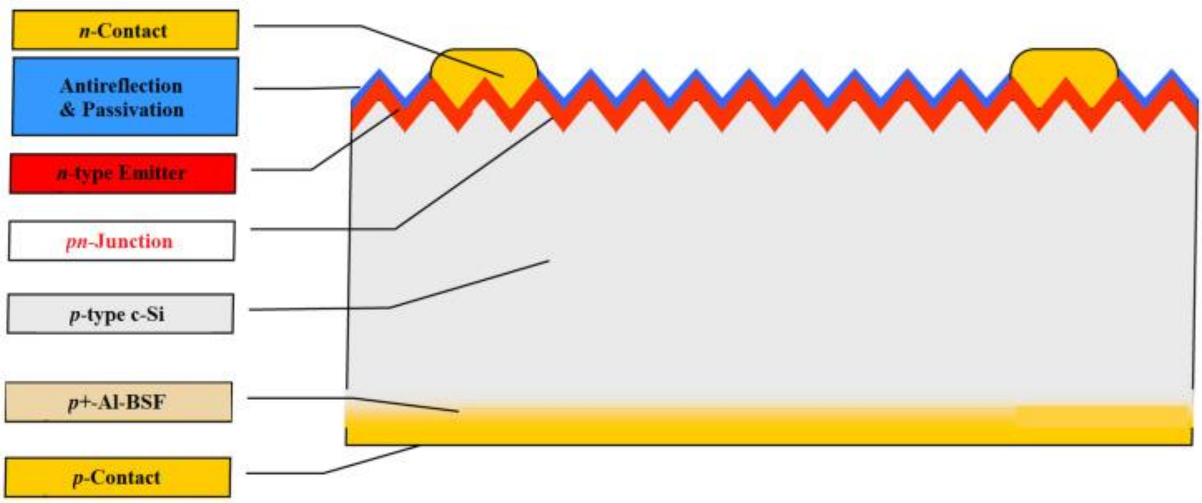

Figure 3-2 Silicon solar cell structure [19]

3.2.3 Types of solar cells

3.2.3.1 Monocrystalline Cells:

Monocrystalline solar cells, known for their distinctive coloring, are made from highly pure silicon, resulting in the highest efficiency among all solar cell types, exceeding 20%. These cells are made from cylindrical silicon ingots, with four sides cut to create rounded-edge silicon wafers for monocrystalline panels. They not only exhibit superior electrical power output but also offer space efficiency, requiring fewer cells per unit of output. Monocrystalline cells have the longest lifespan and often come with warranties of up to 25 years. However, their higher cost is attributed to the significant silicon wastage during the four-sided cutting process, making polycrystalline and thin film cells more popular choices for cost-conscious consumers. [20]

3.2.3.2 Polycrystalline Cells:

Polycrystalline solar cells, introduced in 1981, were the first solar cells in the industry. Unlike monocrystalline cells, polycrystalline cells are not cut but are made by pouring melted silicon into a square mold, making them more affordable with minimal silicon wastage. However, they are less efficient, typically operating at 13-16% efficiency, due to lower purity. Polycrystalline cells also have lower space efficiency and lower heat tolerance compared to monocrystalline cells, affecting their performance in high temperatures. [20]

3.2.3.3 Amorphous Cells:

Thin film solar cells made out of amorphous silicon are traditionally used for smaller-scale applications, including things like pocket calculators, travel lights, and camping gear used in remote locations. A new process called "stacking" that involves creating multiple layers of amorphous silicon cells has resulted in higher rates of efficiency (up to 8%) for these technologies; however, it's still fairly expensive. [20]

3.2.3.4 Thin-Film Solar Cells:

Thin film solar cells have experienced significant growth, representing around 5% of the solar cell market by 2011. While current efficiencies range from 7-13%, ongoing research aims to achieve efficiencies as high as 16% in future models. Thin film technology offers cost advantages, ease of mass production, flexibility, and better heat and shading tolerance. However, it requires more space, making it less ideal for residential applications, and has a shorter lifespan compared to crystalline cells. Various photovoltaic substances are used in thin film technology for different applications. [20]

Figure 3-3 Types of solar cells [21]

3.2.4 Electrical characteristics of a solar cell

Under a given illumination, every photovoltaic cell is characterized by a current-voltage (I-V) curve representing the various electrical configurations the cell can assume. Three physical quantities define this curve:

Open-circuit voltage:V_{co}. This value represents the voltage generated by an illuminated cell that is not connected to any external circuit.

Short-circuit current:I_{cc}. This value represents the current generated by an illuminated cell when its positive and negative terminals are directly connected.

Maximum power point: MPP (also known as maximal power point), which is obtained at optimal voltage and current values:V_{opt}, I_{opt}(sometimes referred to asV_{mpp},I_{mpp}). [22]

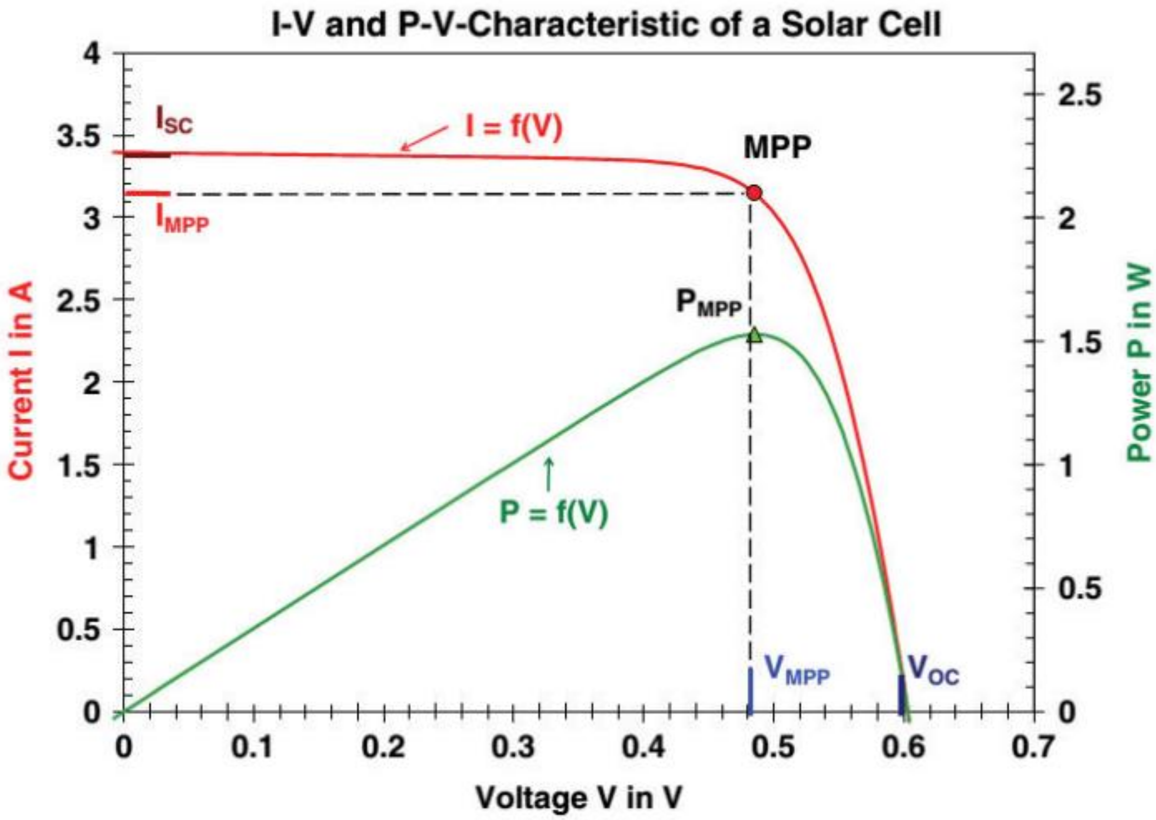

Figure 3-4 Characteristic curves I-V (red) and P-V (green) [23]

3.2.5 Standard **test condition:**

In order to compare the power output of various solar panels accurately, standardized test conditions are utilized. These conditions include a radiation intensity of 1,000 W/m², a temperature of 25 degrees Celsius, and an air mass value of 1.5 (AM 1.5). By establishing these homogeneous test conditions, it becomes possible to make fair and meaningful comparisons between different solar panel models. [23]

3.2.6 The Influence of Light Intensity on the Performance of Solar Cell

The experimental results show that the open circuit voltage, short-circuit current, and maximum output power of solar cells increase with the increase of light intensity. Therefore, it can be known that the greater the light intensity, the better the power generation performance of the solar cell. [24]

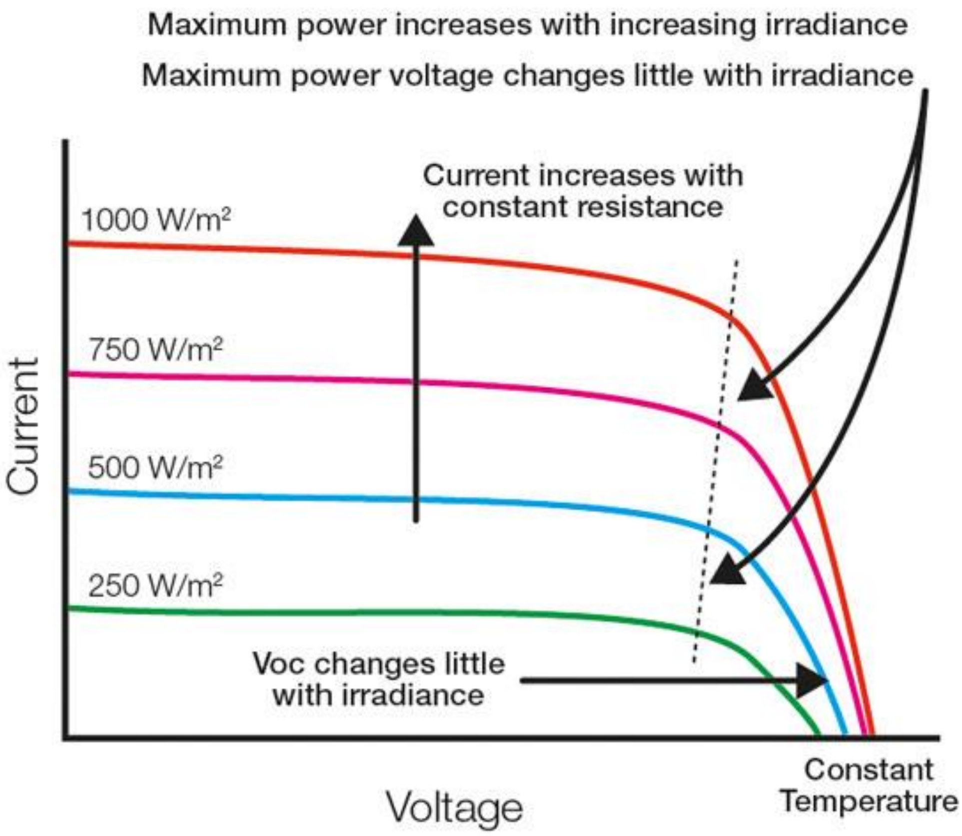

Figure III-3-5 characteristics of a solar panel at different light intensities [25]

3.2.7 The Influence of temperature on the Performance of Solar Cell

It may seem counter-intuitive, but solar panel efficiency is affected negatively by temperature increases. Photovoltaic modules are tested at a temperature of 25 degrees C° (STC), and depending on their installed location, heat can reduce output efficiency by 10-25%. As the temperature of the solar panel increases, its output current increases exponentially, while the voltage output is reduced linearly. In fact, the voltage reduction is so predictable, that it can be used to accurately measure temperature. [26]

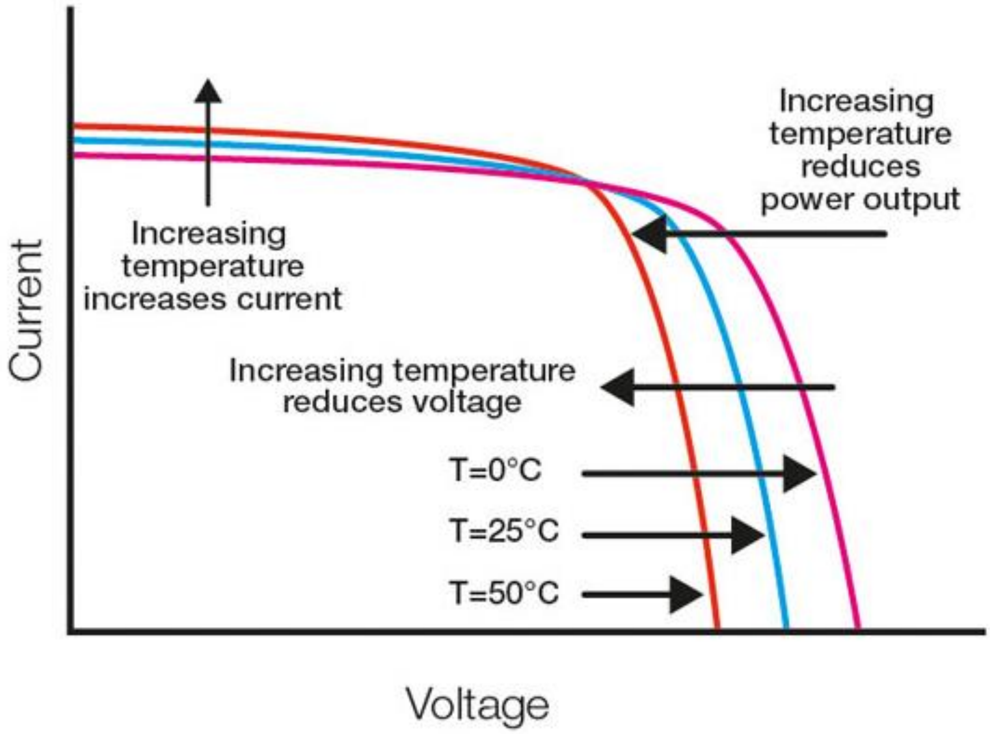

Figure 3-6 characteristics of a solar panel at different characteristics of a solar panel at different temperature [25]

3.2.8 Connection of solar panels

Solar photovoltaic panels can be electrically connected together in series to increase the voltage output, or they can be connected together in parallel to increase the output amperage. Solar PV panels can also be wired together in both series and parallel combinations to increase both the output voltage and current to produce a higher wattage array. [27]

3.2.8.1 Connecting Solar Panels Together in Series

To series wire the panels together you connect the positive terminal to the negative terminal of each panel until you are left with a single positive and negative connection. [27]

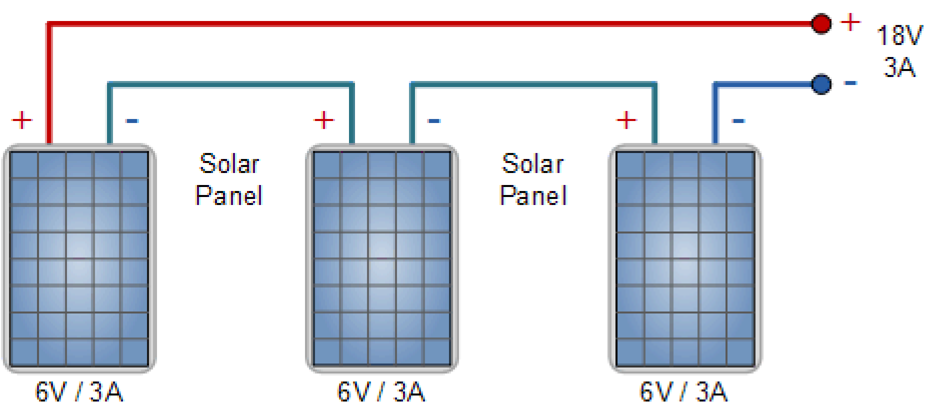

Figure 3-7 Solar Panels in Series of Same Characteristics [27]

3.2.8.2 Connecting Solar Panels Together in Parallel

For parallel connected solar panels, you connect all the positive terminals together (positive to positive) and all of the negative terminals together (negative to negative) until you are left with a single positive and negative connection to attach to your regulator and batteries. [27]

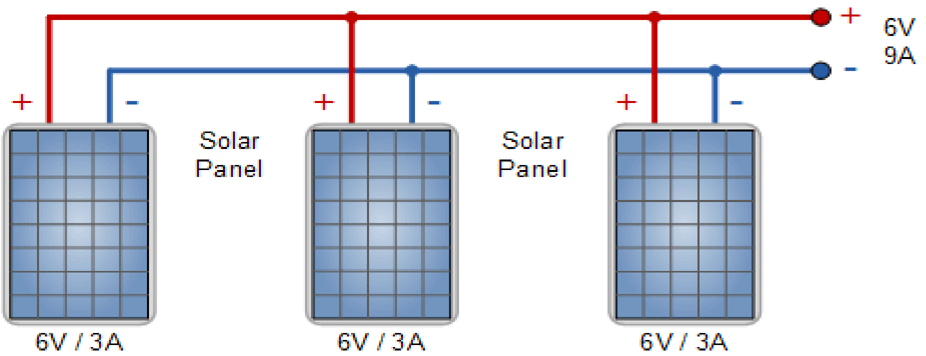

Figure 3-8 Solar Panels in Parallel of Same Characteristics [27]

Table 3-1 Connection of solar panels

Connection type	In series	In parallel
Voltage (V)	Sum of voltages	No change
Current (A)	No change	Sum of currents
Power (W)	Sum of power	Sum of power

3.2.9 Types of PV systems

3.2.9.1 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. The schematic diagram of such a system is shown in Figure 3-9. 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. [28]

Figure 3-9 Schematic diagram of a direct-coupled PV system. [28]

3.2.9.2 Stand-alone applications

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. A schematic diagram of a stand-alone system is shown in Figure 3-10. As can be seen, the system can satisfy both DC and AC loads simultaneously [28].

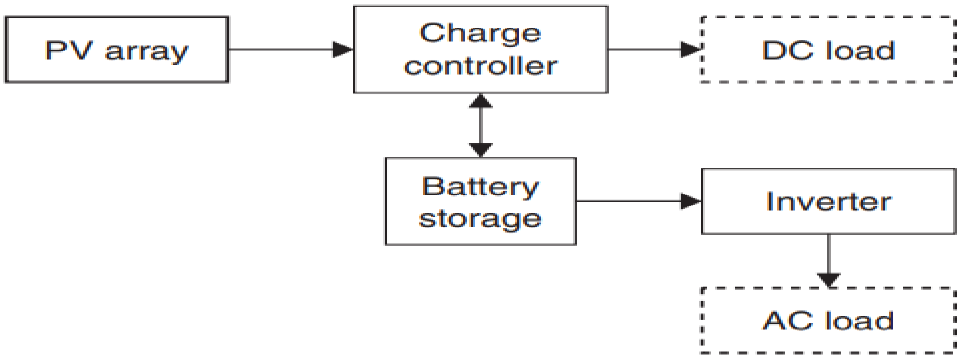

Figure 3-10 Schematic diagram of a stand-alone PV application. [28]

3.2.9.3 Grid-connected system

Nowadays, it is 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). 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. A schematic diagram of a grid-connected system is shown in Figure 3-11. [28]

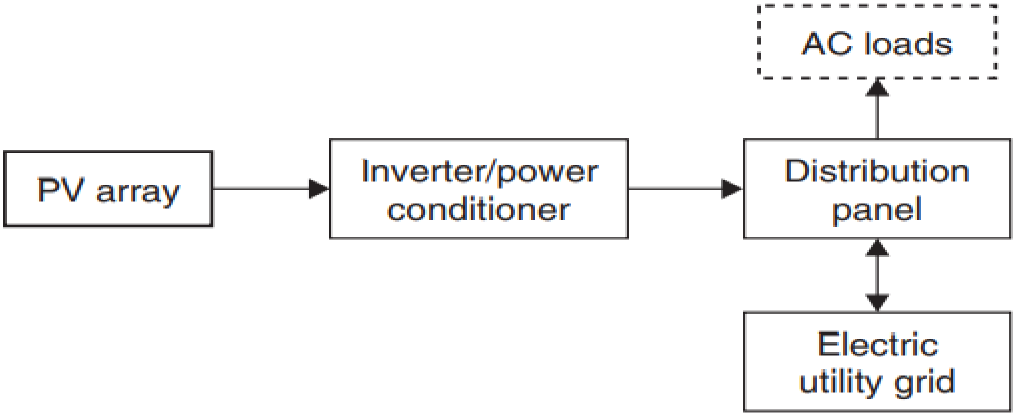

Figure 3-11 Schematic diagram of a grid-connected system. [28]

3.2.9.4 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. The diesel engine generator can also be a renewable source of electricity when the diesel engine is fed with biofuels. A schematic diagram of a hybrid-connected system is shown in Figure 3-12. Again, in this system, both DC and AC loads can be satisfied simultaneously. [28]

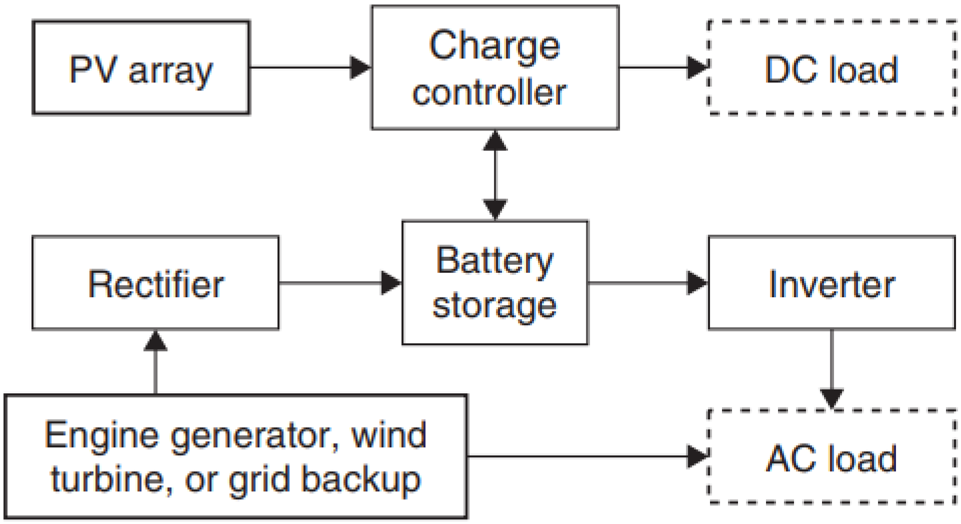

Figure 3-12 Schematic diagram of a hybrid connected system. [28]

3.2.10 Component of a PV system

3.2.10.1 PV panels

A solar panel, also known as a photovoltaic (PV) module, is a device that converts sunlight into electricity through the photovoltaic effect. It is a collection of interconnected solar cells, which are made of semiconductor materials, typically silicon. When sunlight strikes the solar panel, it excites the electrons in the semiconductor material, creating a flow of direct current (DC) electricity. [29]

3.2.10.1.1 Solar Panel Parameters

Short Circuit Current (I_{sc}): Short circuit current is the maximum current produced by the solar cell, it is measured in ampere (A) or milli-ampere (mA). [30]

Open Circuit Voltage (V_{oc}): Open circuit voltage is the maximum voltage that the cell can produce under open-circuit conditions. It is measured in volt (V) or milli-volt (mV). [30]

Maximum Power Point (P_m): Maximum power point represents the maximum power that a solar cell can produce at the STC (i.e., solar radiance of 1000 W/m2 and cell operating temperature of 25°C). It is measured in W_{power} or simply W_p. [30]

$$\mathbf{P_m = I_m . V_m} \tag{3.1}$$

Current at Maximum Power Point (I_m): It represents the current which the solar cell will produce when operating at the maximum PowerPoint. [30]

Voltage at Maximum Power Point (V_m): It represents the voltage that the solar cell will produce when operating at the maximum PowerPoint. [30]

Fill Factor (FF): It represents the area covered by $I_m - V_m$ rectangle with the area covered by $I_{sc} - V_{oc}$ rectangle. The fill factor represents the squareness of the I – V curve. It is represented in terms of the percentage (%), the higher the fill factor in percent the better is the cell. [30]

Efficiency (η): A solar cell efficiency is defined as the maximum output power (P_m) divided by the input power (P_{in}). It is measured in percentage (%), which indicates that this percentage of input sunlight power is converted to electrical power. The input power is power density. Therefore, to calculate efficiency multiply P_{in} at STC by area. The efficiency can be calculated as follows: [30]

$$\eta = \frac{P_m}{P_{in} . Area} \quad (3.2)$$

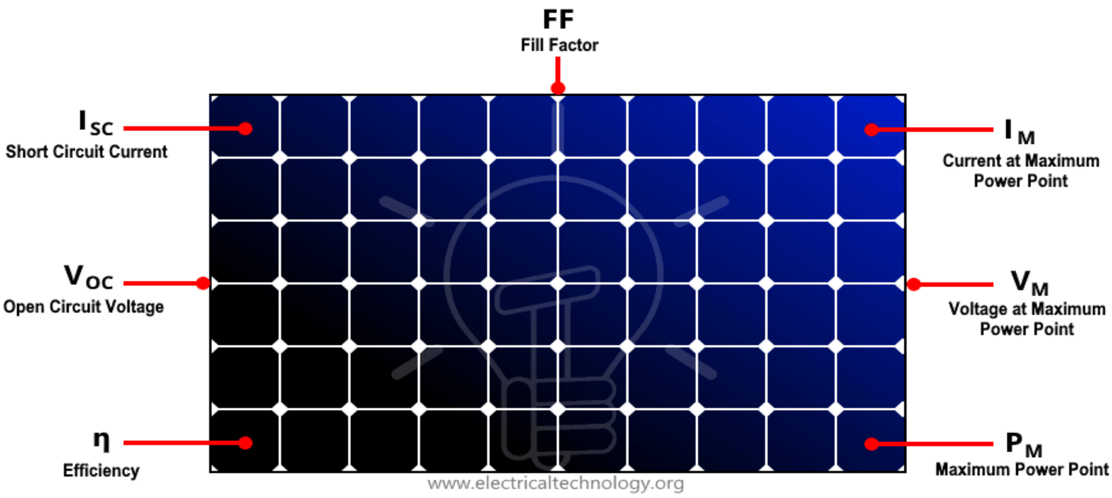

Figure 3-13 Solar Panel Parameters [30]

3.2.10.2 Inverters

An inverter is used to convert the direct current into alternating current electricity. The output of the inverter can be single or three phase. Inverters are rated by the total power capacity, which ranges from hundreds of watts to megawatts. Some inverters have good surge capacity for starting motors, and others have limited surge capacity. The designer should specify both the type and size of the load the inverter is intended to service. The inverter is characterized by a power-dependent efficiency, η_{inv}. Besides changing the DC into AC, the main function of the inverter is to keep a constant voltage on the AC side and convert the input power, P_{in}, into the output power, P_{out}, with the highest possible efficiency, given by: [28]

$$\eta_{inv} = \frac{P_{out}}{P_{in}} = \frac{V_{ac} I_{ac} \cos(\varphi)}{V_{dc} I_{dc}} \tag{3.3}$$

With:

$\cos(\varphi)$: power factor.

V_{dc}: current required by the inverter from the DC side.

I_{dc}: input voltage for the inverter from the DC side.

3.2.10.2.1 Grid inverter

Grid-tied solar systems require grid-tie inverters that can communicate with the grid. These inverters prioritize supplying power to your home from the solar panels and export any excess electricity to the grid. They do not include energy storage to store solar power. When the solar panels aren't producing enough electricity, the system can import the shortfall from the grid [31].

3.2.10.3 Charge controller

Controllers regulate the power from PV modules to prevent the batteries from overcharging. The controller can be a shunt type or series type and also function as a low-battery voltage disconnect to prevent the battery from over-discharge. The controller is chosen for the correct capacity and desired features [28]

3.2.10.3.1 Types of charge Controller

PULSE WIDTH MODULATION (PWM) CHARGE CONTROLLER

Simple PWM, or ‘pulse width modulation’ solar charge controllers, have a direct connection from the solar array to the battery and use a basic ‘rapid switch’ to modulate or control the battery charging. The switch (transistor) opens until the battery reaches the absorption charge voltage. Then the switch starts to open and close rapidly (hundreds of times per second) to modulate the current and maintain a constant battery voltage. This works ok, but the problem is the solar panel voltage is pulled down to match the battery voltage. This, in turn, pulls the panel voltage away from its optimum operating voltage (V_{mp}) and reduces the panel power output and operating efficiency. [31]

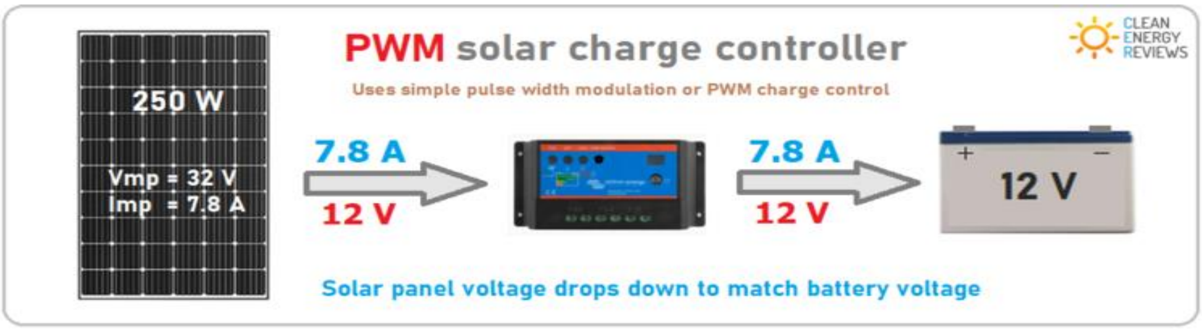

Figure 3-14 PWM Solar Charge Controllers function [31]

MPPT

MPPT stands for Maximum Power Point Tracker; these are far more advanced than PWM charge controllers and enable the solar panel to operate at its maximum power point, or more precisely, the optimum voltage and current for maximum power output. Using this clever technology, MPPT solar charge controllers can be up to 30% more efficient, depending on the battery and operating voltage (V_{mp}) of the solar panel. [32]

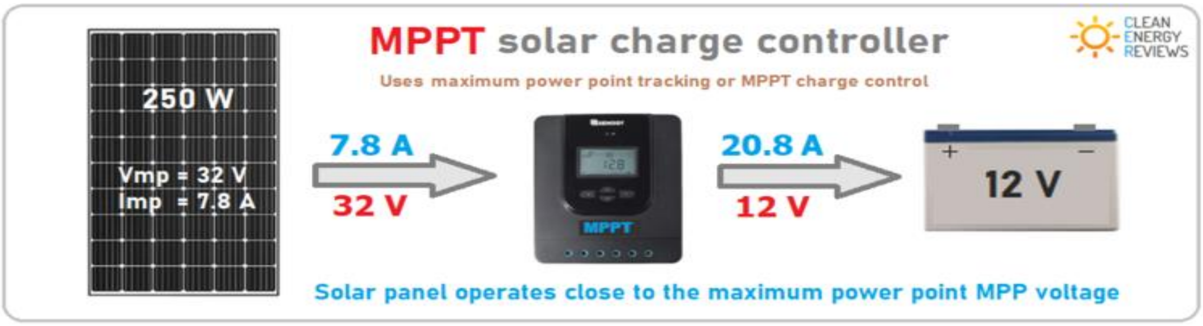

Figure 3-15 MPPT Solar Charge Controllers function [32]

3.2.11 Smart Meter

Smart Meter or Net Meter are a type of meters that run bi-directionally, allowing them to properly account for the net energy you've used, which is all the energy you've consumed minus the energy your solar system produced. All owners of a grid-tied solar system will need a bi-directional utility meter to keep track of the electricity solar systems are transferring to the grid [33]

Figure 3-16 Smart meter function [33]

3.2.12 Mounting Structure

Solar panel mounts and racks are equipment that secures solar panels in place. Mounting allows the panels to be adjusted for optimal tilt, which can be based on latitude, seasons, or even time of day to ensure maximum solar energy production. The most common locations for mounting are on the roof, using solar roof mounts, or on the ground with ground-mount options. [34]

3.2.13 Combiner Box

A PV combiner box is an electrical distribution box where DC breakers are housed. Its main purpose is to combine multiple DC inputs from the panels in the system into a single DC output. This output is then connected to a charge controller or inverter, depending on the type of system. They also allow you to transition to larger wires between the array and the batteries or inverter to minimize transmission voltage drop. [35]

3.2.14 Wiring and Cables

DC cables connect modules together to form strings, and connect several strings in parallel. Only "solar" cables can be used. Solar cables used outdoors on roofs must be UV-resistant and protected against the action of ozone. They must also be certified to operate at temperatures from -20°C to 80°C. The temperature requirement must also apply to all materials used in the equipment used in the installation. [36]

3.2.14.1 Cable section

it is important to select conductor sizes that can handle the current without causing a significant voltage drop. The 2% limit ensures that the voltage remains within an acceptable range for efficient operation of the system. [36]

The cable section, S, can be calculated using the following formula:

$$\boldsymbol{S = \frac{\rho . L . I}{\varepsilon . V_A}} \tag{3.4}$$

With:

ρ : is the resistivity of the cable in Ω.m. It depends on the material. (For a copper cable, it is 1.7 × 10^{-8} Ω.m.)

L: is the length of the cable in meters.

I :is the current flowing through the cable in amperes.

ε: is the voltage drop in volts.

V_A is the voltage at the starting point of the cable in volts.

3.2.14.2 MC4 connectors

MC4 is the name of the connection type on all new solar panels, providing an IP67 waterproof and dustproof safe electrical connection, they are used to connect solar panels together and to connect panels to the rest of the system. They are designed to be easy to install and remove, and to provide a secure and reliable connection that is resistant to water and dust [37]

Figure 3-17 MC4 female and male connector [37]

3.2.15 Protection equipment

Circuit breakers: Circuit breakers are essential switching devices that ensure user safety by tripping and interrupting power supply to a load when errors occur. They are widely employed to switch different types of loads. Specifically, for transformer isolating inverters, a double pole DC breaker or isolator is necessary. This breaker should have ratings capable of breaking 1.25 times the Short Circuit Current (Isc) rating of the solar PV array, as well as 1.2 times the Open Circuit Voltage (Voc) of the array. [38]

Fuses: Fuses are rated based on voltage and current handling capacities, specified under specific environmental conditions. They need to be derated at higher temperatures. IEC 60269-6 and UL 248-19 provide standards for protecting PV modules from overcurrent conditions, recommending a 20% margin in voltage and a 25% margin in overload current. The PV source output fuse should be 1.56 times the short circuit current rating of the module, with the conductor rating higher. The conductor should be rated to 9 times (n-1) A for n parallel strings. The array protection fuse should have a current rating of n times the short circuit current of one string. [39]

surge protector: surge protector is an electrical device designed to protect electrical equipment from voltage spikes or surges in power supply. In the context of solar systems, surge protectors play a crucial role in safeguarding the system components, such as inverters and PV modules, from potential damage caused by power surges, lightning strikes, or grid disturbances. By diverting excess voltage safely to the ground, surge protectors help prevent electrical equipment from being overwhelmed and maintain the integrity and reliability of the solar system. [40]

Grounding: Grounding is a technique used to establish an electrical connection between the aluminum frame of the solar modules, and the outer frame of the inverter of a system and the Earth. This connection serves multiple purposes, including providing a safe path for electrical faults to be redirected to the ground, reducing the risk of electrical shock to individuals, and improving the overall stability and performance of the system by minimizing electromagnetic interference and voltage fluctuations. By creating an effective link to the Earth, grounding helps maintain a reliable and secure electrical environment. [41]

3.3 Conclusion

In conclusion, photovoltaic systems have revolutionized the renewable energy sector by harnessing solar energy. This chapter has explored the photovoltaic effect, types of solar cells, and their electrical characteristics. We have also discussed the influence of external factors on solar cell performance. Additionally, we have examined the components of a photovoltaic system, emphasizing their crucial role in efficient and safe operation

Chapter 4
Sizing and simulation of a hybrid PV system

4.1 Introduction

The process of system sizing is a crucial aspect of designing efficient and reliable solar energy systems. In this chapter, we dive into the various methodologies used for system sizing, ranging from manual calculations to software simulations. By carefully considering factors such as inverter selection, solar panel design, array configuration, cable cross-section, and protection mechanisms, we can optimize the performance of the solar energy system. Additionally, we explore the techno-economic aspect of system sizing, including payback calculations to assess the financial viability of the project. Furthermore, we examine two widely used software tools, PVsyst and HOMER Pro, which provide comprehensive simulation capabilities for evaluating system performance and energy production. Through this chapter, we aim to equip readers with the knowledge and tools necessary to effectively size solar energy systems and make informed decisions.

4.2 Charge identifications

Table 4-1 Electrical power of air treatment units

	Absorbed power (kW)	nominal intensity (A)	Apparent power (kVA)
Air treatment unit floor 04	102,01	206,7	136,05
Air treatment unit floor 01 and 02	57,58	112,7	74,18
Total	**159,59**	319,4	210,23

According to the data we were provided with, the total power consumption of our system is **159,59 kW**

4.3 System sizing

4.3.1 Choosing the inverter

$$\boldsymbol{P_{inv} = \frac{P.F_s}{\eta}} \quad \textbf{(4.1)}$$

With:

P_{inv}: inverter power (W)

P: system power (W)

F_S: security factor ($\approx$ 1,25)

η: inverter efficiency ($\approx$ 0.9)

Therefor:

$$P_{inv} = \frac{159.59\ .\ 1{,}25}{0{,}9} = 221{,}66\ \mathbf{kW} \tag{4.2}$$

The inverter we going to use should support at least **221,66 kW** and for safety measures we will use a **250 kW** inverter.

Our choice is COG225KTH model provided by CoHeart Power [42].

Table 4-2 COG225KTH data sheet [42]

Model No.		COG225KTH	
Specification			
Power		250 kW	
Price		€4,930 / Unit	
Warranty		5 Years	
Input Data (DC)		**Output Data (AC)**	
Max. DC Power	300 kW	Max. AC Power	250 kW
Max. DC Voltage	1500 V	Nominal AC Power	225 kW
Rated DC Voltage	850 V	Output AC Voltage Range	680~880 V
Min. DC Voltage to Start Feed In	500 V	Nominal AC Voltage	800 V
Max. DC Current	360 A	Rated AC Voltage	800 V
MPP(T) Voltage Range	500~1500 V	Max. AC Current	179 A
No of MPP Trackers	12	Rated AC Current	179 A
DC Inputs	24	Frequency Range	45-65 Hz
Connectors	MC4	Frequency	50, 60 Hz
		Power Factor (cosθ)	0.8
		Distortion (THD)	< 3 %
		No of feed-in phases	3
		Max. Efficiency	99%
		Euro Efficiency	98.5 %
General Data			
Dimensions (H/W/D)	1000x700x320 mm	Protection Class	IP65
Weight	95 kg	Humidity	0-95 %

Power Consumption at Night	< 1 W	Cooling	Fan
Noise Level	< 49 dB(A)	Max. Altitude	3000 m
Operating Temperature	-20 ~ +65 °C	Interface	RS 485, WLAN
Transformer	Transformerless	Display	LED
Protection Features			
Anti Island Protection (EN²S), Short Circuit Protection, Overload Protection, Overvoltage Protection, Overcurrent Protection, Overtemperature Protection, Residual Current Device (RCD), Reverse Polarity Protection, Surge Protection, DC Load Disconnector, Ground Fault Monitoring, Isolation Monitoring, Grid Monitoring			

4.3.1 Solar panel

For the solar panel we will use Risen Solar 450W Mono Solar Panels [43].

Table 4-3 Risen Solar 450W Mono Solar Panels Data sheet [43]

Model NO.		RSM144-7-450M	
Material	Monocrystalline Silicon	Warranty	25 Years
Specification	2108*1048*35mm	Weight	24.5kg
Rated Power in Watts-Pmax(Wp)	450	Module Efficiency (%)	20.4
Open Circuit Voltage-V_{oc}(V)	49.7	Maximum Power Voltage-V_{mpp} (V)	41.3
Short Circuit Current-I_{sc}(A)	11.5	Maximum Power Current-I_{mpp}(A)	10.9
Max. System Voltage	1500V DC	Junction Box	IP 68 Rated , with 3 Bypass Diodes
Operating Temperature	-40 °C ~+ 85 °C	Temperature Coefficients of $P_$max	-0,37 %/°C
Temperature Coefficients of V_{oc}	-0,29 %/°C	Temperature Coefficients of I_{sc}	-0,05 %/°C
Nominal Operating Cell Temperature (NOCT)	44 °C ± 2 °C	Max. Series Fuse Rating	20A

4.3.1.1 Number of panels

$$N_p = \frac{P}{P_p \times I_{coff}} \tag{4.3}$$

With:

N_p: Number of solar panels

P: Inverter power (W)

P_p: Solar panel nominal power (W)

I_{coff}: irradiation coefficient

4.3.1.2 How to obtain the irradiation coefficient

By using a meteo data base (PVgis) we select the month with the least amount of irradiation. In our case it's December [45].

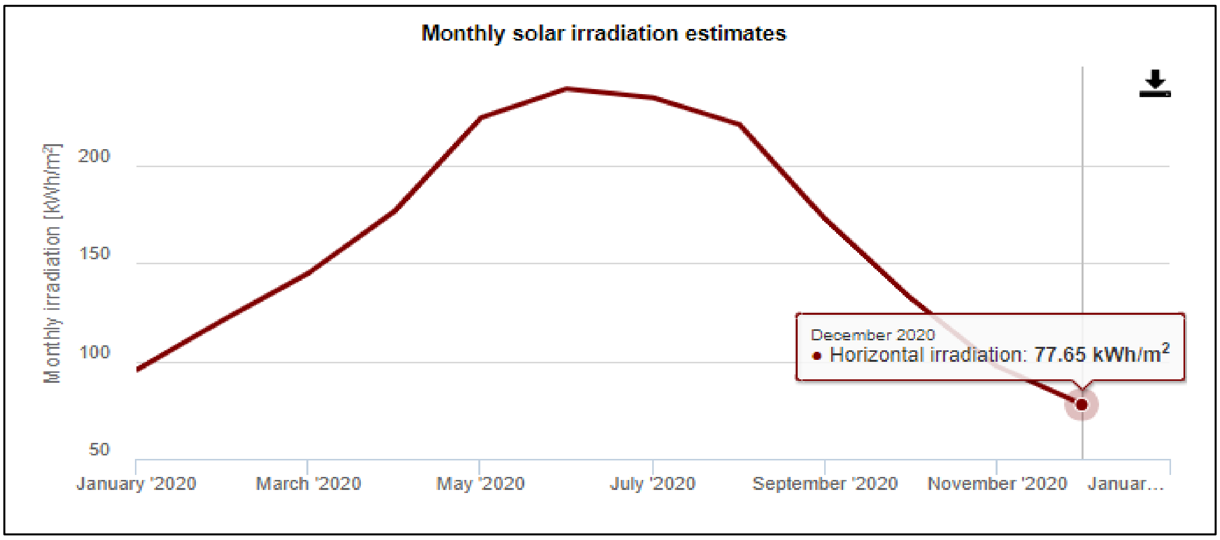

Figure 4-1 Monthly solar irradiation estimates [45]

Then we select the day with the least amount of irradiation and pick the peak of the irradiation.

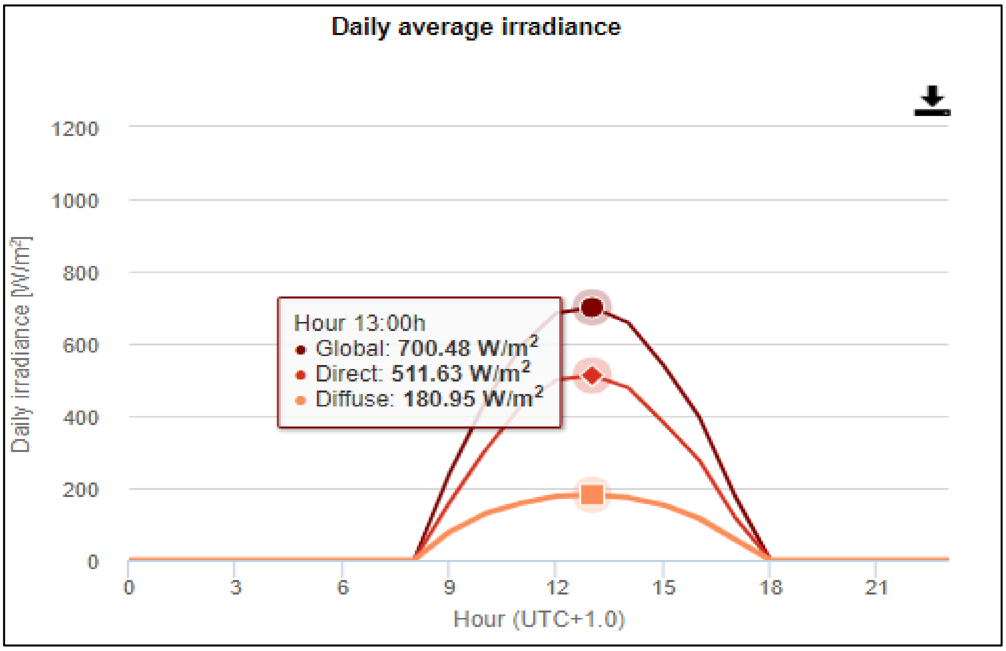

Figure 4-2 Daily average irradiance [45]

$$I_{coff} = \frac{I_g}{I_{STC}} \quad (4.4)$$

I_g: maximum irradiation in the day of least amount of irradiation

I_{STC}: irradiation in standard conditions (=1000 W/m²)

$$I_{coff} = \frac{700{,}48}{1000} \approx 0,7 \quad (4.5)$$

Number of panels

$$N_b = \frac{221{,}66.10^3}{450\,.0{,}7} = 703,68 \approx 710$$

(4.6)

Therefor our system will use **710 panels**.

4.4 Designing arrays

1.1.1.1 Number of modules in series

The are 2 methods to determine the number of panels in series:

Method 1

$$N_{ps} = \frac{V_{dc-max}}{V_{oc}} \quad (4.7)$$

N_ps: Number of modules in series

V_{dc-max}: Maximum system voltage (V)

V_{oc}: Open-Circuit Voltage (V)

$$N_{ps} = \frac{V_{dc-max}}{V_{oc}} = \frac{1500}{49,7} = 30,18 \approx 30 \quad (4.8)$$

Max number of panels in series the PV module can handle is **30 panels** at maximum.

Method 2:

$$N_{ps} = \frac{V_{DC-inv}}{V_{oc}} \quad (4.9)$$

V_{DC-inv}: Max input nominal DC Voltage in inverter

$$N_{ps} = \frac{V_{DC-inv}}{V_{oc}} = \frac{850}{49,7} = 17,10 \approx 17 \quad (4.10)$$

The max number of panels in series the inverter input can handle is **17 panels**.

There for we are going to take **17 panels in series** and that leave us with **30 panels in parallel**.

N.B: The inverter has a Max. DC Current of a 360 A

$$N_{pp} .\ I_{sc} = I_a \quad (4.11)$$

N_pp: Number of parallel panels

I_sc: Short circuit current (A)

I_a: array current (A)

$$30 .\ 11,5 = 345\,A < 360\,A \quad (4.12)$$

Therefor our inverter can handle the current of the array.

1.1 Array output at critical points

Case 1: STC condition

Irradiance 1000W/m² Cell Temperature 25°C, Air Mass AM1.5.

System critical power:

$$P_c = N_p \,.\, P_{mpp} \tag{4.13}$$

P_c: Critical power of the system (W)

$$P_c = 710 \,.\, 450 = 319500\, W \tag{4.14}$$

Case 2: Max irradiance with the lowest temperature

According to **PVgis** data the minimum recorded irradiance in our coordination is I= 1137,59 W/m² [45].

According to **PVgis** data the maximum recorded temperature in our coordination is T= 2,76 °C and for our study we will take T= -5 °C just in case [45].

$$I = 1000 \frac{W}{m^2} \longrightarrow P_{mpp} = 450\, W$$

$$I = 1137{,}59 \frac{W}{m^2} \longrightarrow P_{mpp-1} = 511{,}92\, W \tag{4.15}$$

$$P_{mpp-G} = \frac{1137{,}59 \,.\, 450}{1000} = 511{,}92\, W \tag{4.16}$$

Temperature Coefficients of **Pmax: -0,37 %/°C**

$$\Delta T = 25 - (-5) = 30\ ℃ \tag{4.17}$$

ΔT: difference in temperature between STC and measured temperature

$$1\ ℃ \longrightarrow -0{,}37\%$$

$$30\ ℃ \longrightarrow -11{,}1\ \% \tag{4.18}$$

$$P_{mpp-G} = 511{,}92\, W \longrightarrow 100\ \%$$

$$P_{mpp-T} = -56,82\ W \ \longleftarrow\ -11,1\ \% \tag{4.19}$$

$$P_p = P_{mpp-G} - P_{mpp-T} = 511,92 - (-56,82) = 568,47\ W$$

(4.20)

$$P_c = P_p\,.N_p = 568,47\,.710 = 403613.7\ W \tag{4.21}$$

P_{mpp-G}: Panel maximum power after considering the effect of irradiation (W)

P_{mpp-T}: Panel maximum power after considering the effect of temperature (W)

Case 3: Lowest irradiance with the max temperature

According to **PVgis** data the maximum recorded irradiance in the day with the least amount of irradiance in our coordination is I= 700,48 W/m² [45].

According to PVgis data the maximum recorded temperature in our coordination is T= 37,47 °C and for our study we will take T=45 °C just in case [45].

$$I = 1000\frac{W}{m^2} \longrightarrow P_{mpp} = 450\ W$$

$$I = 700,48\frac{W}{m^2} \longrightarrow P_{mpp-1} = 315,216\ \ W \tag{4.22}$$

$$P_{mpp-1} = \frac{700,48\,.450}{1000} = 315,22\ W \tag{4.23}$$

Temperature Coefficients of Pmax: -0,37 %/°C

$$\Delta T = 25 - (45) = -20\ ℃ \tag{4.24}$$

$$1\ ℃ \ \longrightarrow\ -0,37\%$$

$$-20\ ℃ \ \longrightarrow\ 7,4\ \% \tag{4.25}$$

$$P_{mpp-G} = 315,22\ W \ \longrightarrow\ 100\ \%$$

$$P_{mpp-T} = 23,33\ W \ \longleftarrow\ 7,4\ \% \tag{4.26}$$

$$P_p = P_{mpp-G} - P_{mpp-T} = 511,92 - (23,33) = 291,9\ W \quad (4.26)$$

$$P_c = P_p \,.\, N_p = 291,9 \,.\, 710 = 207249W \quad (4.27)$$

1.2Array surface:

Distance between PV panels

According to easy solar shade calculator the distance between panels should be **3,685 m**

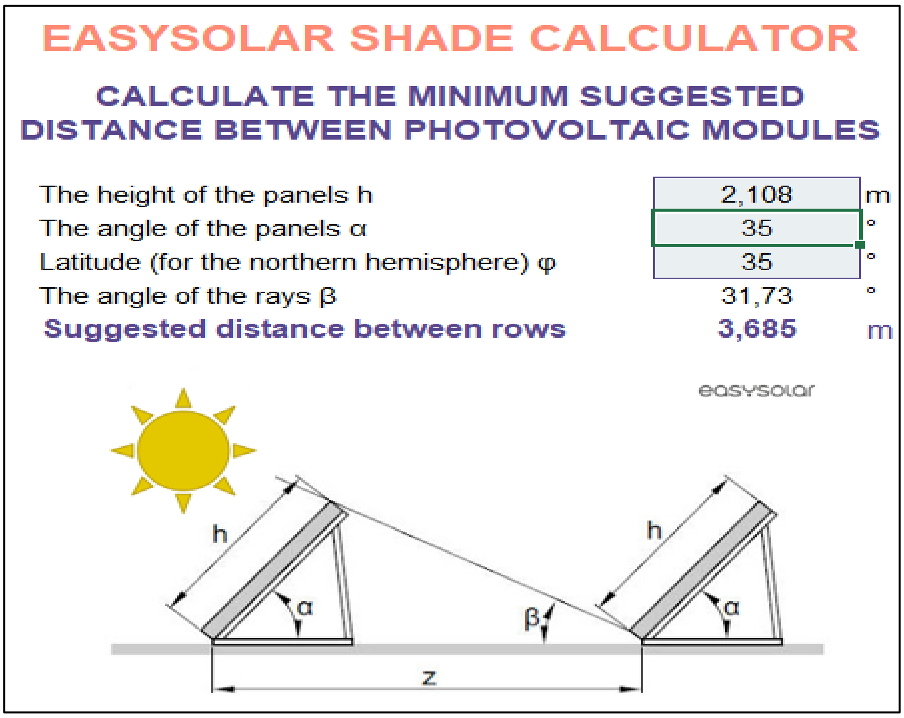

Figure 4-3 Easy solar shade calculator

Now to calculate the projected distance by the tilted PV panel:

$$D = \cos\alpha \,.\, h \quad (4.28)$$

D: projected distance by the tilted PV panel (m)

α: angle of the panel (35°)

h: PV panel height (2,108 m)

$$D = \cos 35 \,.\, 2,108 = 1.726\ m \quad (4.29)$$

Width of the panel: $W = 1{,}048\ m$

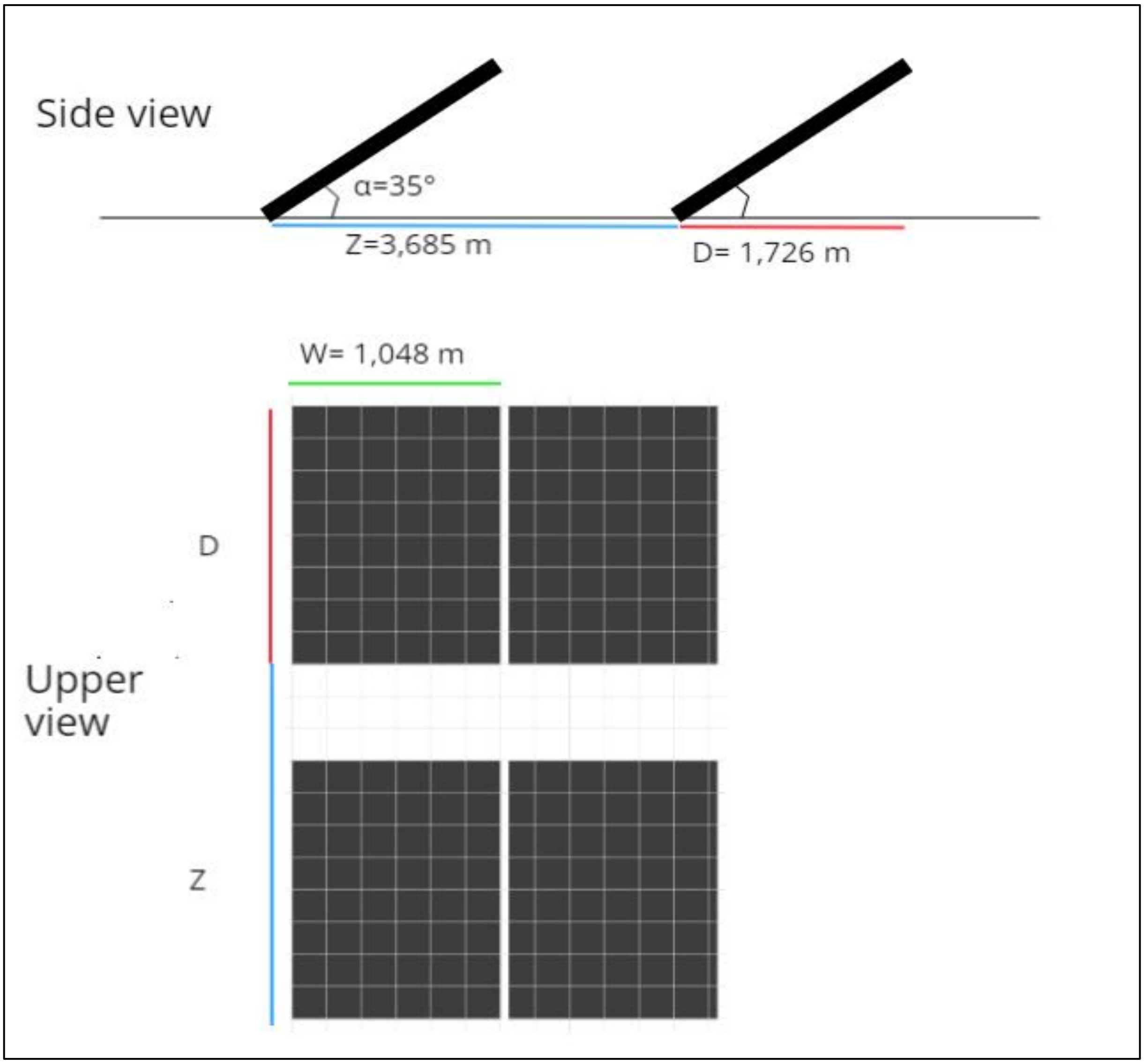

Figure 4-4 Side and upper view of the solar panels

The surface needed by the total number of panels:

$$S_A = N_p \,.\, S_p \tag{4.30}$$

$$S_p = W \,.\, (D + Z) \tag{4.31}$$

S_A: Array surface (m²)

S_p: Surface held by solar panel including structure and distance between panels

$$S_p = 1,048 \,.\, (\,1,726 + 3,685) = 5,67\ m^2 \tag{4.32}$$

$$S_A = 710 \,.\, 5,67 = 4025,7\ m^2 \tag{4.33}$$

Due to the large area occupied by the solar panels we decided to divide our solar array into 2 sub-arrays like shown in the figure (4.5) below:

Figure 4-5 PV array design

Where:

Red rectangles represents where we will place our solar panels, the orange rectangle represents the inverter, and the blue lines represent the cables.

For the sub arrays we will have:17 panels in series with 15 in strings

1.1 Junction box:

$$\boldsymbol{N_{JB} = \frac{N_{pp}}{3}} \qquad \textbf{(4.34)}$$

N_{JB}: Number of junction boxes

3: Number of inputs in junction box

$$\boldsymbol{N_{JB} = \frac{15}{3} = 5} \qquad \textbf{(4.35)}$$

The number of junction boxes per sub array is 5.

1.2Parallel box:

$$N_{PB} = \frac{N_{JB}}{3} \tag{4.36}$$

N_{PB}: Number of parallel boxes

3: Number of inputs in parallel boxes

$$N_{PB} = \frac{5}{3} = 1,66 \approx 2 \tag{4.37}$$

The number of parallel boxes per sub array is 2

1.3cable cross-section:

$$S = \frac{\rho.L.I.2}{V.\varepsilon} \tag{4.38}$$

Maximum voltage drop $\Delta U = 8\% \Rightarrow \varepsilon = 0.08$

Copper resistivity $\rho = 1{,}7.10^{-8}\ \Omega.\mathrm{m}$

$I_{sc} = 11{,}5\ A$

$V_{oc} = 49{,}7\ V$

Between PV field and Junction box:

L=50m

$$V_b = V_{oc}.N_{ps} = 49,7 . 17 = 844,9\ V \tag{4.39}$$

V_b: Branch voltage (V)

$$I_b = N_{pp}.I_{sc} = 1 . 11,5 = 11,5\ A \tag{4.40}$$

I_b: Branch courant (A)

$$S = \frac{1,7 .10^{-8} .50 .2 .11,5}{844,9 .0,08} = 2,89 . 10^{-7}\ m^2 \approx 4\ mm^2 \tag{4.41}$$

Between Junction box and parallel box:

L=10m

$$I_b = 11{,}5\,.\,3 = 34{,}5\,A \quad \textbf{(4.42)}$$

$$V_b = 49{,}7\,.\,17 = 844{,}9\,V \quad \textbf{(4.43)}$$

$$S = \frac{1{,}7.10^{-8}.10\,.2\,.34{,}5}{844{,}9\,.0{,}08} = 1.73\,.\,10^{-7}\,m^2 \approx 4\,mm^2 \quad \textbf{(4.44)}$$

Between 1st parallel box and inverter:

L=10m

$$I_b = 11{,}5\,.\,9 = 103{,}5A \quad \textbf{(4.45)}$$

$$V_b = 49{,}7\,.\,17 = 844{,}9\,V \quad \textbf{(4.46)}$$

$$\boldsymbol{S = \frac{1{,}7\,.10^{-8}.10\,.2\,.103{,}5}{844{,}9\,.0{,}08} = 5{,}2.\,10^{-7}\,m^2 \approx 6mm^2}$$

(4.47)

Between 2nd parallel box and inverter:

L=10m

$$I_b = 11{,}5\,.\,6 = 69A \quad \textbf{(4.47)}$$

$$V_b = 49{,}7\,.\,17 = 844{,}9\,V \quad \textbf{(4.48)}$$

$$\boldsymbol{S = \frac{1{,}7\,.10^{-8}.10\,.2\,.69}{844{,}9\,.0{,}08} = 3.47.\,10^{-7}\,m^2 \approx 4\,mm^2} \quad \textbf{(4.49)}$$

N.B: we oversized the cross section of cables to evade the over charge when the cables overheats

1.1 Protection:

branch fuse

the operating voltage of a fuse:

$$\boldsymbol{V_F = 1{,}15\,.\,V_{oc}\,.\,N_{ps}} \quad \textbf{(4.50)}$$

$$\boldsymbol{V_F = 1{,}15\,.\,49{,}7\,.\,17 = 971.63\,V} \quad \textbf{(4.51)}$$

fuse capacity:

$$\mathbf{1,5}\,.\,I_{sc} \leq I_F \leq \mathbf{2}\,.\,I_{sc} \tag{4.52}$$

$$\mathbf{1,5\,.\,11,5} \leq I_F \leq \mathbf{2\,.\,11,5} \tag{4.53}$$

$$\mathbf{17,25}\,A \leq I_F \leq \mathbf{23}\,A \tag{4.54}$$

We will choose a fuse that can handle up to **1000V** and **20A**

Circuit breakers DC:

fuse voltage rating

$$V_{CF} \geq \mathbf{1,15}\,.\,V_{oc}\,.\,N_{ps} \tag{4.55}$$

$$V_{CF} \geq \mathbf{1,15\,.\,49,7\,.\,17 = 971,63}\,V \tag{4.56}$$

rated current

$$I_{CF} \geq \mathbf{1,5}\,.\,I_{sc}\,.\,N_{pp} \tag{4.57}$$

$$I_{CF} \geq \mathbf{1,5\,.\,11,5\,.\,15 = 258,75}\,A \tag{4.58}$$

We will choose a Circuit breaker that can handle up to **1000V** and **260A**.

DC surge protector

For the DC surge protection, we will use “LY1-C40/3S PV” [46]:

Max continuous operating PV voltage Uc: 1000V DC

Maximum discharge current (8/20µs) Imax: 40kA

AC surge protector

For the AC surge protection, we will use “kSD2019” [47]:

Rated Voltage (max. continuous voltage): 275V~

Max. discharge current(10/350µs): 40kA

4.5 Techno-economic study

Table 4-4 Equipment quantity and price

Equipment	Unit price	quantity	Total price
Solar panel	0.19 $/Wp	250kW	47,500 $
Inverter	5,400 $	1	5,400 $
Cable 4 mm^2	1.11 $	2750	3,052$
Cable 6 mm^2	1.11 $	10	11.1$
Grounding cable 10 mm^2	1.5$	20	30$
Structure	51.74$	710	36,735$
Junction box	295.67$	10	2,956$
parallel box	665.26$	4	2,661$
Labor price	22.17$	510	11,311$
Maintenance	25%	1	22,000$
Total cost (tax free)			129,629$
Total cost (including tax)			154,258.51 $
Total cost (including tax) in DA			21133415,87 DA

N.B: junction box includes: Circuit breakers, AC surge protector, DC surge protector, fuse holder, fuses.

N.B: Parallel box includes: includes the same equipment as a junction box but in bigger values.

N.B: to calculate the maintenance fees we have to calculate the price of all equipment (excluding labor price) then add 1% per year (in our case 25 years of maintenance have been considered).

4.5.1 Payback calculation

A study conducted in the USA by "Friendly Power" on power consumption in hospitals revealed that air ventilation units account for 21% of the total energy usage [16].

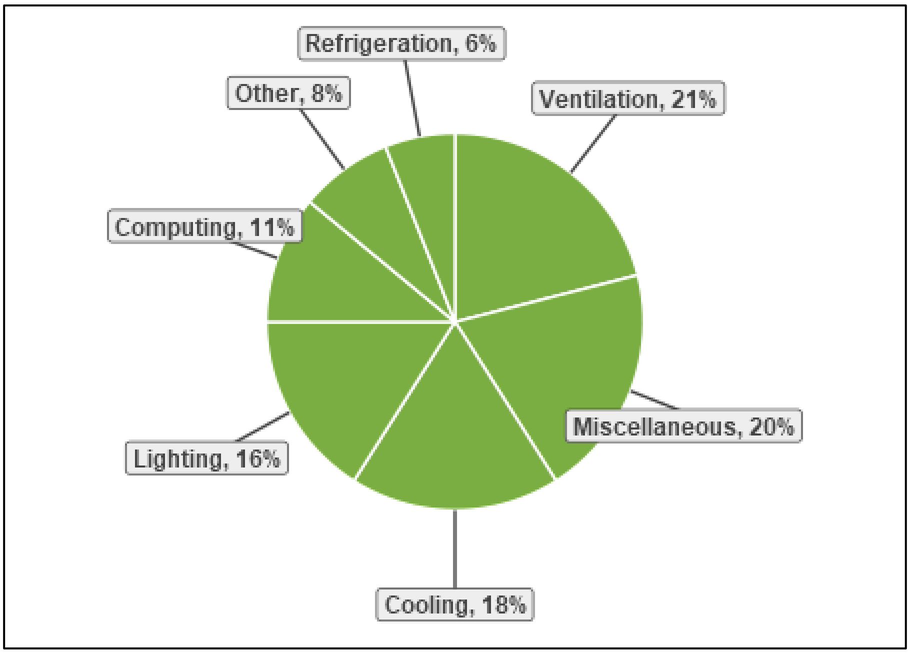

Figure 4-6 Electricity end uses in pacific area [16]

According to the data we were provided with the hospital pays 500000 DA per month for electricity.

$$C_{vent} = 50000 . 0.21 = 105{,}000\ DA/month \quad \textbf{(4.59)}$$

C_{vent}: Ventilation cost per month (DA).

$$\textbf{Yearly payment} = \textbf{105000 . 12} = \textbf{1,260,000 DA} \quad \textbf{(4.60)}$$

$$\textbf{Payback period} = \frac{Total\ cost}{Yearly\ payment} = \frac{21133415{,}87}{1{,}260{,}000} = \mathbf{16{,}77\ years}$$

(4.59)

The project has a payback of 16,77 years, and the estimated period of the project is 25 years therefore our system is fusible

4.6 Software simulation

4.6.1 PVsyst

PVsyst is a comprehensive software package for the study, sizing, and data analysis of complete PV systems. It is used by thousands of engineers globally and is considered the standard for large and utility-scale solar installations. PVsyst can be used to design grid-connected, stand-alone, pumping, and DC-grid (public transportation) PV systems. It includes extensive meteo and PV systems components databases, as well as general solar energy tools.

Some of the main features of PVsyst include system sizing, balancing systems, real-time information about the system's size and constraints, and risk mitigation. PVsyst is known for its accuracy and flexibility. It allows users to input specific data about their solar systems and provides information about potential losses and return-on-investment aspects of a solar PV power system. PVsyst is designed to be used by architects, engineers, installers, and researchers in the solar energy industry [48].

4.6.1.1 Pros of PVsyst:

- Accurate simulation: PVsyst provides precise modeling and simulation of PV system performance, taking into account various factors such as location, system configuration, shading, and weather data. This allows for realistic and reliable predictions of energy production.
- Comprehensive analysis: The software offers a wide range of analysis capabilities, including energy yield assessment, shade analysis, financial evaluation, and sensitivity analysis. These features help in optimizing system design, assessing project viability, and understanding the impact of different variables on performance.
- Detailed component database: PVsyst includes an extensive library of PV modules, inverters, and other system components. This allows users to select specific equipment and accurately model their performance characteristics, ensuring more accurate system simulations.
- Regular updates: The PVsyst software is actively maintained and updated by its developers. This ensures that the tool stays up-to-date with the latest industry standards, technological advancements, and performance models, enhancing its reliability and accuracy.
- Technical support and community: PVsyst have a dedicated support team and an active user community. Users can access resources such as user manuals, tutorials, and forums to seek assistance, share experiences, and exchange knowledge with other PV professionals [48]

4.6.1.2 Methodology

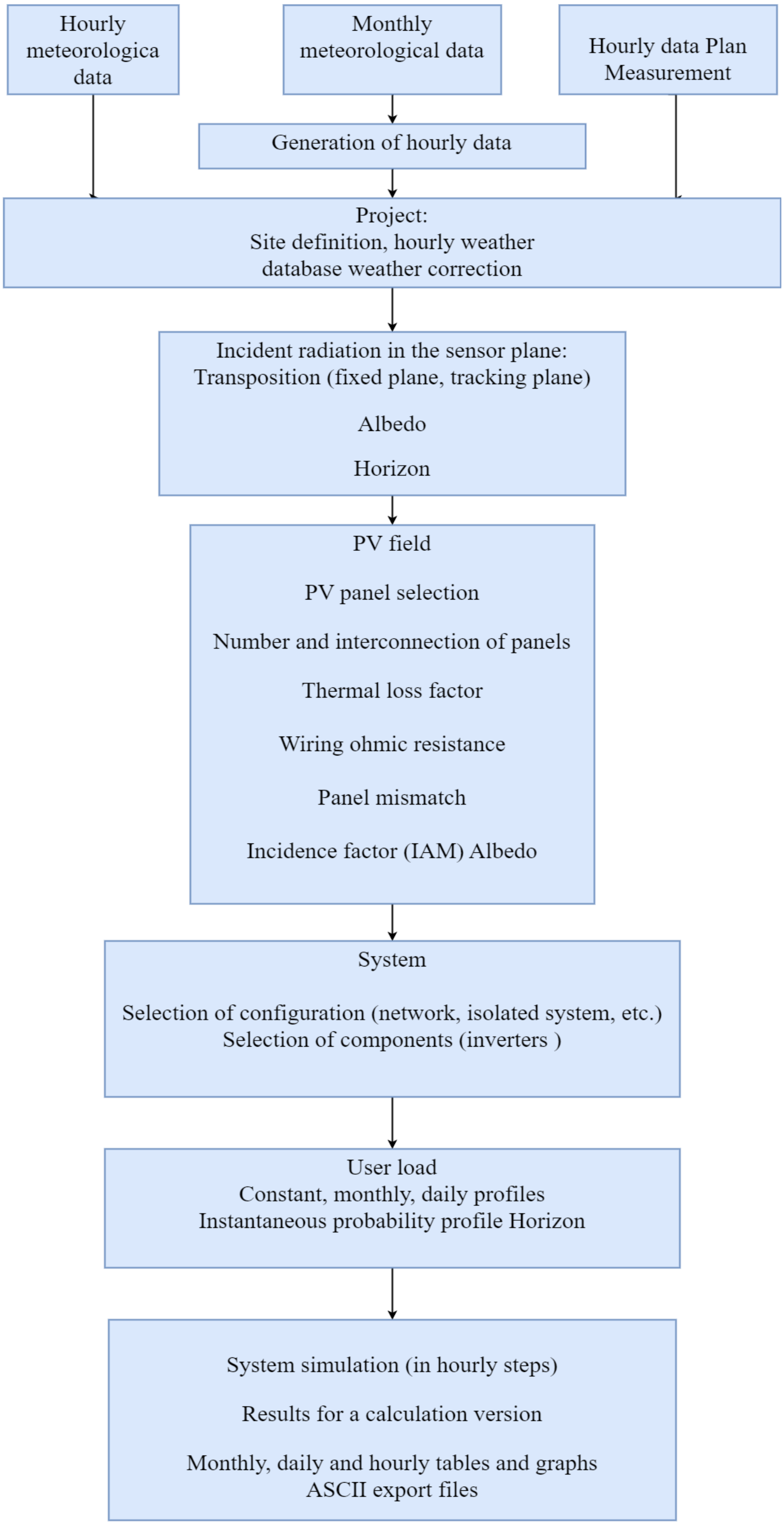

Figure 4-7 Simulation steps with PVsyst [49]

4.6.2 Simulation using PVsyst

4.6.2.1 Implanting our data into PVsyst

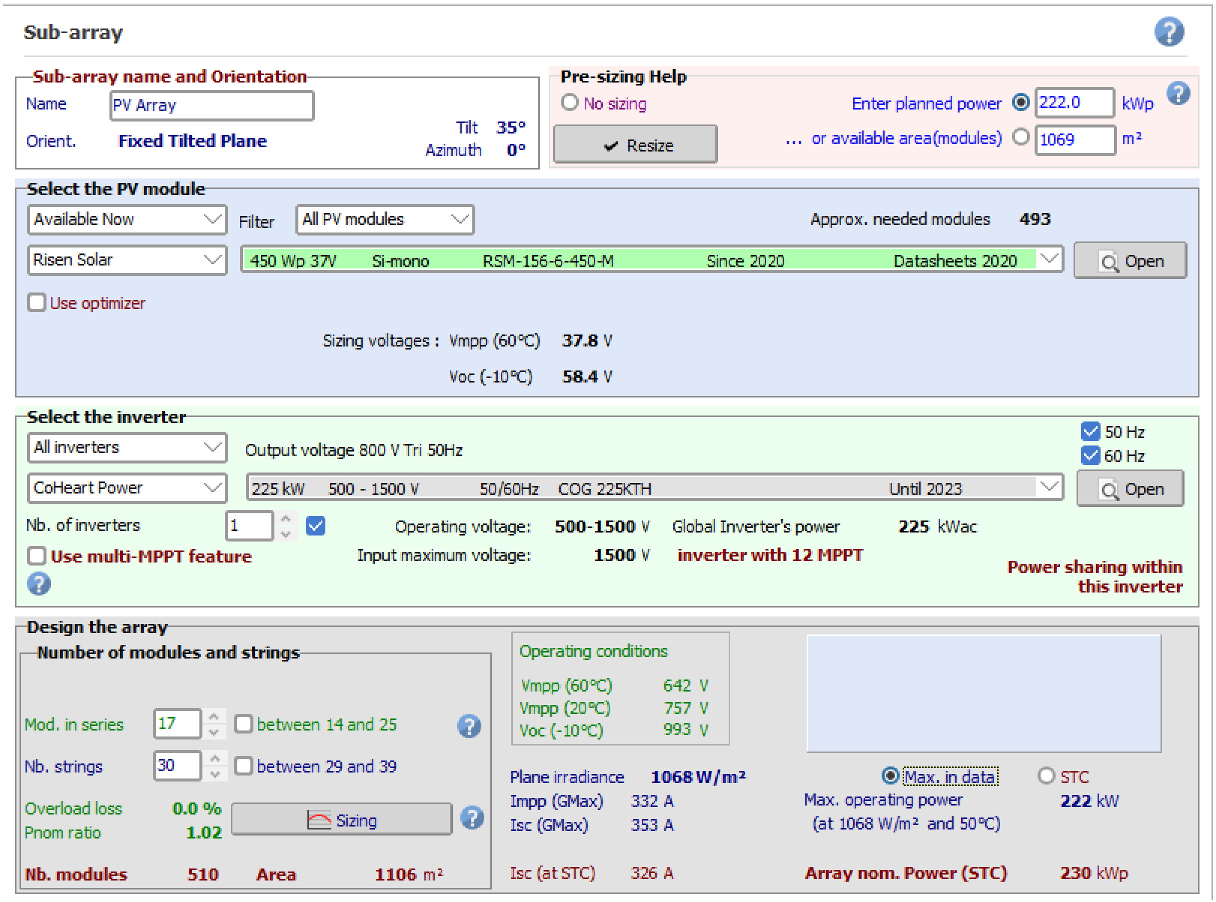

Figure 4-8 Array configuration

4.6.2.2 Results

After running the simulation and generating the report we get the following results:

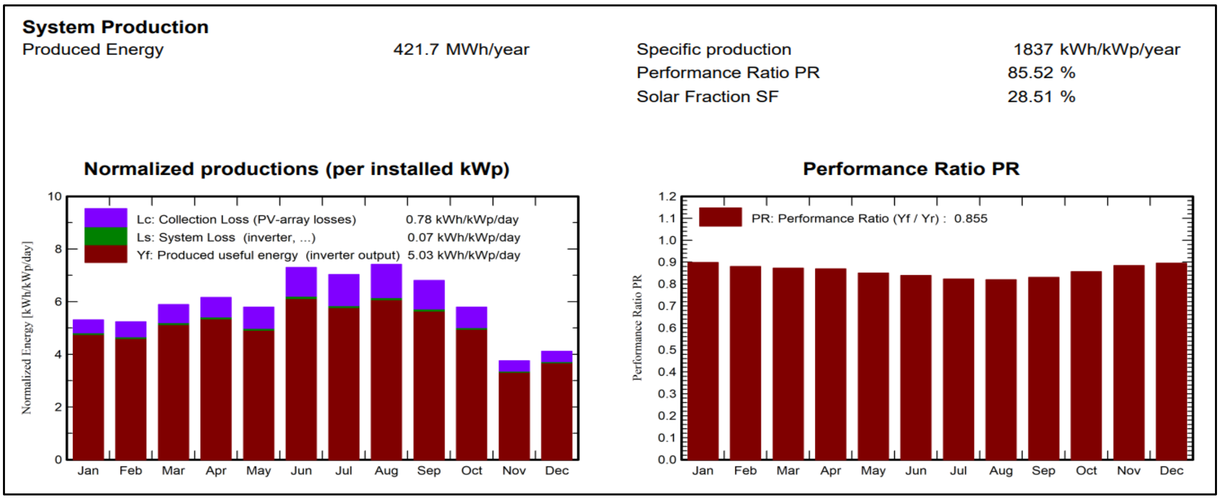

Figure 4-9 General overview

Our system generated a total of 421.7 MWh per year, with a performance ratio of 85.52%. This indicates that our system experienced only a 14.48% loss, which aligns with the expected nominal values. Additionally, the solar fraction for the system stands at 28.51%, indicating that 28.51% of the system's power requirements were fulfilled by solar energy.

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	96.5	27.93	9.55	164.5	162.5	34.31	119.0	31.71	2.180	87.33
February	101.8	36.38	13.00	146.7	144.6	30.02	107.5	27.72	1.896	79.80
March	150.3	57.09	13.84	182.6	179.5	37.03	119.0	33.83	2.719	85.21
April	176.4	64.96	14.26	184.7	181.0	37.36	115.2	34.14	2.699	81.06
May	190.0	74.35	19.89	179.4	175.3	35.49	119.0	33.25	1.734	85.79
June	243.5	65.34	21.31	218.9	213.9	42.76	115.2	40.17	2.004	75.03
July	235.4	71.97	26.69	217.8	213.2	41.67	119.0	39.88	1.243	79.16
August	225.7	59.52	25.93	229.9	225.6	43.83	119.0	41.03	2.225	78.01
September	174.2	50.10	23.71	204.2	200.6	39.43	115.2	36.51	2.393	78.69
October	131.4	44.74	20.28	179.6	177.0	35.73	119.0	33.55	1.731	85.49
November	75.5	36.39	16.08	112.7	111.0	23.21	115.2	22.35	0.529	92.85
December	76.2	32.22	13.27	127.4	125.7	26.53	119.0	25.50	0.690	93.54
Year	1876.9	620.98	18.18	2148.4	2109.8	427.37	1401.6	399.65	22.043	1001.95

Figure 4-10 Balances and main results

Legends

GlobHor: Global horizontal irradiation

DiffHor: Horizontal diffuse irradiation

T_Amb: Ambient Temperature

GlobInc: Global incident in coll. plane

GlobEff: Effective Global, corr. for IAM and shadings

EArray: Effective energy at the output of the array

E_User: Energy supplied to the user

E_Solar: Energy from the sun

EFrGridEnergy from the grid

E_Grid: Energy injected into grid

According to these results (Figure IV.10), which show the simulation results and the electrical energy produced by the system over one year,

we can see that the total energy produced by the solar array is 427,37 MWh with peak production in August with 43,83 MWh.

For the energy consumed we can observe that our system consumed a total of 1401.6 MWh throughout the year Our solar array managed to provide around 400 MWh and the grid provided 1000MWh.

Also, we can observe that the energy of 22 MWh was injected into the grid and that's because the production of the solar array exceeds the consummation from our air treatment units sometimes.

In our case we won't be injecting this exceed energy into the grid instead we will use it in other parts in the hospital to help lowering the power consumption and therefore lower the electricity bill

Next up we can view the loss diagram

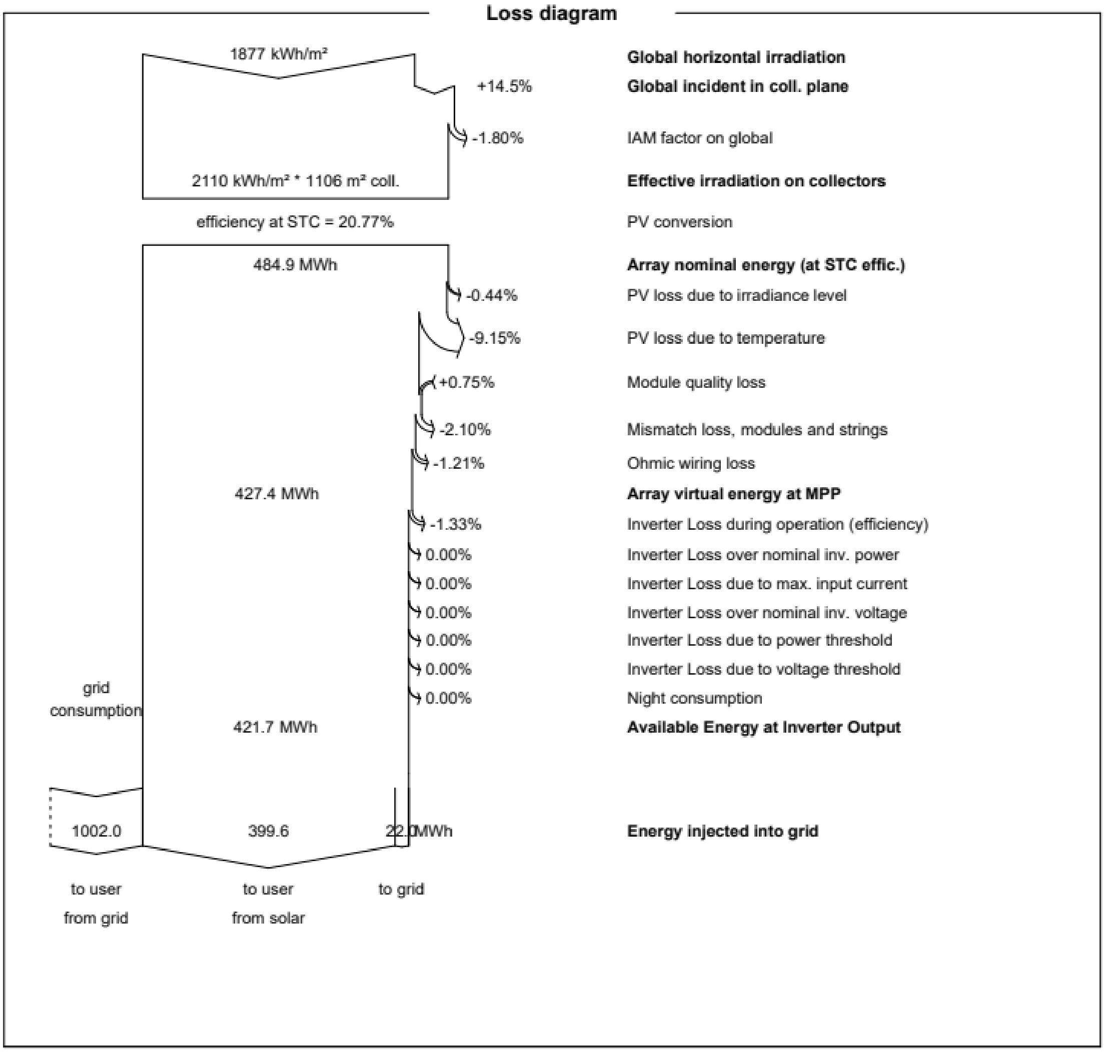

Figure 4-11 Loss diagram

As we move on to the Lost diagram we can see precisely where our system lost and gained energy, we can observe that the biggest losses will do to the temperature.

4.6.3 Homer Pro

HOMER (Hybrid Optimization of Multiple Energy Resources) is a software program used by engineers to optimize the design of various energy systems. It allows renewable energy enthusiasts to simulate different scenarios and find the best and most optimized solutions for their project designs. HOMER Pro is a microgrid software that optimizes microgrid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. HOMER Pro nests three powerful tools in one software product, so that engineering and economics work side by side: simulation, optimization, and sensitivity analysis [49].

4.6.3.1 Pros of HOMER Pro:

- HOMER Pro is a powerful software that optimizes the design of various energy systems, making it easier for engineers to simulate different scenarios and find the best and most optimized solutions for their project designs.
- HOMER Pro nests three powerful tools in one software product, so that engineering and economics work side by side: simulation, optimization, and sensitivity analysis.
  This allows users to compare thousands of possibilities in a single run, see the impact of variables that are beyond their control, and understand how the optimal system changes with these variations.
- HOMER Pro is a microgrid software that optimizes microgrid design in all sectors, from village power and island utile ties to grid-connected campuses and military bases. It is the global standard for optimizing microgrid design.
- HOMER Pro has a full-featured 21-day trial period, after which users can choose a licensing scheme that works for them. There are also student and academic pricing options available for HOMER Pro [49].

4.6.3.2 Methodology:

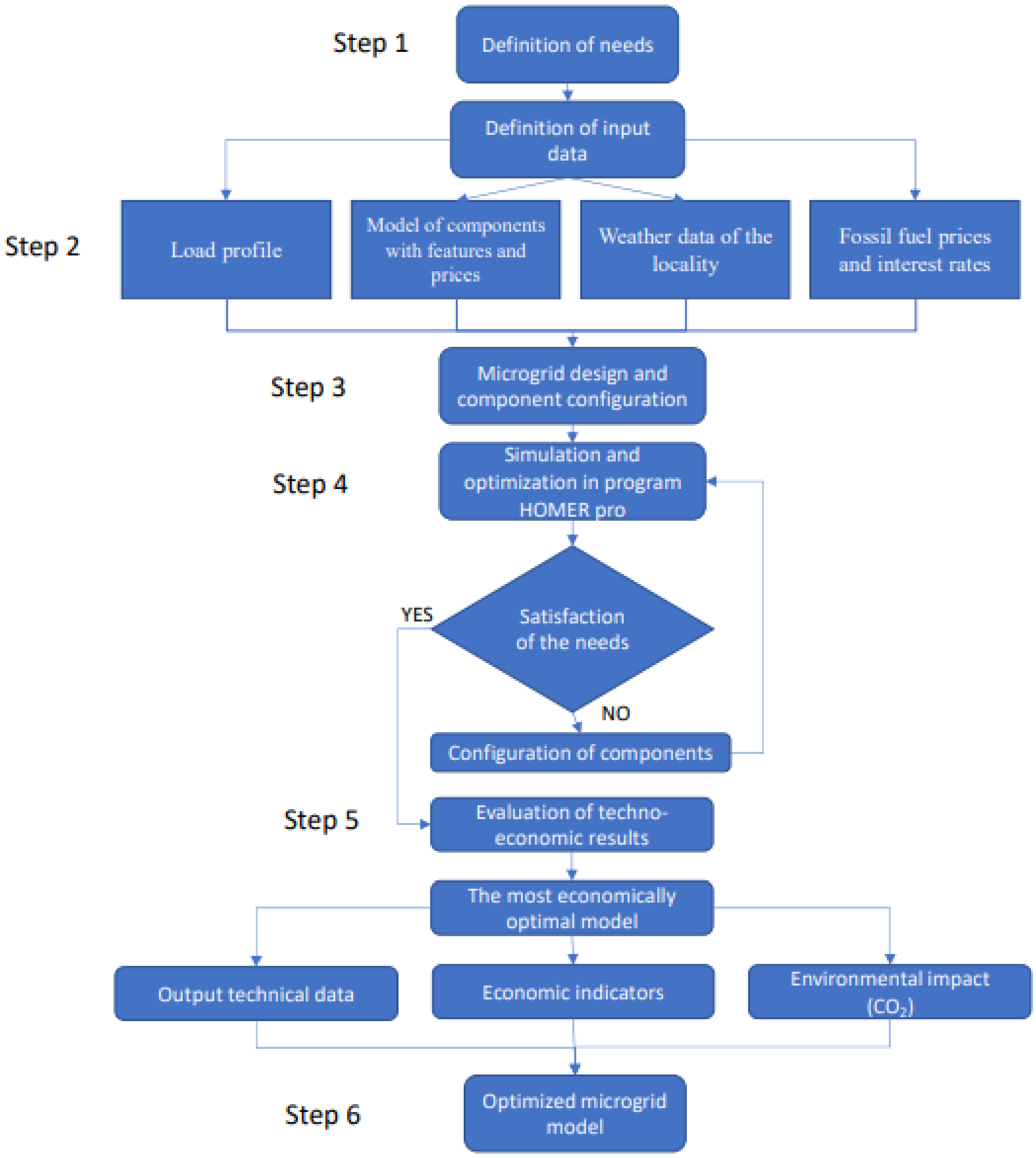

Figure 4-12 Graphic representation of methodology with flow diagram [50]

4.6.4 Simulation using HOMER pro

Table 4-5 HOMER pro results

Architecture			**System**
PV array (kW)	Grid (kW)	INVERTER (kW)	Ren Frac (%)
230	999999	225	24.69547
	999999		1.221245E-13

Cost			
NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
576896.1	0.0315838	40869.11	48560
614464.8	0.034	47531.54	0
PV array		**Grid**	
Capital Cost ($)	Production (kWh/yr)	Energy Purchased (kWh)	Energy Sold (kWh)
43700	361583.1	1063994	14935.27
/	/	1397987	/

In this table we can see the difference between our hybrid PV system(blue) and grid connected system(transparent), we can observe that:

The COE (the price of 1 kWh) of the PV system is lower than the grade system.

The operating cost per year of the PV integrated system is lower than the grid connected system.

The PV array production is not that different from the one that we obtained from the software PVC and also that implies to the energy burst and the energy sold.

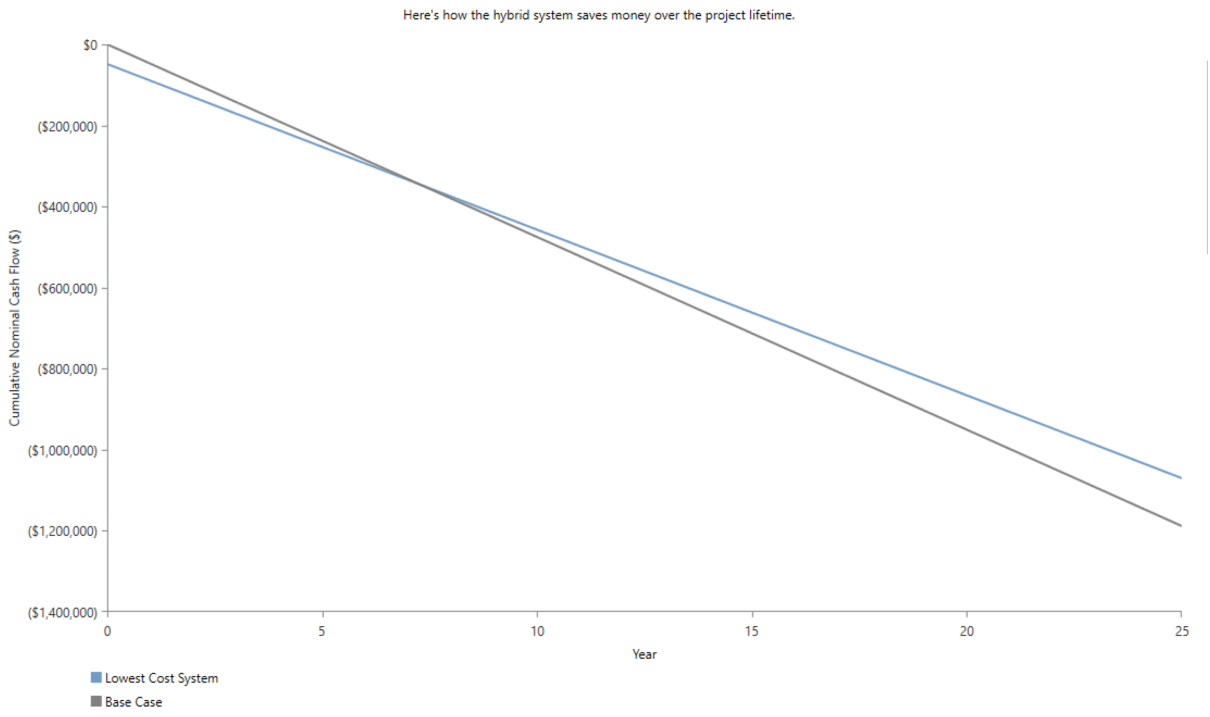

Figure 4-13 Cost over project lifetime PV system (blue) grid system (black)

Economic Metrics

IRR	13%
ROI	9.7%
Simple Payback	7.3 yr

Cost Summary

	Base Case	Lowest Cost System
NPC	$614,465	$576,896
Initial Capital	$0.00	$48,560
O&M	$47,532/yr	$40,869/yr
LCOE	$0.0340/kWh	$0.0316/kWh

Figure 4-14 financial data of the project

According to HOMER pro results the payback of the project is 7,3 years.

4.7 Conclusion

System sizing plays a crucial role in ensuring the successful implementation of solar energy systems. In this chapter, we discussed the manual sizing approach, which involves carefully selecting inverters, designing solar panels and arrays, determining array output at critical points, addressing junction box requirements, optimizing cable cross-sections, and implementing protection mechanisms. Furthermore, we explored the techno-economic study aspect, which includes calculating the payback period to assess the financial feasibility of the project. Additionally, we examined two powerful software tools, PVsyst and HOMER Pro, which enable accurate and detailed simulation of system performance. These software solutions provide valuable insights into energy production and assist in making informed decisions regarding system sizing.

Conclusion:

In conclusion, this thesis has explored the integration of photovoltaic (PV) systems in air treatment units as a means to reduce energy consumption in CANASTEL Hospital, located in Oran, Algeria. By examining the technical, economic, and environmental aspects of this integration, valuable insights have been gained, which can contribute to the adoption of sustainable energy practices in healthcare facilities.

Through the comprehensive analysis conducted, it has been established that the integration of PV systems in air treatment units offers significant potential benefits. By harnessing solar energy, hospitals like CANASTEL can substantially reduce their reliance on conventional energy sources for air conditioning and ventilation. This not only leads to considerable cost savings but also mitigates the environmental impact associated with energy consumption, contributing to a greener and more sustainable healthcare infrastructure.

The findings of this study indicate that the technical feasibility of integrating PV systems in air treatment units is viable, considering the availability of abundant solar resources in Algeria. However, careful system design, performance optimization, and integration planning are crucial to ensure seamless operation and maximize energy efficiency. Additionally, the economic viability of such integration heavily depends on factors such as initial investment costs, government incentives, and long-term operational savings.

Furthermore, the environmental impact assessment conducted emphasizes the positive environmental benefits of integrating PV systems. By reducing reliance on fossil fuel-based electricity generation, the hospital can significantly reduce greenhouse gas emissions, contributing to climate change mitigation and environmental preservation.

The conclusions derived from this thesis provide valuable guidance for decision-makers, facility managers, and energy professionals in the healthcare sector. The study highlights the potential of PV integration to address energy efficiency and sustainability goals, while also promoting the development of renewable energy infrastructure in Algeria.

Moving forward, it is recommended that further research be conducted to evaluate the long-term performance and economic viability of the integrated PV systems in CANASTEL Hospital. Continuous monitoring and optimization of the system will be essential to ensure optimal energy generation and usage. Additionally, the replication of this study in other healthcare facilities across the country and region can provide a broader perspective on the applicability and scalability of this approach.

Ultimately, the integration of PV systems in air treatment units represents a significant step towards achieving a more sustainable and energy-efficient healthcare sector. By embracing renewable energy technologies, CANASTEL Hospital and similar institutions can set an example for other healthcare facilities, fostering a greener and healthier future for Algeria and beyond.

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