DEMOCRATIC AND POPULAR REPUBLIC OF ALGERIA MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
MOHAMED BOUDIAF UNIVERSITY - M'SILA

FACULTY OF SCIENCES
PHYSICS DEPARTMENT
N°: PH/ENR/03/2025

جامعة محمد بوضياف - المسيلة
Université Mohamed Boudiaf - M'sila

DOMAIN: MATTERIAL SCIENCES
SECTOR: PHYSICS
OPTION: ENERGY PHYSICS AND RENEWABLE ENERGIES

Thesis presented for obtaining the Academic Master's degree

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Title

Improving Photovoltaic Panels Performances Using Cooling Systems

Defended before the jury composed of:

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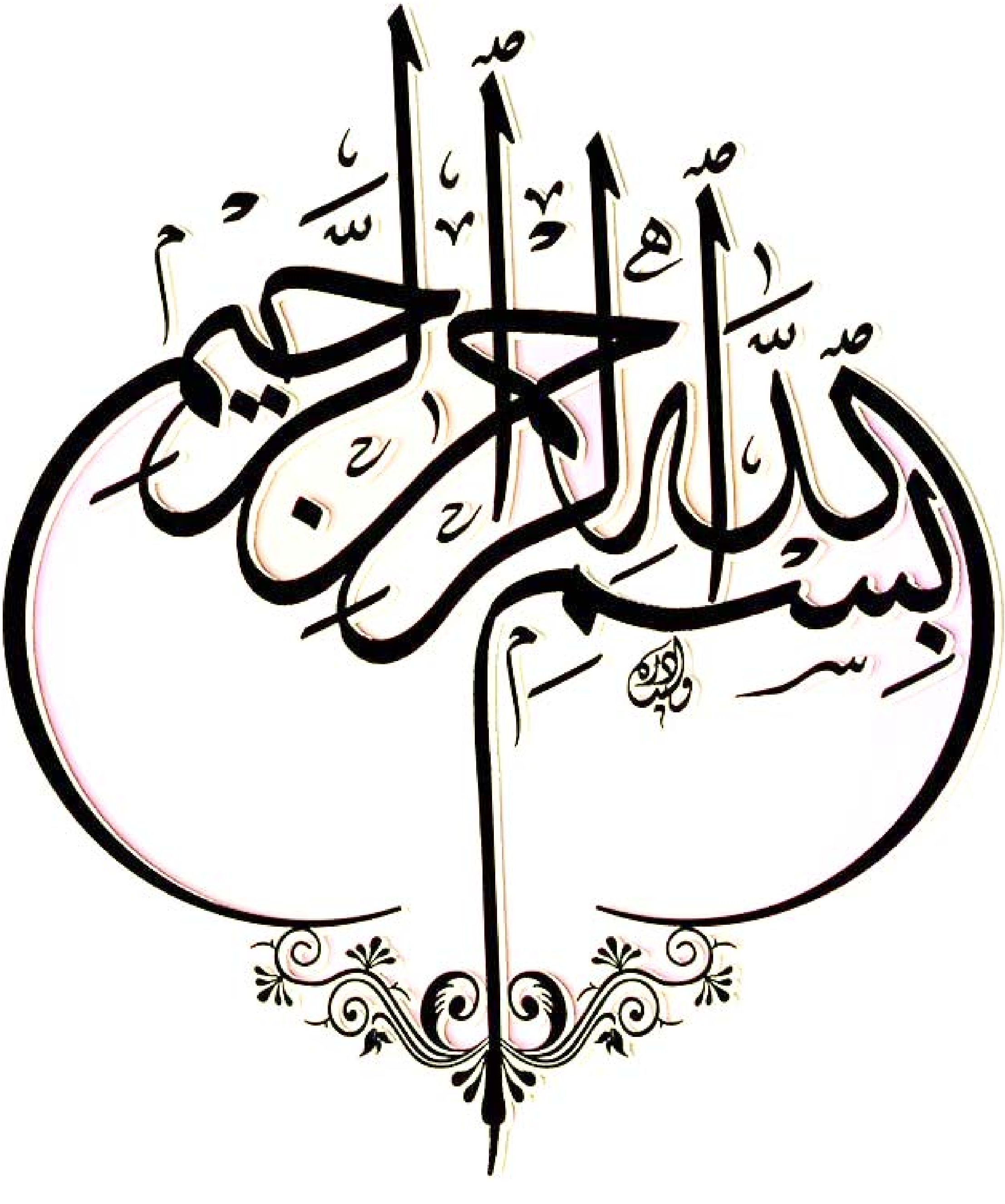
2024 /2025


بسم الله الرحمن الرحيم

ACKNOWLEDGMENT

We extend our deepest gratitude and appreciation to our supervising professor "Dr. Z. HADDAD", who has generously shared his knowledge and valuable guidance, serving as an exemplary model of dedication and professionalism. We also express our great appreciation to the assistant supervisor "Pr. A. DEBIH", who has been a true supporter with his insightful remarks and precise guidance, making this work more refined and comprehensive.

We would also like to thank Mr " GHOLEM ELLEH Mohammed" manager of Meteorology station of M'sila and to everyone who contributed, even in a small way, to the success of this work—whether through advice, support, or encouragement. We will never forget those who believed in our abilities, stood by our side, whether with a motivating word, constructive guidance, or even a reassuring smile.

W.C. DEBIH and S. BAOUCHE

DEDICATION

To my beloved family, who gave me strength and inspiration in my most challenging moments. To my parents, who instilled in me a love for knowledge and ambition and were always my greatest source of support in my academic journey

To my sister "Wafa" and my brothers "Walid and Abderrahmane", who have been my companions along the way. No matter the challenges, their encouraging words and valuable advice have been my guiding light .

To everyone who gave me their time, even if just a little, to help me complete this work, to those who see science as a tool for societal progress, and to every researcher seeking knowledge and enlightenment, unbound by limitations, believing that science is a light for all minds.

W. C. DEBIH

DEDICATION AND GRATITUDE

To those whose prayers lit my path, and whose presence in my heart was a solace in every hardship,

To those who taught me that determination is not born of nothingness, but forged in love and nurtured in the embrace of safety…

To my family, who have always been my first home and my unwavering support,

To my dear parents, who showered me with affection and taught me through patience the true meaning of glory,

To my siblings, whose presence was a comforting shadow in times of struggle and a source of joy in moments of triumph…

I dedicate this work to you, not as a personal achievement, but as a continuation of all that you have given me—love, sacrifice, and unwavering support.

To you belongs the credit, to you belongs my heart, and to you I owe this light I have reached.

S. BAOUCH

Summary

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General Introduction

With a growing global emphasis on sustainable power, solar panels have become a go-to source for capturing sunlight and converting it into eco-friendly energy. Nevertheless, these panels' biggest hurdle is the upsurge of their temperature while they are being operated, which not only causes a decrease in their efficiency but also limits the amount of energy they can produce. Cooling systems come in handy at this point. They are designed to improve the thermal performance of photovoltaic panels by employing advanced methods such as water cooling or using cooling agents like ethylene glycol.

The output of solar panels relies on a number of factors, such as the nature of the materials employed in construction, conditions of work, and the magnitude of solar radiation received. During their continuous exposure to sunlight, the cells of panels stock up on heat that is more than necessary, thus leading to the increase of their temperature that will consequently lead to the reduction of their output voltage and efficiency of the whole system. Several experiments have proven that every temperature rise affects the performance negatively. Thus, it is important to have good cooling systems in place so that they could help reduce this effect.

In general, raising the efficiency of photovoltaic panels requires a study of how their temperature can be regulated by different methods. One of the very popular ways is water cooling. In this case, water is sprayed on the panel’s surface in order to cool it and thus increase its performance. An alternative, however, is the use of a cooling liquid such as ethylene glycol. This liquid has a very high heat absorption capacity and can therefore minimize the heat generated in solar cells, thus being a very efficient source of energy production increase.

In this research, we will also look at the performance of a photovoltaic panel under three different conditions: without any cooling, with water cooling, and with ethylene glycol cooling. The result analysis will provide us a way to evaluate the capability of each cooling technique and identify the most efficient method for solar energy production improvement, especially in the hot regions like Algeria.

The goal of this research is to give a definitive insight into the best cooling strategies that can be realistically implemented to increase the photovoltaic panel's efficiency, focusing on both the technical and economic aspects. We thus intend to unlock the full capacity of solar energy as a green and dependable power source.

CHAPTER -I-

Photovoltaic Panel

I. 1. Introduction

Energy is a fundamental part of national development and sustainability. Fossil fuels have long been the most widely used energy source on the world. However, as a consequence of rapid population growth, improved living standards, and the expansion of energy consuming activities in both developed and emerging nations, global energy consumption has been put under great pressure .This activities have raised two major concerns: the depletion of the most readily available energy resources (mostly oil) and the worsening problem of global warming due to the rapidly rising emissions of greenhouse gases like carbon dioxide and methane. The challenge facing the planet is to reduce climate change and global warming by using clean and cost-effective (RE) sources, which should be properly managed and utilized [1].

Renewable energy is commonly defined as energy generated from natural resources, such as sunlight, wind, rain, tides, and geothermal heat. Contrary to conventional energy sources (including coal, oil and natural gas), renewable energies have almost any negative impacts on the environment, as they do not produce waste or greenhouse gas emissions, therefore, RE stands as the best and most effective solutions to environmental challenges and concerns regarding energy sustainability.

The majority of renewable energies sources are originate directly or indirectly from the sun. Recently, solar energy has emerged as the most promising RE options due to its abundance, versatility, and ease of implementation with minimal environmental impact in terms of land use [2]. The term solar energy refers to the energy which is harvested directly from the sun. Each day, the sun emits an enormous amount of energy to the earth’s surface (e.g., in one hour, it receives 172000 TWh of energy), far more than enough to supply the world’s energy demands if effectively harnessed. Electricity Generation from the sun can be achieved through photovoltaic panels (PV).

A PV system produces electricity by directly converting solar energy into electrical power using PV cells (solar panels/modules), which are the system’s most crucial components [3]. PV power generation systems are highly regarded for their low operational cost, minimal maintenance requirements and environmental benefits [2]. Table 1 presents the main advantages and disadvantages of PV systems. Despite the high initial cost of photovoltaic panels, PV systems, particularly grid-connected ones, have been widely adopted in numerous countries due to their potential economic benefits in the medium and long term [2].

I. 2. Definition

Solar energy is one of the best and most efficient ways to generate electricity. It helps mitigate the alarming acceleration of climate change caused by the emission of large amounts of carbon dioxide and other pollutants when fossil fuels are used in massive quantities. However, fossil fuels are a non-renewable resource and will eventually run out.

Given the most readily available source of energy on the Earth planet, solar energy is often used to generate electricity in two main ways. The first is by using photovoltaic cells (PV), which rely on semiconductor materials that produce electricity by exposing them to direct sunlight through the photovoltaic effect. The second way is by converting solar energy into heat, concentrated solar power (CSP) technology, which is then directed to operate turbines. According to the International Renewable Energy agency (IRENA), the first method (PV) technology, has surpassed the second one (CSP) in terms of efficiency, widespread adoption, and ease of use. [4, 5]

Figure I.1. PV cells, panel and array and real panels

I. 3. Principle of Operation of the Photovoltaic Cell

Photovoltaic solar cells, which are composed of a PN-type semiconductor junction, generate electrical power directly from sunlight through a physical process known as the photovoltaic effect [6], while emitting no pollutants or environmentally harmful combustion products. This makes them an environmentally friendly and sustainable option for generating electricity. The photocurrent production concept of PV cells is depicted in Figure 2,when sunlight, which contains photons of varying energies, strikes the surface of the solar cell typically made from semiconductor materials such as silicon the atoms of these materials absorb photons with energy levels higher than the material's energy band gap. This photon absorption excites electrons from the valence band into the conduction band, resulting in the generation of electron-hole pairs.

The internal electric field at the PN junction plays a crucial role in separating these charge carriers: electrons are driven toward the negative region and holes toward the positive region. This immediate and effective separation prevents the recombination of carriers within the cell and enables electric current flow once the cell is connected to an external circuit. The electrons flow through the external load from the positive layer to the negative layer, producing direct current (DC) voltage, typically ranging from 0.5 to 0.8 volts, depending on the type of semiconductor material used and the specific manufacturing techniques, including the absorption coefficient, thickness of the active layer, and carrier separation efficiency.

Since the output voltage of a single cell is relatively low and not sufficient for practical use, multiple solar cells are connected in series to form a photovoltaic (PV) module. These modules can be further connected in series and/or in parallel to construct a complete PV panel. In series configurations, voltage values are multiplied while the current remains constant; in parallel configurations, current values increase while the voltage remains unchanged. This modular configuration allows for adjustment of the system output to match the requirements of electrical loads or power inverters.

To analyze and predict the performance of solar cells under varying environmental conditions, PV cells are typically modeled using an equivalent electrical circuit. This circuit includes a photovoltaic current source, a diode representing the PN junction, and both series and parallel resistances to account for losses due to material properties and connection quality. Solar cell operation is characterized by drift and diffusion currents in reverse and forward bias conditions, respectively. Most cells operate in reverse bias mode, where the drift current generated by the electric field in the depletion region is crucial for optimal performance. When the junction is exposed to sunlight, photons with energies exceeding the band gap energy are absorbed, resulting in the formation of electron-hole pairs. These carriers are separated by the electric field within the junction, generating a photocurrent that is directly proportional to the intensity of the incident solar radiation.

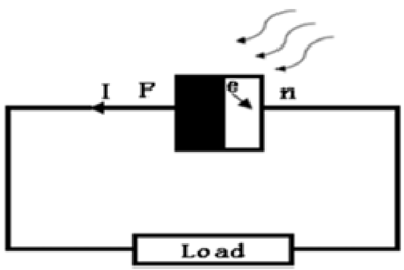
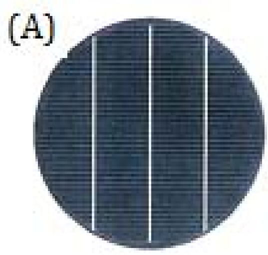
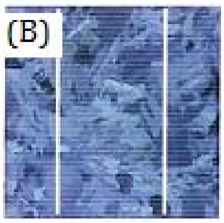


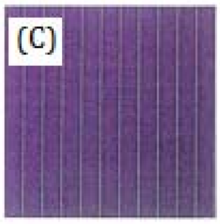
Figure I.2. Photocurrent generation principle [7]

I. 4. Classifications of solar PV materials

PV solar cell materials, which represent 90% of the global market, are determined based on several key factors, including subtle differences in silicon purity, cost, available space, and operational efficiency. The detailed classifications listed are typically used in commercial manufacturing processes to ensure the highest levels of quality and performance. [4,8]







(A) Mono crystalline silicon solar cells (B) Polycrystalline silicon solar cells (C) Amorphous silicon solar cells

Figure I.3. The principal types of cells [9]

I. 4.1.The principal types of cells.

Characteristic of cells are present in **Table –I.1-. [10]**

Tecnology	Cells efficiency (laboratory)	Cells efficiency (production)	Module efficiency (production)
Mono crystalline	24.7%	21.5%	16.9%
Polycrystalline	20.3%	16.5%	14.2%
Amorphous	13%	10.5%	7.5%

I. 4.1.1. Mono crystalline silicon solar cells

Monocrystalline solar panels are known for their elegant appearance, with a uniform color compared to the bluish hue of polycrystalline panels. Their manufacturing process uses the **Czochralski** technique, extracting high-quality cylindrical silicon rods, precisely cut on all sides, giving them an efficiency of between 20% and 1 %.

These Mono crystalline silicon solar panels are highly space efficient, capable of generating two to three times more power than thin-film technologies. They also have a lifespan of approximately 25 years. However, the overall performance of these panels can be affected by environmental factors such as shade, dirt, or snow accumulation, which can cause a complete circuit failure. They operate more efficiently in warmer climates, but their performance may decline as temperatures rise. [11]

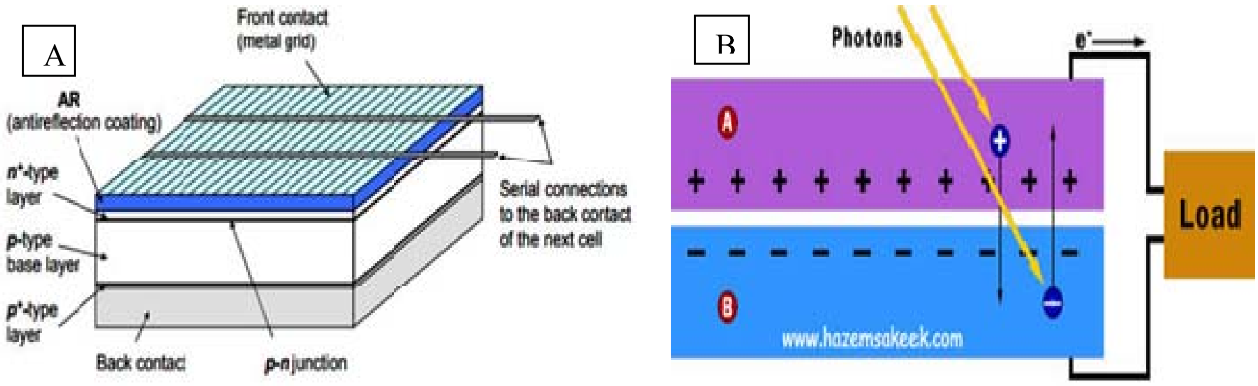


Figure I.4. (A) Crystalline silicon solar cell structure , (B) Working of crystalline PV cell [4]

I. 4. 1. 2. Polycrystalline silicon solar cells

Polycrystalline silicon is produced through several stages, typically involving the melting of raw silicon and molding into square-shaped molds. After solidification, it is cut into ready-to-use pieces for further manufacturing. These cells are characterized by sharp edges (not rounded). The production process for this type of solar cell is simpler and more cost-effective than the manufacturing of monocrystalline cells, as it reduces raw silicon waste. Additionally, it offers good efficiency relative to its price, making it one of the most widely used methods for manufacturing solar panels used in homes and factories. [4]

I. 4. 1. 3. Amorphous silicon solar cells

This type of solar cell is typically used in small electronic devices that require low electrical power, such as calculators and small digital and electronic watches. The manufacturing process relies on a technique called stacking, where multiple thin layers of amorphous silicon are stacked on top of each other, increasing electricity production and improving efficiency to a range between 6% and 8%.

One of the key characteristics of this technique is that the amount of silicon required for manufacturing these cells does not exceed 1% of the silicon used in crystalline silicon solar cells, making it a more cost-effective option for applications that do not require high levels of energy. [4]

I. 4. 2. Other types

I. 4. 2. 1. Thin-film solar cells (TFSC)

Thin-film photovoltaic cells are considered a good alternative to traditional manufacturing technologies, as they are obtained by depositing one or several layers of photovoltaic materials onto a specific substrate. This approach allows for larger-scale production in a simpler and more cost-effective manner compared to other solar cells, although it requires more space due to its moderate efficiency.

Nevertheless, the impact of environmental factors, such as high temperatures, humidity, and others, is lower compared to monocrystalline and polycrystalline cells, granting them more stable performance in different environments.

Due to their smooth and uniform surface, these cells have a more aesthetically pleasing appearance; however, their performance deteriorates at a faster rate than other types of solar cells, which may make their lifespan the shortest. Nevertheless, their low cost and ease of production have made them a suitable option for many applications that do not require high energy levels.

Over the past decade, the market for thin-film photovoltaic cells has experienced rapid growth, with annual production rates increasing by approximately 55% to 60%, reflecting the rising demand for this technology. Based on the type of material used in the deposition process, these cells are classified into different categories(Figure 5), which helps improve their efficiency and expand their use in modern solar energy systems. [12, 13]

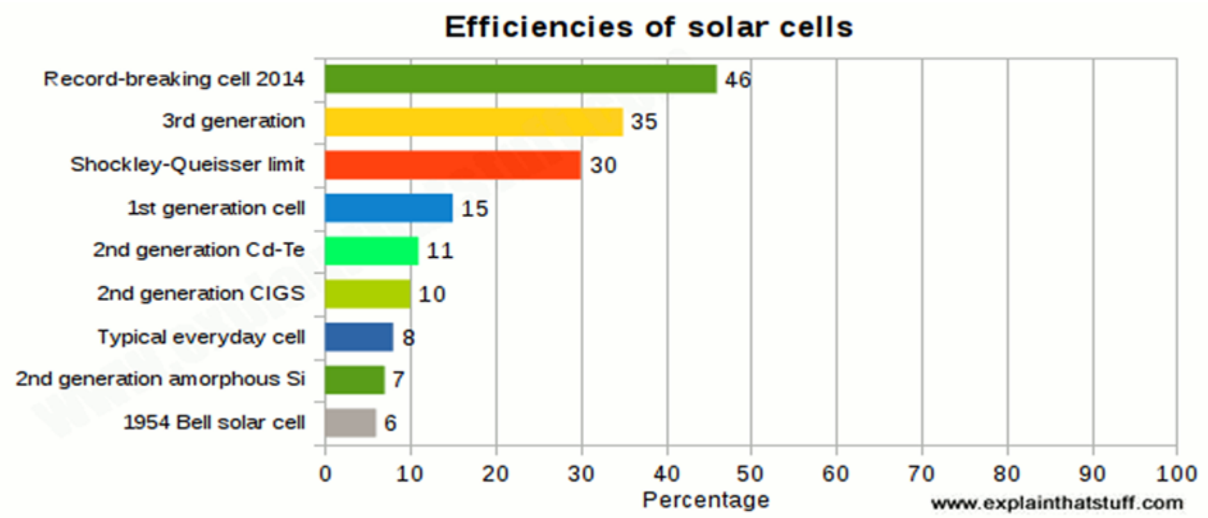


Figure I.5. Efficiency of different solar cells

I. 4. 2. 2. Cadmium telluride solar cells (CdTe)

One of the most notable advantages of cadmium telluride thin-film photovoltaic cells is their high efficiency, ranging between 9% and 11%. This makes them superior to crystalline silicon solar cells in terms of cost-efficiency. Their promising performance, combined with lower production costs, has contributed to their increasing use in large-scale solar energy projects.

I. 4. 2. 3. Copper indium gallium selenide solar cells (CIGS)

Copper indium gallium selenide solar cells are among the most promising thin-film technologies, offering efficiency levels between 10% and 12%. Their ability to achieve strong performance makes them a competitive alternative to conventional silicon-based solar cells.

However, the presence of cadmium selenide (a highly toxic compound) poses a significant challenge to this technology, limiting its widespread acceptance and necessitating the development of safer alternatives. [4]

I. 4. 2. 4. Building-integrated photovoltaic

This advanced approach combines materials and techniques from crystalline-based and thin-film solar cells to create integrated energy solutions for buildings. BIPV technology allows photovoltaic cells to be embedded seamlessly into facades, roofs, windows, and walls, transforming traditional structures into energy-producing elements. Despite its numerous advantages, the higher costs associated with integrating solar materials with conventional building components make it a more expensive option compared to standard solar installations. However, on going advancements in this field are gradually improving the feasibility and affordability of BIPV systems. [4]

I. 4. 2. 5. Nano crystals in solar cell technology

The efficiency of current solar cell technologies varies (Figure 6) , with first-generation solar cells reaching approximately 22%, while second-generation cells operate at around 15%. The theoretical efficiency limit, known as the Shockley-Queisser limit, defines the upper efficiency threshold between 31% and 41%.

Nano crystal solar cells are an emerging technology designed to surpass this theoretical limit. These cells feature substrates coated with selected nano materials such as cadmium telluride (CdTe), copper indium gallium selenide (CIGS), or silicon. The use of these advanced materials enhances light absorption and improves efficiency beyond conventional methods. In addition to increasing energy output, nanocrystal solar technology holds promise for reducing production costs, making it a more economically viable option. However, challenges related to electrical conductivity must be addressed to ensure optimal performance and reliability. [4]

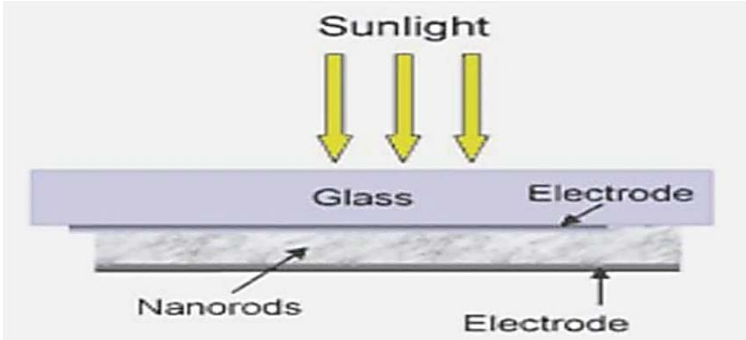


Figure I.6. Nano-Crystal technology

I. 4. 2. 6. Organic /polymer solar cells

Recent research has led to significant developments and notable advancements in the field of organic semiconductors and conductive polymers, improving the energy conversion efficiency of photovoltaic cells. Organic solar cells stand out for their low production cost and large-scale manufacturability, benefiting from widely used polymer coating technologies. [4]

I. 5. Factors Affecting the Efficiency of Photovoltaic Cells

Several factors influence the efficiency of photovoltaic cells, the most prominent being temperature, the tilt angle, and the proper positioning of the cell to maximize direct sunlight exposure. Additionally, daily and seasonal variations, such as solar radiation intensity, play a crucial role. Beyond these, other considerations must be taken into account to achieve optimal performance.

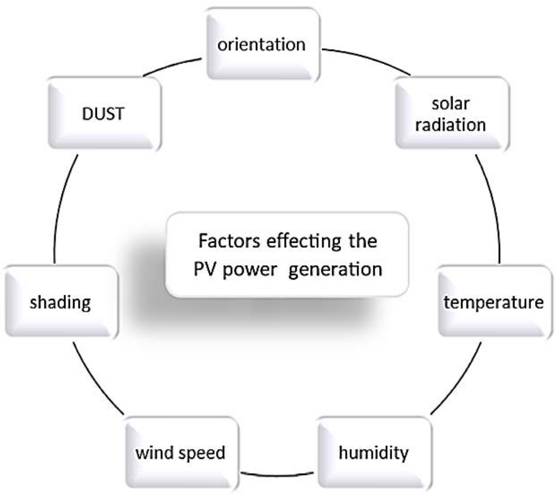


Figure I.7. The main factors influencing PV power generation.

I. 5. 1. Temperature Effect

An increase in ambient temperature leads to a rise in the temperature of the solar cell itself, which in turn causes a decrease in the generated power and the open-circuit voltage of the photovoltaic cell. Although there is a slight increase in the short-circuit current, the overall result is a noticeable reduction in the cell's performance efficiency. [14]

I. 5. 2. Orientation

The positioning of photovoltaic (PV) modules plays a crucial role in optimizing sunlight absorption, which directly influences energy output. The optimal orientation for these modules varies based on the geographical location of the installation. Incorrect alignment can lead to a significant reduction in power generation. [14]

I. 5. 3. Solar radiation

The output current of a photovoltaic (PV) cell is directly proportional to the amount of solar radiation it receives. Consequently, a reduction in solar radiation results in a decrease in the output current, which in turn lowers the power generated by the PV module. [14]

I. 5.4. Humidity

Humidity plays a crucial role in influencing the efficiency of solar cells. It creates a thin film of water on their surface, which can adversely affect the performance and reduce the efficiency of photovoltaic (PV) modules. [14]

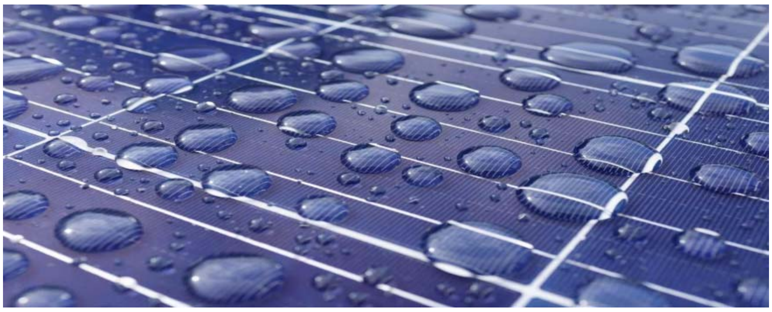


Figure I.8. The impact of humidity on PV panel efficiency

I. 5. 5. Shading

Shading has a direct impact on the amount of electricity generated by photovoltaic cells, as it reduces the amount of solar energy reaching the cell’s surface. Similarly, the accumulation of dust can cause partial shading of parts of the cell, which negatively affects its efficiency. Therefore, it is essential to ensure that photovoltaic systems are free from shading and obstructions, as these can significantly reduce energy production. However, the effect of shading is less pronounced in thin-film cells. Studies have shown that shading just one cell within a photovoltaic module can lead to a significant decrease in the efficiency of the entire module [14]

I. 5. 6. Wind speed

Wind movement indirectly affects the performance of the solar cell by influencing its surface temperature. Wind stimulates convective heat transfer currents, which leads to an increase in the convective heat transfer coefficient. This, in turn, enhances the transfer of heat from the cell's surface to the surrounding environment. The cooling effect resulting from wind movement helps reduce the internal temperature of the solar cell, thereby improving its efficiency [14].

I. 5.7. Dust

The presence of accumulated dust on the surface of a photovoltaic (PV) module obstructs solar radiation, leading to a decline in its efficiency and a subsequent decrease in energy output. [14]

Figure I.9. Dust Accumulation on Photovoltaic Solar Panels

I. 6. Advantages and disadvantages of PV systems.

I. 6. 1. Advantages:

- ✓ An energy source that is renewable and costless.
- ✓ Produces the electricity that is clean and eco-friendly.
- ✓ Does not release harmful gas during the production of power.
- ✓ It has a minor impact on the environment, so it is a good option for sustainable living.
- ✓ It runs quietly, which is the reason why it is the best choice for city and residential settings.

- ✓ Requires significantly less operational and maintenance costs in contrast to other renewable energy technologies.
- ✓ Permits the generation of electricity near the point of use. [14]

I. 6. 2. Disadvantages:

- ✓ The installation requires a high initial cost.
- ✓ The installation needs quite a large surface area.
- ✓ The technology is highly dependent on advances in technology.
- ✓ The system's performance is impacted by local conditions and climate change.
- ✓ Solar panel efficiency still lags behind that of other renewable energy sources.

  Integrated or Grid-Tied Systems. [14].

I. 7. Applications of solar PV panels

There are three main types of photovoltaic energy available: off-grid, grid-tied, and hybrid systems. Off-grid (stand-alone) systems work independently, keeping the energy in batteries to provide electricity at night.

On the other hand, grid-tied systems connect directly to the power grid, thus not requiring battery storage. This configuration not only allows more people to utilize solar energy but also guarantees a strong and stable power supply independent of the climate. Meanwhile, the hybrid arrangement combines grid connectivity with battery backup, thus securing the continuous availability of power if the grid fails or there is a power outage. [15]

I. 7. 1. Grid Versus Off-Grid

Areas that are distant and use portable systems have batteries as their only energy supply, however being in a city they can choose if getting connected to the network or to have their energy that is based on the capacity and current demand. The integration of the network can enable to return the electricity left over from the solar panels to the grid during the day and to pull power from the grid at night [16]. The difference in expense between buying a converter from DC to AC with a grid controller instead of using batteries is proportionally related to the scale of the system. One of the benefits of being grid-dependent is the lower risk of having to change batteries, which are expected to be the main issue with stand-alone systems in the long run. However, a disadvantage of the grid connection option is the requirement for an adequate number of solar panels to ensure the system’s generation of power is at a level that utility companies will accept.

The grid-connected systems most importantly have to satisfy the technical side of the integration including voltage regulation, frequency synchronization, harmonic distortion mitigation, power factor optimization, and rapid response capabilities [16]. The power output of a solar photovoltaic system decides whether it will mitigate electricity expenses or be a net power generator that could be sold to the utility provider. As the use of air conditioning goes up, so does the demand for energy during the summer period, which places much strain on the grid. Solar panels could be the most reliable option since they produce power right at the time of highest temperatures [16]. Key Components of a Grid-Connected System:

- ❖ Direct current to Alternative current Converter: The converter is used for the purpose of voltage stability.
- ❖ Maximum Power Point Tracker (MPPT): It is a booster converter for the individual panels and a buck converter for multiple interconnected panels [16], improving efficiency .
- ❖ Capacitor: It reduces voltage and then the DC-AC converter is the one that will smoothen the flow of the current.
- ❖ Inverter: The inverter regulates voltage and frequency to conform to the grid standards.
- ❖ Controller: Tracks the grid frequency at regular intervals and then compares it with the output of the inverter so as to stabilize energy distribution.

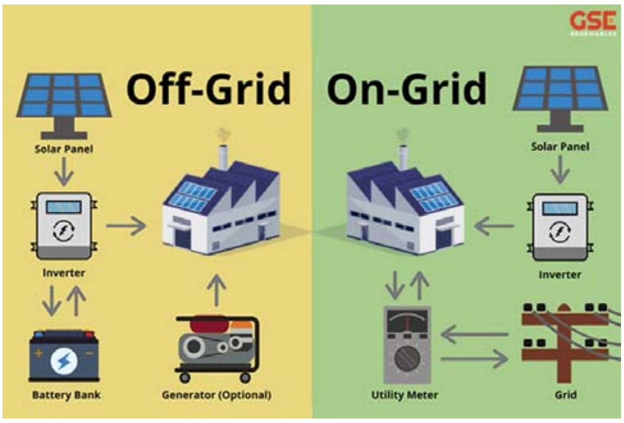


Figure I.10. The Difference Between the On-Grid and Off-Grid Solar Power System.

I. 7. 2. Hybrid Systems

A hybrid system is a structure that combines the functionalities of a stand-alone and grid-connected system. It uses a variety of subsystem controllers which regulate energy distribution and support the utility during the operation, store excess energy, and ensure the energy flow between the system and the grid is managed properly. The basic parts of a hybrid system that are presented in the figure 2.9 above are the solar panels, a Maximum Power Point Tracker (MPPT), the charge controller, storage batteries, and an inverter [16].

The charge controller takes care of the batteries, decides if there is a need for charging, the smart inverter that is coupled with the grid and the system processes the detection of the power failure. Thereby, the system provides a secure power supply of the grid disconnected from a grid and a backup power system which can also supply power to the main system in case of a grid outage. The system employs the same tools as before, albeit some of the parts need to be changed or adapted. Despite these changes, the advantages of the system remain in place. It is possible to use a hybrid system in an industrial situation as the system is still reliable though a little expensive. To be precise, in areas where the loss of power can bring the production to a halt, people could use this hybrid system as a power backup to keep the machine running even when there is a grid fault.

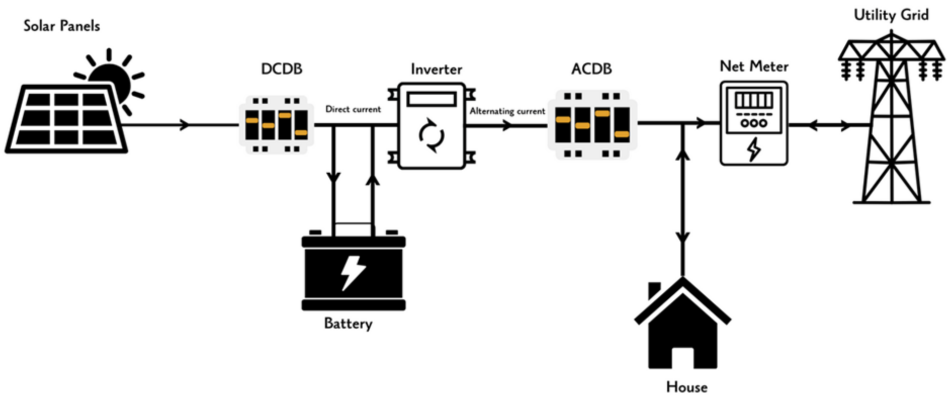


Figure I.11. Hybrid Solar System Diagram

I. 7. 3. Stand-alone solar systems

The immediate applications of solar energy were in space satellites, in which the power supplies at first were internal sources and lasted only a few weeks or months. A solar cell integration that extended the operation time for a number of years was introduced in the satellite designs. The knowledge derived from spaceflights were then implemented in off-grid areas where electrical infrastructure is not present and the electricity is mainly produced using diesel generators [15]. As the price of fuel is rising, underdeveloped countries have become more and more interested in solar energy. Thus, at present, the mission of international innovation and technology was then set to an effort [15].

Regions that are not connected to the central grid and are requiring power constantly uses solar panels for the primary source of energy and fuel-powered generators as the backup power sources [17]. The configuration of solar panels loaded with the reserve electric power is that when there is a decrease in solar radiation, it can function the same, and there are other systems with an excessive number of batteries that still can produce high power [17]. Due to drastically higher costs which come from the transportation of the fuel, usage of only solar panels is necessary as the emergency stop .

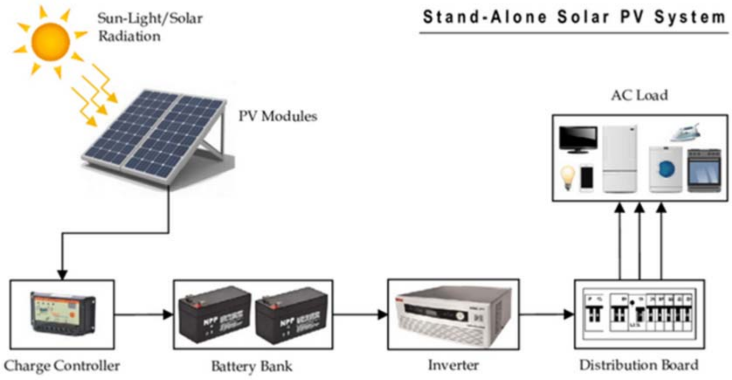


Figure I.12. Configuration of stand-alone solar PV energy system.

Stand-Alone Systems have the capacity to power the electricity needs of small scale applications like streetlights and water pumps or load larger areas such as residential properties. The basic parts of such a system are the photovoltaic panel, a charge controller, and a battery. Should AC (alternating current) power be mandatory, an inverter becomes an indispensable element of the whole set-up. In relation to this, a Maximum Power Point Tracking (MPPT) is so devised to steer the voltage and cut down the losses to the minimum in transferring energy power to both batteries and loads. The diversified system specifications depend on the need of the location being served, especially on the required energy in nighttime, which demands accurate calculations so as to determine the battery storage and panel capacity. The reliability is the final factor and it includes the powerfulness and steadfastness of the system.

Advantages:

1. They do not need to be interconnected within the electric line and are, therefore, self-reliant.

2. They can provide communities with the electric power supply that is independent of diesel and gasoline, increasing access to clean technology.

3. They are cheaper in areas that are difficult to reach by the utility company than the extension of power lines.

I. 8. Conclusion

The intention of this chapter is to provide a holistic and coherent insight into the photovoltaic (PV) technology sector by demonstrating the fundamental ideas that form the paradigm of the field. The first step we took in the chapter was to explain the meaning of photovoltaic energy and stating the general principles that are used for the sun's energy transformation into electrical energy, underscoring the concept's significance without dealing with its details.

We then moved on to enumerate the general categories of the materials that are used in the construction of solar cells and at the same time showing the heterogeneity in the structure and properties of these materials that reflect the constant growth in this crucial sector. Additionally, we touched on the environmental and operational factors that are responsible for the productivity of photovoltaic cells with the purpose of underlining the key role that they play in determining the real-life performance of PV systems.

We also brainstormed a few key advantages and obstacles associated with the operation of photovoltaic systems, with a special focus on the possible threats resulting from lack of balanced regulatory policy, disproportionately high costs, the environmental, and the technical issues. By the same token, we were outlining the most frequent applications in the different types of systems, and no matter the application is in a network of connected systems or the standalone isolation types, the same broad area is covered therein.

CHAPTER –II-

Cooling systems

Chapter –II- Cooling systems

II. 1. Introduction

Solar energy is considered to be a clean, renewable source for thermal and electrical energy since photovoltaic solar panels are now widely utilized, with low operating costs and environmental impacts compared to fossil fuel power plants. While the price of solar panels continues to decrease thanks to technological advancements, their initial cost is higher than that of conventional power plants. They are, however, expected to become more competitively priced in the near future. It is true that photovoltaic panels have low efficiency due to the heat they generate, which in turn, raises their temperature and subsequently harms their performance. Research shows that every 1°C rise in temperature directly causes efficiency to drop by 0.5%, thus requiring investigation into water and air cooling methods, low thermal conductivity materials, solar tracking systems that improve energy capture, as well as the creation of hybrid panels designed for simultaneous electricity and thermal energy production. Due to innovative advancements, solar panels are expected to become cheaper and more efficient, increasing their adoption rate and promoting a sustainable energy future.

II.2. The Need for cooling

Externally, solar panels are influenced by climatic factors (variables) like sunshine, wind speed, moisture, temperature, and dust. In controlled environments like the Building Integrated Photovoltaic (BIPV) systems mounted on the surface of buildings, efforts are aimed at the reduction of the operating temperature, vertical surfaces (facades) which are not easily angled toward sunlight present unique challenges). Hence, various overheating solutions cooling techniques have been developed and reviewed to address the concern of overheating and effectiveness.

II. 3. Cooling Technologies Classification

The approaches taken to cool solar cells can be divided into two broad groups:

II. 3. 1. Active Cooling

This type requires the use of cooling fluids, e.g. air or water, and energy to operate fans or pumps [18, 19]. Increased energy use is always a negative economically. The balance of consumption and giving out energy is critical when thermodynamic output of solar cells is taken into account.

II. 3. 2. Passive Cooling (natural cooling)

This approach utilizes wind, water, and solid state materials to control heat in space that needs to be regulated. It is built on three basic techniques:

- Ventilation Cooling
- Hydro Cooling
- Conductive Heat Cooling

Supporting silicon structures, often called heat transfer pipes or cooling tubes combine one or more radiators called heat sinks [20].

Self-cooling is a new self-sustaining phenomenon that helps conserve resources and capital.

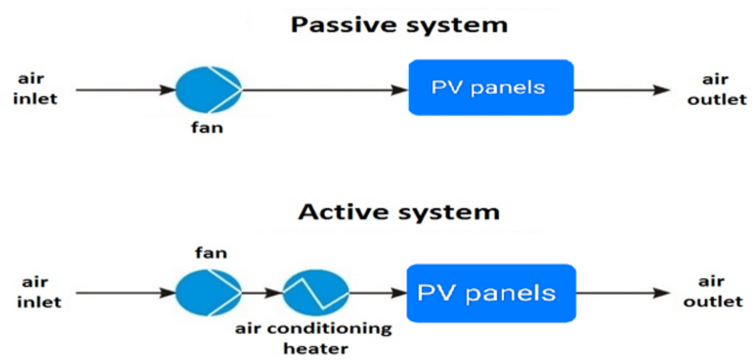


Figure II.1. Active and passive cooling systems

II. 4. Air cooling

Natural airflow cooling is the easiest and the least expensive way which does not lead to the usage of electricity. However, the efficiency is not the highest due to the low density and volumetric heat capacity of air as well as its thermal conductivity. The method could be improved by using wide finned surfaces, similar to metallic surfaces, or by integrating photovoltaic (PV) modules into the exterior walls of buildings in such a way that there will be a space allowing the air to flow between the panels and the walls. The temperature of the PV panels, in this case, drops to 50-70°C.

While cooling through forced air ventilation, an outdoor experiment executed in Singapore reflected an increase of the insulation capacity of PV panels from 8-9% to 12-14%. The place is not hot, as the maximum air temperature there only reaches up to 31°C, which in turn ensures that this cooling system works effectively .[21]

II. 5. Water Cooling

II. 5. 1. Front surface water cooling

II. 5. 1. 1. Definition

One of the best active cooling technologies that air the front side of solar panels with water guarantees that the surface temperature is even and it helps in the extraction of scattered dirt particles [22]. This technique can be a cause of approximately 9% increase in the power efficiency of solar panels where different cooling rates will depend on the velocity of water flow through the system.

In the paper released by (**K. A. Moharram**) and other authors, the study of the performance of PV panels was carried out using water cooling as means of lessening water consumption and the electrical power for cooling, in particular, desperate cases of extremely hot and arid places like desert areas [23]. They developed a spray jet-based cooling system in which the cooling starts at the point when the PV surface temperature has already reached the maximum allowable value, according to the model used. Figure.II.2

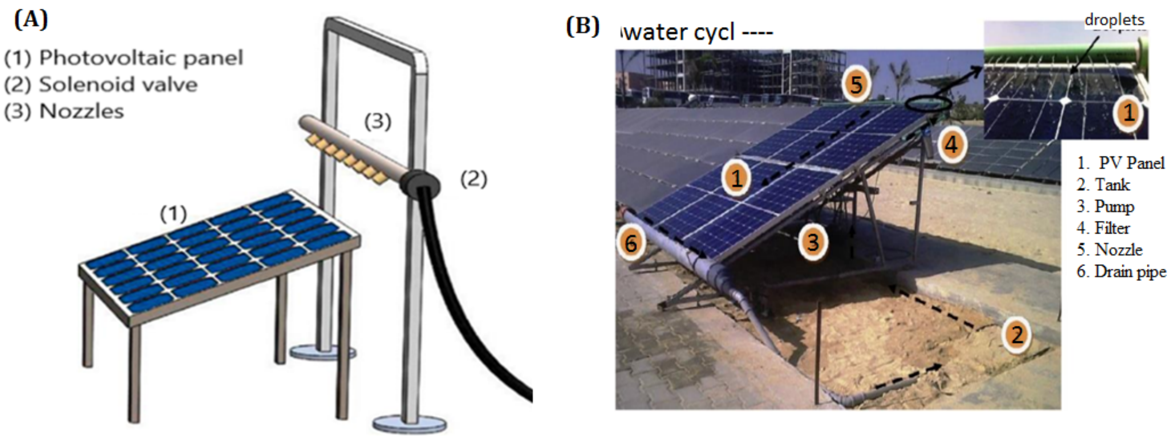


Figure II.2. (A) Schematic diagram of the PV with cooling sprayers[24],
(B) Experimental system [23]

II. 5. 1. 2. An Additional Benefit of Surface Cooling for Solar Panels.

Solar panels cleaned with water do not simply eliminate dirt and other waste, but also create a cooling effect which makes their efficiency higher. When the dust is accumulated frequently in certain areas, like deserts, and no cleaning action is taken, the presence of the dirt layer becomes a serious hurdle which weakens the performance of the solar panel by blocking sunlight and can even cause an energy output reduction of 30% within a month. On the other hand, water-based cleaning can be used to remove such obstacles and to ensure that the level of light reaching the panels is the most suitable, which in turn will make the photovoltaic conversion better. Moreover, the increase in the energy of the water generates a cooling effect that allows the panels to control their temperature, thus reducing the adverse effects of the excess heat that would have otherwise happened to the panels.

The regular maintenance of the panels leads to the sustainability of their lives by reducing overheating and minimizing material wear caused by the accumulation of the dust layers. The solar industry is going to unveil solutions that are aimed at optimizing water consumption while keeping the efficiency at the highest possible peak, such as recycled water systems and self-cleaning mechanisms. Recycled water systems and self-cleaning mechanisms are the answer to the increasingly hostile solar panel domain and their relevance to the environment is great and at the same time, the impact of building them is minimal. [25]

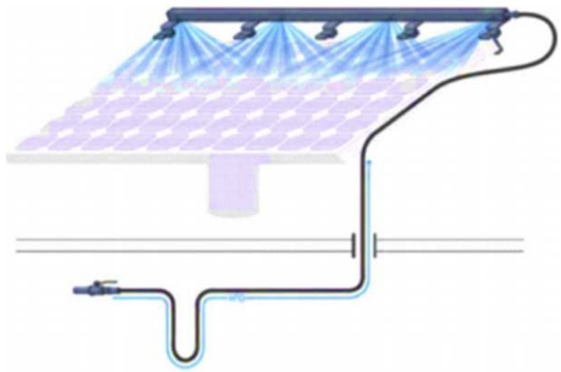


Figure II.3. A view of Water spraying [25]

II. 5. 2. Back surface water cooling

Backside of the photovoltaic panels was cooled through the water by spraying, which was then gathered and directed to the receptacle. A re-circulatory mechanism containing borehole heat exchanger is used for clean water that is used to further increase the cooling effect of the system, and next, water is re-cycled through the panels so that they are cooled down again in addition to the other cooling methods, as portrayed in Figure re 15. [7, 26]

Water cooling can also function on the lower side to improve heat conduction or as a protective shield. Yet, it is of less force than the cooling of the upper side in the temperature reduction.

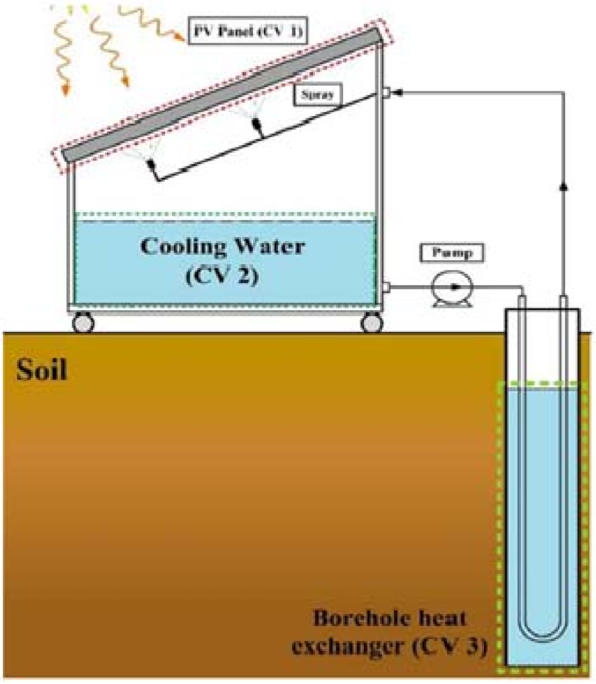


Figure II.4. System diagram [26]

II. 6. Cooling using Phase Change Materials (PCM)

The range of temperature within which a phase change material operates dictates its selection. These materials can be obtained both in laboratories and commercially, and they can be classified into three categories: inorganic, organic, and eutectic mixtures. Thermally, most of these materials do not possess the all requisite features for storage which makes it critical to choose the most economical option that fulfills the required property for the system.

Utilizing phase change materials on the photovoltaic modules' rear side aid in keeping the temperature at the module's melting point. These materials can absorb a certain amount of heat during the phase change from solid to liquid and release the heat when reverting to solid, thus helping in thermal stabilization. Furthermore, the control of temperature regulation is to be done while considering the quantity of the material analysis and the time required for the analysis. Since the system is built to work under a varying climate, defining the properties of the material poses a significant challenge. Alternative approaches must be sought owing to the system's continuous changes in solar radiation, external temperature, wind speed, and the substantial impact these parameters have on the corners of the photovoltaic module and the phase change material. [7]

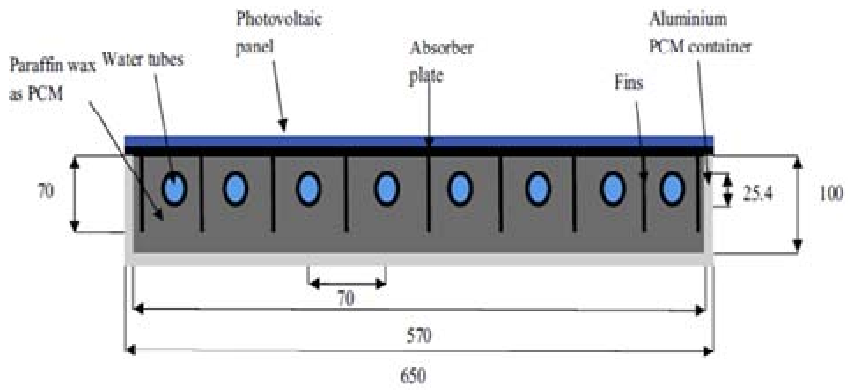


Figure II.5. Schematic diagram of water based PV/T-PCM system (dimensions in mm) [27]

II. 7. Peltier

Thermoelectric (T.E.) cooling is also a technology used to reduce the temperature of P.V. panels by converting excess heat into electrical energy. The system operates based on the Peltier effect, which allows the panel to be cooled using electrical energy. The fundamental principles behind thermoelectric cooling include the Peltier effect and the Seebeck effect. In a specific direction, the Peltier effect induces a thermal flow at an electrified junction, resulting in heating on one side and cooling on the other. The heating/cooling flow rate depends on temperature differences and electrical voltage/current. Najafi and Woodbury [28] developed a model for P.V. cell cooling using a Peltier element, demonstrating the feasibility of integrating thermoelectric cooling for high-concentration P.V. cells. A study conducted by Borker et al. [29] experimentally evaluated thermoelectric cooling in P.V. modules, revealing an efficiency improvement from 8.35–11.46% to 12.26–13.27%. Benghanem et al. [30] observed that the temperature of P.V. cells decreased from 83°C to 65°C using T.E. modules. For reliability, the energy consumption of the T.E. module should be significantly lower than the electricity produced via cooling P.V. panels.

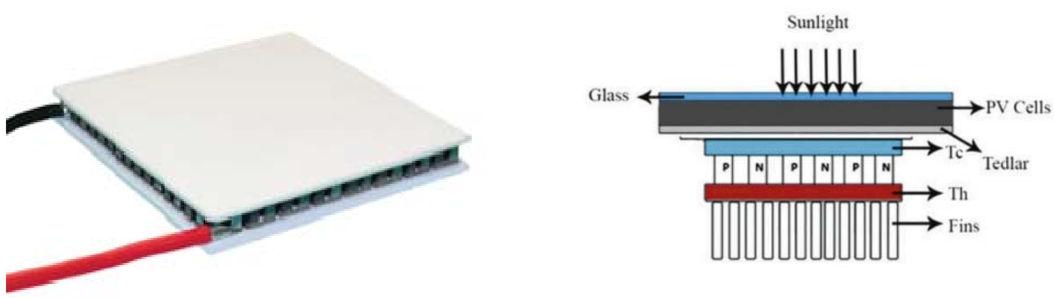


Figure II.6. Peltier effect [31]

II. 8. Fins

II. 8. 1. Definition

Fins is a term used to describe these parts or components which are used to enhance the cooling or heating capability of a device by providing additional surface area for heat transfer.

Fins can be found in home heating radiators, car radiators, as well as in the microprocessors of electronic systems [32].

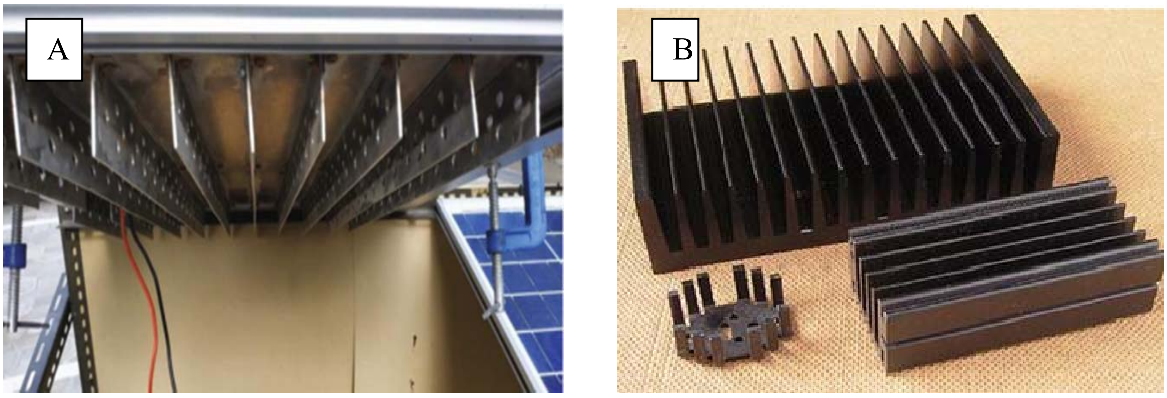


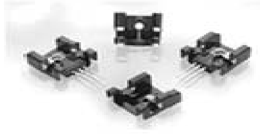
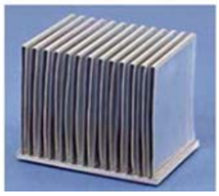
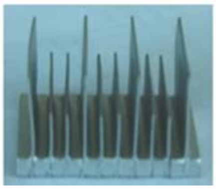
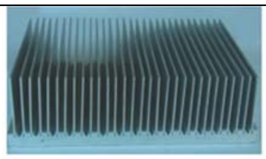
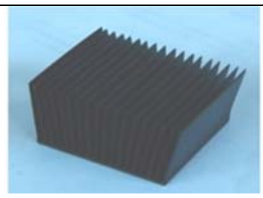
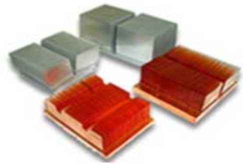
Figure II.7. A, Heat sink configuration on the back of the PV panel

B, passive cooling systems by air. [7]

II. 8. 2. Selection of Fins

Fins are fitted when large quantities of heat needs to be removed in small volumes such as car radiators, air cooled engine casings and evaporators in air conditioning systems. Fins are more effective with liquids than with gases because the former allows for greater convective heat transfer. Gases, even if they have a lower transfer rate, do benefit from the presence of fins. Compared to wider and more spaced apart fins, narrow and closely spaced ones perform better. While increased spacing yields better results, efficiency is lost due to pressure losses if the spacing is minimized too much. Furthermore, fin performance improves with higher thermal conductivity (λ). Fins are chosen based on a trade-off between cost, pressure losses and the rate of heat transfer. Table II. 1. [33]

Table II. 1. Classification of fins types

Extruded	**Stamped**	**Bonded**	**Folded Fin**
			
Heated metal is forced through a profiled die	Metal stamped to form a particular shape	Individual fins are bonded with epoxy to a pre-grooved base	Fins are pre-folded and then brazed or soldered to a plate base
Single fin Assembly	Swaged	swaged	Skived
			
Individual pieces of fin and spacer material are stacked and then brazed to create the desired shape	Individual fins are placed in a pre-grooved base and then a roller or punch will swage the sides to the fins	Heated metal is compressed into a form mold to the desired shape	Fin are skived from a solid piece of Material, usually copper

II. 9. Caloduc

II. 9. 1. Definition of a Heat Pipe (Caloduc)

A heat pipe is a heat transfer device that is very much efficient, and its principle of operation is based on a phase transition of a volatile liquid, which then is used for transferring heat between two solid surfaces. During the process, the liquid is heated and thus evaporates and then travels as a gas through the pipe to the other end, where it condenses, and there the heat stored is released. Finally, the liquid gets back to the hot end by means of capillarity, gravity, or centrifugal force; hence the cycle can go on.

Perfectly, extremely high is the thermal conductivity of the heat pipe, recording even 100 kW/(m·K) for a long pipe, while copper is about 0.4 kW/(m·K) which is only 0.4% from the heat pipes, what makes them very good heat transfer solutions [34,35]. The canal formed in the pipe wall allows efficient transfer of heat. In addition, the heat transfer is still a little limited. What's more, the working fluid should be of a minimum temperature to ensure the process is effective. Surprisingly, an unplanned increase in the heat transfer coefficient over the original design can actually cause a negative effect, by depleting the heat pipe's performance rather than improving it. In the same way, the use of a fan as part of the heat pipe system could potentially work against it, as this could lead to a significantly reduced cooling efficiency.

Consequently, not only the operating temperature of the pipe but also the maximum heat transfer capacity are dependent in the closest way on the capillary structure or other methods by which the liquid is returned to the hot area such as gravity or centrifugal force [36].

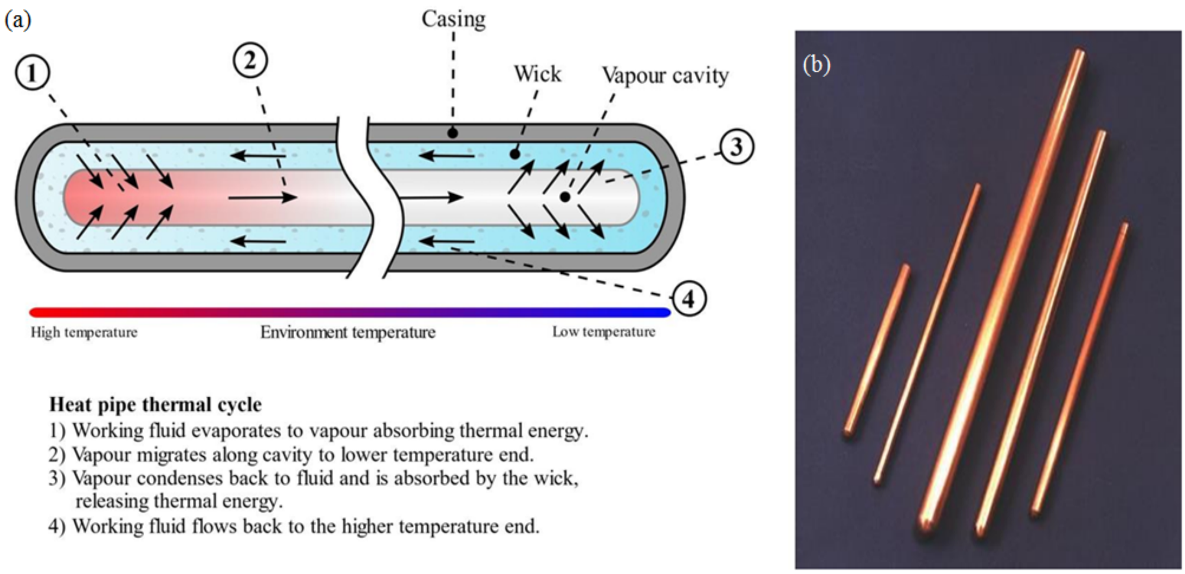


Figure II.8. (a) Schematic figure of the components and the mechanism of a heat pipe containing a wick. (b) real pipe.

II. 9.2. Caloduc materials and working fluid

II. 9.2.1.The three main Components of Heat Pipes

Main Parts of Heat Pipes:

1. The outer case
2. The internal wick
3. The working fluid

II. 9.2.2. Thermal Performance and Selection of Materials:

For heat pipes which are used in operation without maintenance, the most important thing for long-life, good performance of the heat pipe system is the compatibility of the container, wick, and working fluid. The thermo-syphons were reinvented in 1963 and since then there have been many years-long studies that have been done to evaluate material and liquid compatibility, with some tests that have lasted for many decades. These studies examine the possible appearance of several issues, such as non-condensable gas formation, material transport, and corrosion [37].

Envelope material/wick combinations, together with working fluids that are widely used [38]:

- ✓ Copper / Water: In the field of electronics, it is the most used cooling system.
- ✓ Copper or Steel / R134a Refrigerant: This combination is suitable for energy recovery in HVAC systems.
- ✓ Aluminum / Ammonia: This couple is necessary for space vehicle thermal management.

II. 9.2.3. Heat Pipe Application by Envelope Material and Working Fluid:

- ✓ Super alloy / Alkali Metals (Cesium, Potassium, Sodium): This couple is reused in high-temp. heat pipes, especially for the primary temperature calibration.
- ✓ Stainless Steel / Gases (Nitrogen, Oxygen, Neon, Hydrogen, Helium): This pair is well suited to pipes that work at below the level of 100 K.
- ✓ Copper / Methanol: This application is used when the electronic equipment must operate at lower temperatures than water.
- ✓ Aluminum / Ethane: This couple is in the spacecraft thermal management when ammonia is likely to freeze out.
- ✓ Refractory Metals / Lithium: They are suitable for uses higher than 1,050°C (1,920°F) [39].

II. 9. 2. 4.Types of Heat Pipes:

- ✓ Vapor Chambers: It distributes heat over surfaces which are seemingly flat.
- ✓ Variable Conductance Heat Pipes (VCHP): This is a technique that uses heat to turn a gas non-condensing.
- ✓ Pressure-Controlled Heat Pipes (PCHP): These types are designed to regulate temperature precisely.
- ✓ Diode Heat Pipes: They will accept a huge amount of heat flowing in only one direction.
- ✓ Thermosiphons: They change the phase of the liquid back to the heat end with the help of gravitational force.
- ✓ Rotating Heat Pipes: It takes advantage of centrifugal forces to get the liquid back to the evaporator.

They are all designed to fit their purpose and the applications for each of the types differ, such as electronics cooling and advanced thermal systems, specifically. [39]

II. 10. Microchannel heat exchanger

One of the common cooling methods among the various, the so-called heat exchanger technology is a process that efficiently transfers heat from one medium to another or between different fluids. The best efficiency of the process is at high temperatures. The flow rate of the cooling medium can be an optimum one utilizing CFD analysis to reach the maximum efficiency.

Microchannel cooling is quite a good solution to ensure photovoltaic (P.V.) cells to remain within their optimal performance range. Also, microchannels can be used as P.V.T. hybrid systems.

Aluminium fins with the help of wind can be very helpful in photovoltaic cell cooling. Although, among the major challenges that still need solutions for its further adoption are the feasibility of the experimental setup scaling up and the improvement of microchannel manufacturing efficiency.

II. 11. Radiative sky cooling (photonic cooling)

The cooling of the photovoltaic panels that are affected by the combination of the condition of the atmosphere that allows for transparency in the 8-13 μm wavelength band and the sky, which functions as the heat sink. To cool the P.V. cells the solar power point is being studied and the contrast between the atmosphere and the outer space, which used to dispose of the heat, was the main idea that the radiative cooling theory was based on.

The description of the experimental radiative cooling device is the contributions that lead to the new idea emerging in the field of solar energy (Figure II.9) [40]. The researchers Zhu et al. made the first step in their most recent research by testing radiative cooling using solar absorbers. It was also successfully demonstrated the feasibility of the cooling structure a transparent photonic structure sharing its function between sunlight transmission and blocking of infrared radiation, when deployed below a solar panel, without causing any shades on the panel.

The temperature of solar cells decreased by as much as 13°C when radiative cooling was exerted. Radiative sky cooling acts as a passive cooling process that is employed in the thermoelectric generator systems to keep the cold side at temperatures lower, taking advantage of the thermal gradient between the Earth and the outer space. [41]

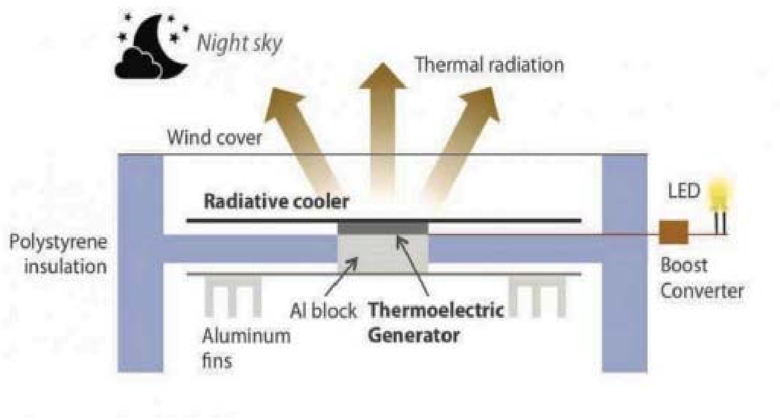


Figure II.9. Passive Radiative sky cooling.

II. 12. Nano-fluid based cooling

The performance of photovoltaic (P.V.) panels is enhanced using nano-fluids, which consist of nanoparticles mixed with water to improve heat transfer [42]. Different nanoparticles are utilized in varying weight percentages to optimize efficiency [42–44]. The nanoparticles used include:

- Boehmite
- Aluminium oxide (Al_2O_3)
- Zinc oxide (ZnO)
- Titanium oxide (TiO_2)
- Magnetite (Fe_3O_4)
- Silicon carbide (SiC)
- copper oxide (CuO)

II. 13. Evaporative cooling Evaporative

Evaporative cooling is an effective technique that leverages water evaporation to lower the temperature of P.V. panels, similar to how sweat cools our skin on a hot day. The process relies on the evaporation of water interacting with surrounding air to achieve thermal equilibrium. Evaporative cooling is one of the most practical and promising methods for heat management in P.V. systems. Although the expected benefits of evaporative cooling are high, only a limited number of studies have adopted this approach. The significant aspects of evaporative cooling are:

- Ease of implementation.
- Much lower cost
- The strategy works well in hot and dry climates (see Figure II.10).

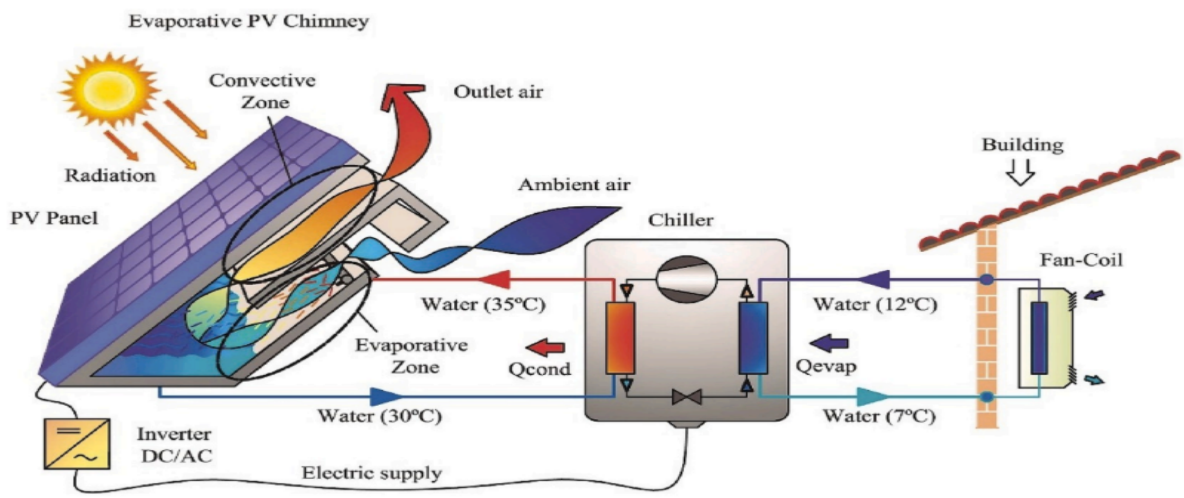


Figure II.10. Scheme of Evaporative P.V. cooling scheme proposed [45].

II. 14. Spectrum filter cooling (optical beam spiltter)

Optical beam splitters are also referred to as spectrum filters and they work by allowing a certain range of light, while the rest is reflected or absorbed. Among the fluids used in PV collectors are a variety of vapour, organic liquids, and nano-fluids that function as selective absorbing fluids or as optical filters [46, 47]. One of the strategies to achieve optoelectronics performance greater than 30% of conversion efficiency is to use a liquid as an optical filter between sunlight and solar cells (Fig. II.11). The use of liquid filters can also be seen for direct sun illumination of solar cells. This is called the low-concentration photovoltaics-inverted pyramid-tandem with a **Lagoda**'s liquid filter and the lamp so that the light drilling down multi-junction tandem cells. The optical beam level could be adequate for the pip environment, which is easy to handle. Liquid, translucent filters may be automatically controlled by the solar trackers using glocal intelligence at the village, district, regional, and global levels for operation or by a timely scheduled robot. Heat, pollution, ozone layer destruction, and intensive sunlight at certain times of the day are transmitted, and they have to be filtered by the natural environment. Solar radiation in the range from ultraviolet to near-infrared can be intercepted by easily detector-equipped magnetic and folded with temperature-optimal liquid filters. [48–50]

- coconut oil,
- silicone oil,
- glycerine,
- ethylene glycol, etc.

There are good examples of liquid filters. Being the oil that holds the Zoo, he has explored the use of common household food products for the extraction of bio-hydrogen that is used in algae production to achieve zero pollution in the cell of an algae reactor. Exhausted mineral oil as an optical filter that is effectively applied

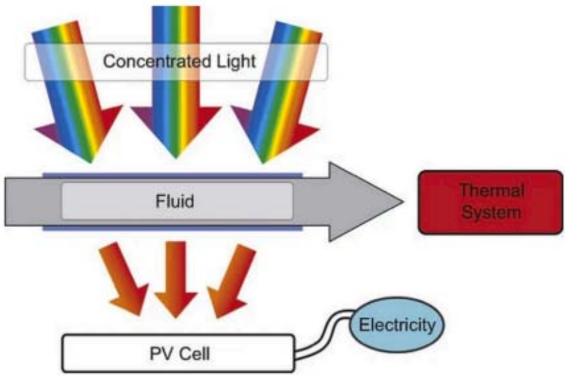


Figure II.11. Sketch of the P.V. cell using a fluid as optical filter [47].

II. 15. Hybrid/multi-concept cooling systems

Hybrid PV/T systems consist of a photovoltaic module integrated with a thermal absorber, where optimizing both electrical and thermal performance simultaneously is challenging. Technically, hybrid PV/T solar collectors can be designed to achieve up to 80% of total capacity. However, research on various hybrid cooling systems using configurations such as PV/T + PCM, PCM + nanofluid, heat pipe + heat sink, and heat sink + PCM remains limited.

The integration of nanofluid with a PCM-based PV/T system has been studied and compared to conventional PV modules [51]. In an experiment conducted by **Karami** et al, water-based Boehmite at a concentration of 0.01% was used for cooling photovoltaic panels, leading to a 27% efficiency improvement [52].

II. 15. 1. Key Features of the Integrated PV System

- ☒ -Operates within a temperature range of 30–100°C.
- ☒ -The design must balance the reduction in PV cell efficiency with the enhanced thermal system performance at higher temperatures.
- ☒ -These technologies offer significant economic benefits for residential and commercial applications with high electrical and thermal energy demands

II. 16. Conclusion

Throughout this chapter, we were familiarized with the basic principles and tactics in the thermal management of photovoltaic systems. It was explained how the temperature plays a crucial role in the efficiency and performance of the solar cell. We started by making an attempt to clarify the idea of cooling and then we indicated and detailed the main factions of methods of heat prevention in the solar panels. The goal was the broadest possible presentation of ways to cool, e.g., air and water-based realizations, use of innovative materials like phase change material, thermoelectric module, and special items such as fins, heat pipes, and micro channel exchangers. Further, we showed other solutions such as radiative cooling, Nano fluid applications, evaporative systems, and spectrum filtering that is a signal of growth in the R&D of this sector. With these solutions in all, we pinpointed the need to marry the correct thermal management system with the photovoltaic system, with the aim of lengthening the life of the system, achieving the highest operational efficiency, and making the whole system convenient for the usage under different climatic conditions.

CHAPTER –III- expérimental study

Chapter – III- Expérimental study

III. 1. Introduction

Solar energy is a promising renewable resource for a carbon-free future. However, increased solar panel temperature significantly reduces efficiency, lowering generated current, voltage, and power. This limits their economic viability in hot regions. This experimental study aims to address this challenge by testing active cooling techniques to enhance solar panel performance.

This chapter generally deals with the performance of solar panel when utilized the two different liquid as the cooling liquid; water and ethylene glycol. The first direct effect of the cooling method on the panel's temperature will be studied and then this will be followed by observations of the consequences on the main electrical variables such as the current (I), the voltage (V), and the generated electrical power (P). This chapter is going to describe the comparison of the thermal properties of both water and ethylene glycol as the cooling mediums, and then how these properties contribute to the whole cooling efficiency and solar panel performance..

The research sets out to give practical insights about the ideal heat management strategies for photovoltaic panels, allowing them to be used as reference for the designing of more efficient, reliable, and applicable solar systems in a variety of climatic conditions. The analysis of the thermal and electrical behaviors of the cooled panels will greatly help introduce innovative and sustainable solutions that will drive the promotion of solar energy as a primary source of the new energy landscape.

A- Definition: CATIA :

Acronym of **computer-aided three-dimensional interactive application**) is a multi-platform software suite for computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), 3D modeling and product lifecycle management (PLM), developed by the French company **Dassault Systèmes.**

Since it supports multiple stages of product development from conceptualization, design and engineering to manufacturing, it is considered a CAx-software and is sometimes referred to as a 3D product lifecycle management software suite. Like most of its competition, it facilitates collaborative engineering through an integrated cloud service and have support to be used across disciplines including surfacing & shape design, electrical, fluid and electronic systems design, mechanical engineering and systems engineering. CATIA is more popular, among the end users, for its better surface designing characteristics. That's why it is most widely used in automobile and aerospace industries.

Besides being used in a wide range of industries from aerospace and defence to packaging design, CATIA has been used by architect **Frank Gehry** to design some of his signature curvilinear buildings and his company **Gehry Technologies** was developing their **Digital Project** software based on CATIA.

The software has been merged with the company's other software suite 3D XML Player to form the combined Solidworks Composer Player.

CATIA started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault to provide 3D surface modeling and numerical control functions for the CADAM software they used at that time to develop the Mirage fighter jet. Initially named CATI (conception assistée tridimensionnelle interactive – French for interactive aided three-dimensional design), it was renamed CATIA in 1981 when Dassault created the subsidiary Dassault Systèmes to develop and sell the software, under the management of its first CEO, Francis Bernard. Dassault Systèmes signed a non-exclusive distribution agreement with IBM, which was also selling CADAM for Lockheed since 1978. Version 1 was released in 1982 as an add-on for CADAM.

During the eighties CATIA saw wider adoption in the aviation and military industries with users such as Boeing andGeneral Dynamics Electric Boat Corp.

Dassault Systèmes purchased CADAM from IBM in 1992, and the next year CATIA CADAM was released. During the nineties CATIA was ported first in 1996 from one to four Unix operating systems, and was entirely rewritten for version 5 in 1998 to support Windows NT. In the years prior to 2000, this caused problems of incompatibility between versions that led to $6.1B in additional costs due to delays in production of the Airbus A380.

With the launch of Dassault Systèmes 3DEXPERIENCE Platform in 2014, CATIA became available as a cloud version.

B- Relation temperature, PV production, friability

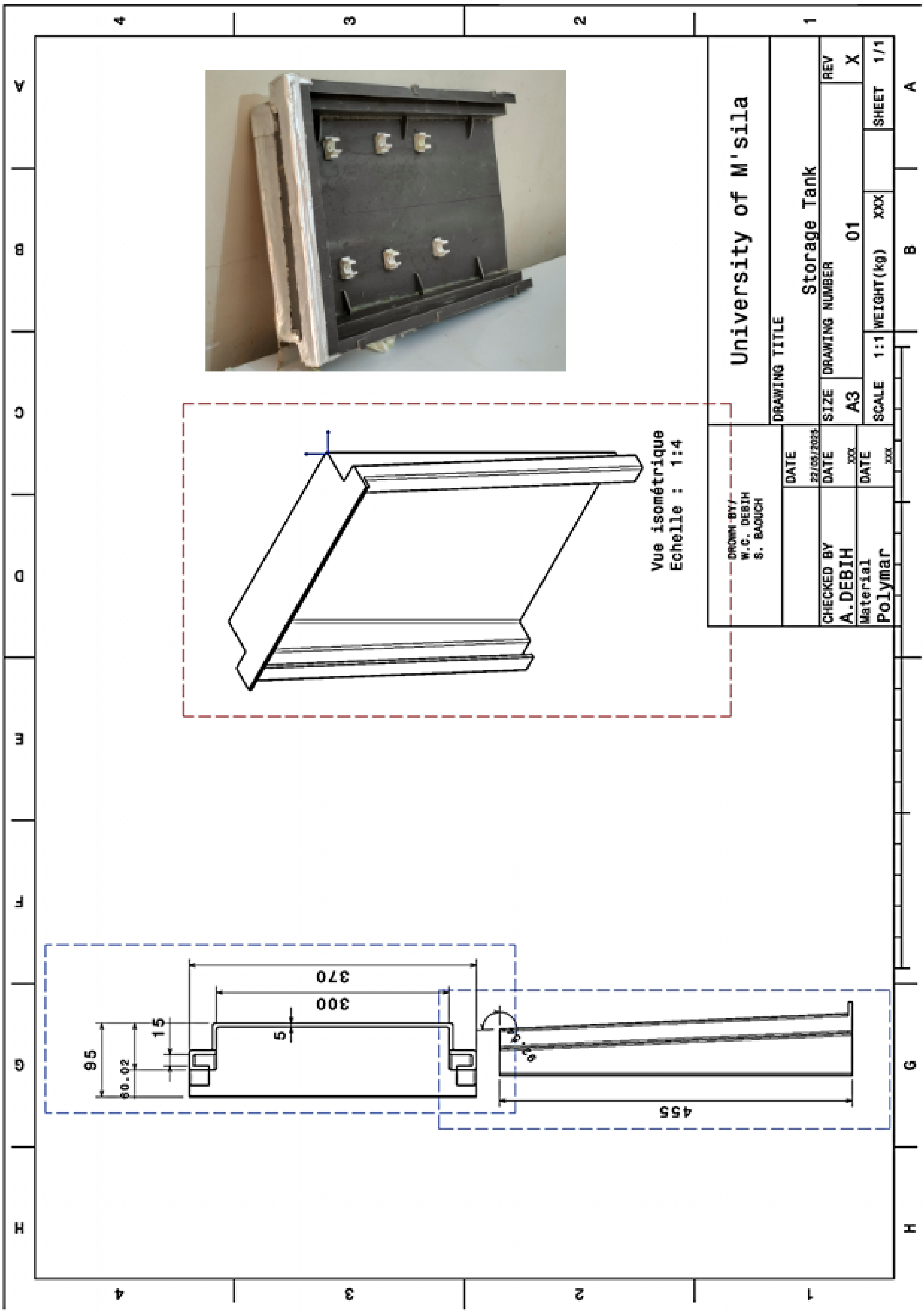
Temperature has a significant impact on the electricity production of photovoltaic solar panels. Generally, temperatures above 25°C reduce efficiency, while lower temperatures can slightly increase it. The reliability of solar panels is not directly affected by temperature, but extreme temperatures can affect their lifespan.

In this chapter we will present the effect of cooling on the efficiency and reliability of the photovoltaic panel; therefore the objective is to evaluate the thermal and electrical performance of this panel. In order to improve the operating conditions by cooling with cold water or by proposing an innovative geometric configuration. Thus, they are based on the modification of the cooling element on the change of the glycol water cooling fluid (**$C_2H_6O_2$**). These changes aim to increase the amount of solar energy absorbed and the heat transfers between the heat transfer fluid and the absorber or to reduce or even eliminate the external thermal increases of the solar collector.

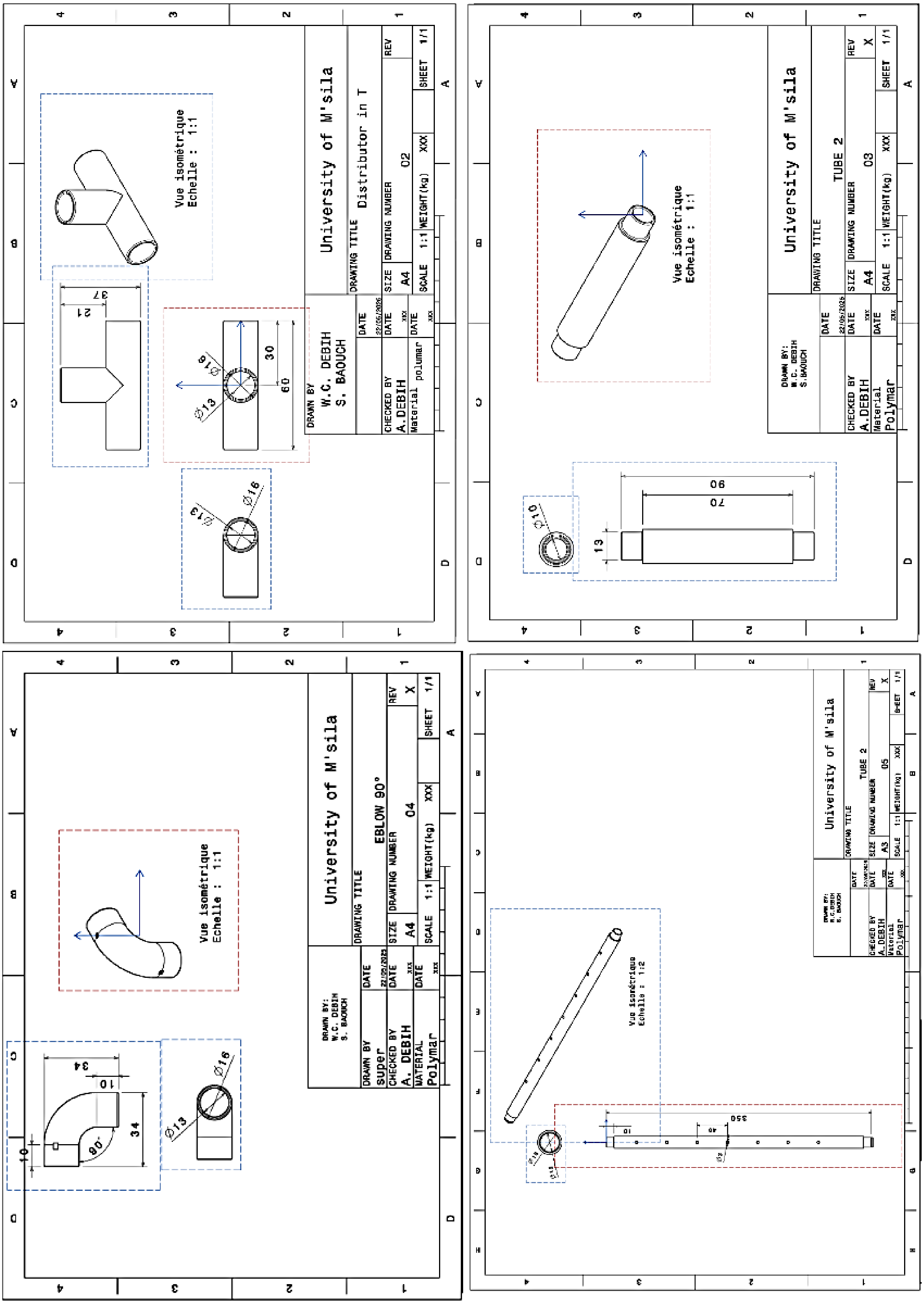
During photovoltaic conversion in the solar collector, heat is generated, thus increasing the temperature at the photovoltaic cell and causing a drop in its efficiency. This phenomenon is due to the part of the solar radiation not absorbed by the cells and which will cause its heating. On the other hand, this part of the absorbed radiation is lost in the form of heat. The objective of this work is to increase the electrical efficiency of the collector, that is to say its electrical output by reducing the operating temperature.

III. 2. From design to implementation of cooling system

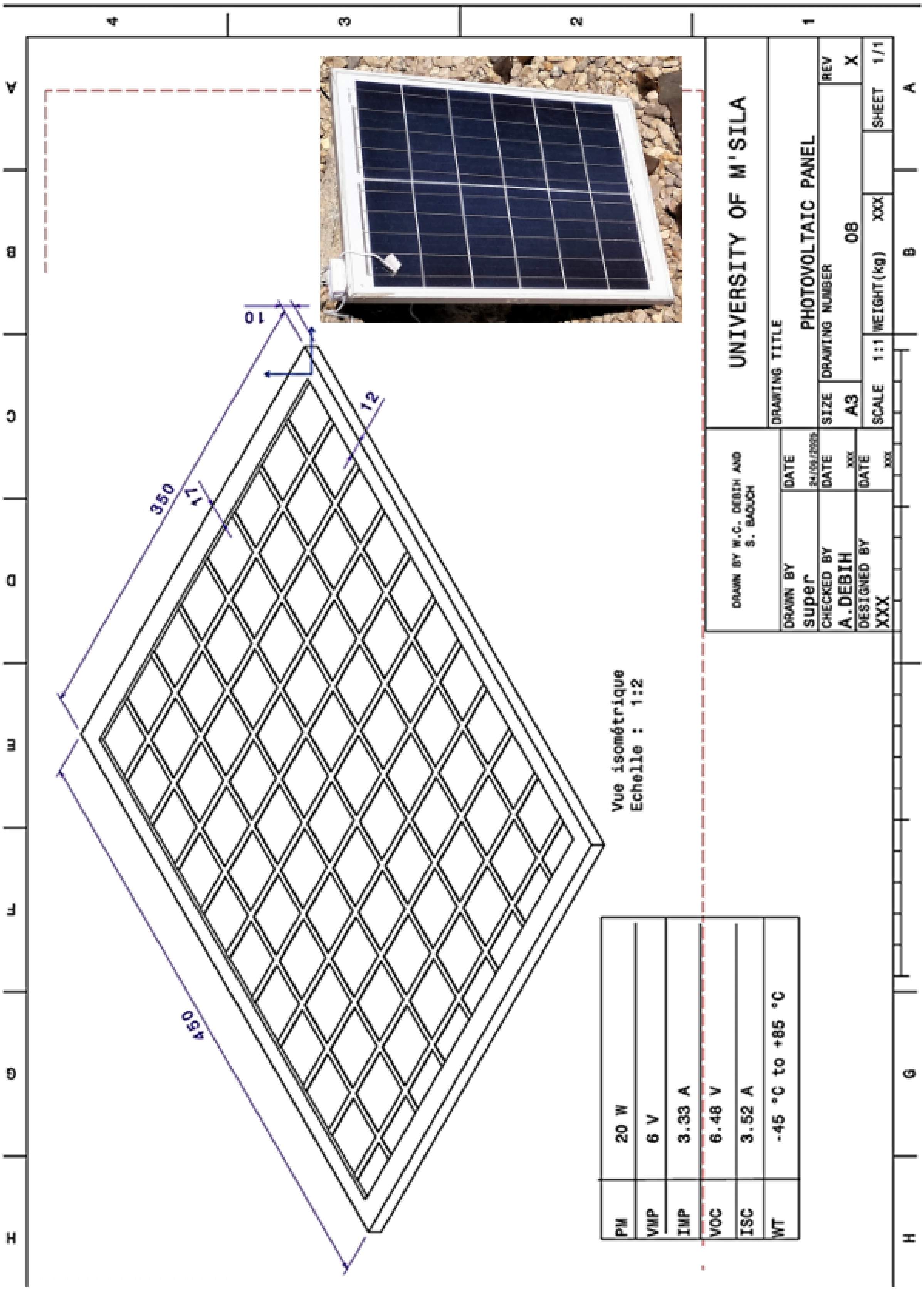
III. 2. 1- Storage Tank Figure III.1.



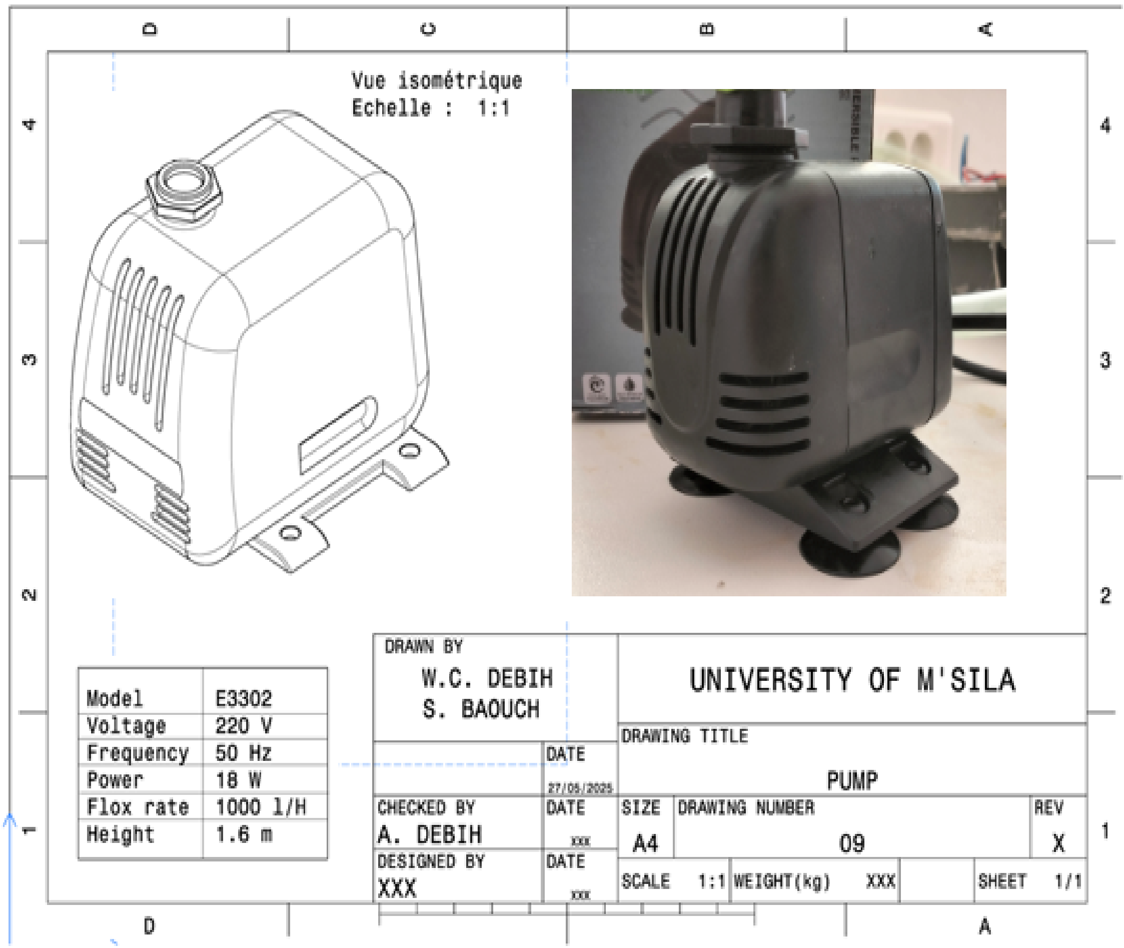
III. 2. 2- Eblow in T, Chort, long pipe ane eblow in 90°, Figure III.2.

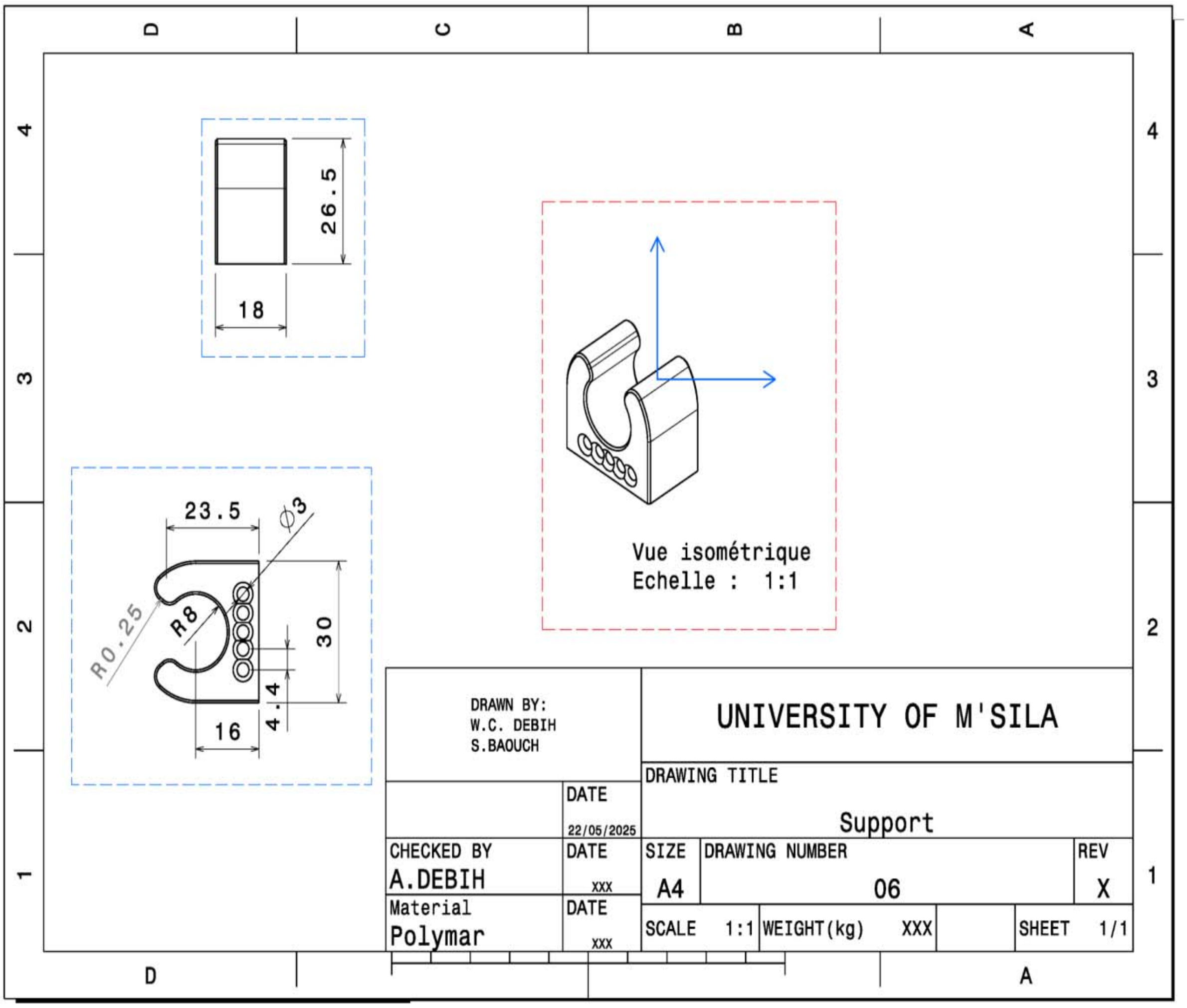


III. 2. 3- Photovoltaic Panel, Figure III.3.



III. 2. 4- Pump of alimentation and pipe supports, Figure III.4.

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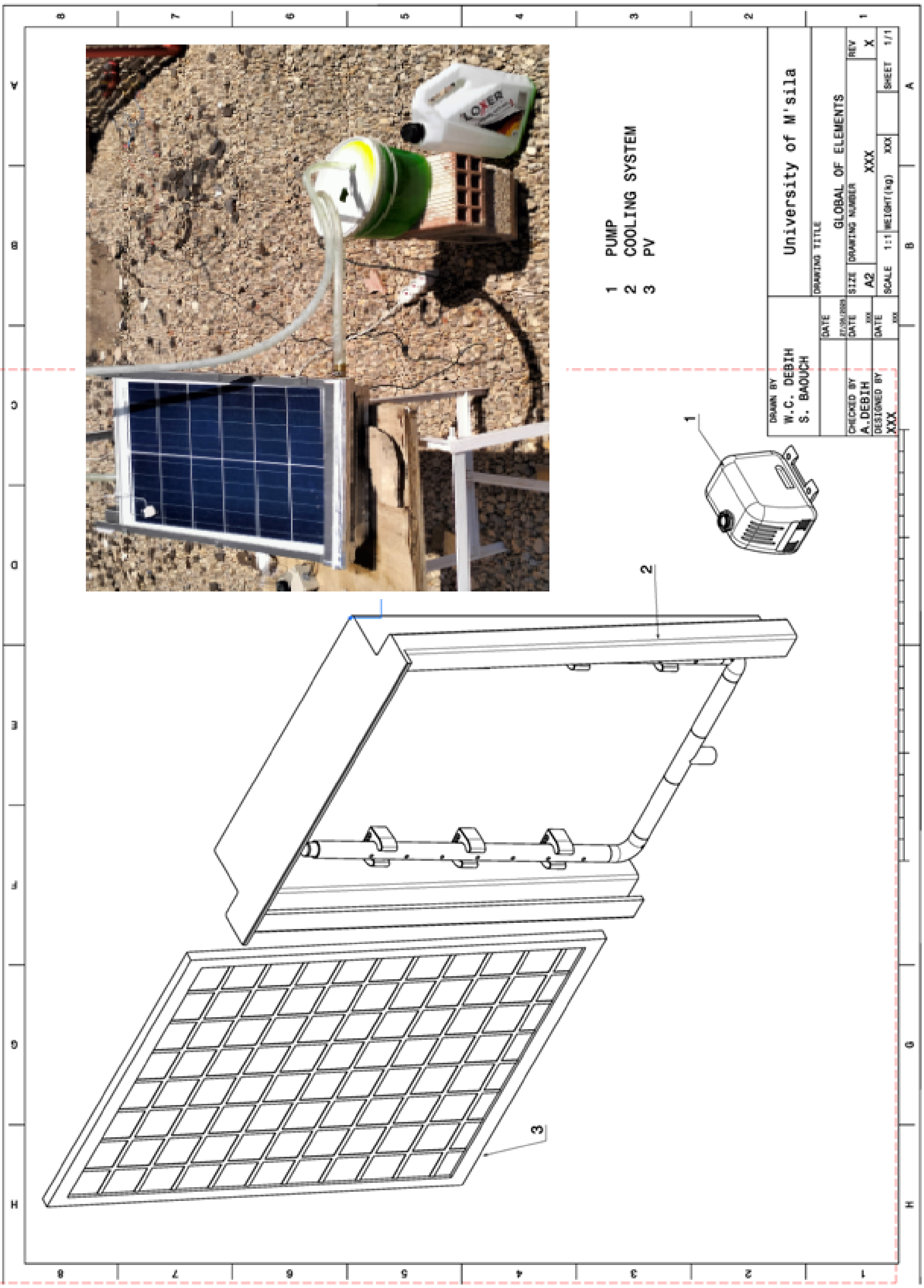
III. 2. 5- Global assembly, Figure III.6



III. 3. Results and discussion

III.3.1. Tests without cooling

III.3.1.1. Variation of current in function of temperature.

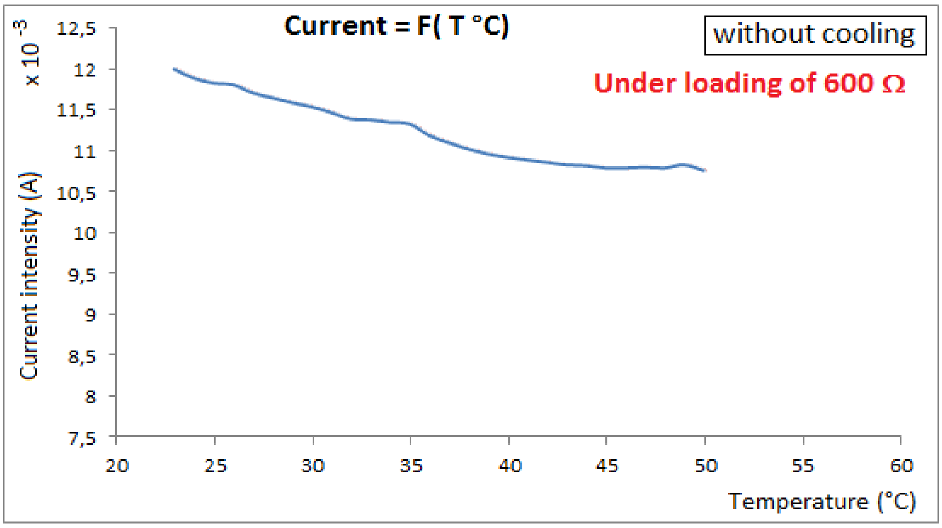


Figure III.7. Variation in electric current intensity (I (A)) in function of temperature (T(°C))

Figure III.7.Shows the changes of electric current intensity (I (A)) with variation of temperature. We can see that when the temperature is rising the electric current of the solar panel decreases thus the current changed from 12 mA at T = 23°C to 10.766mA at T = 50°C, under a resistive load of 600 Ω.

III.3.1.2. Variation of Voltage in function of temperature.

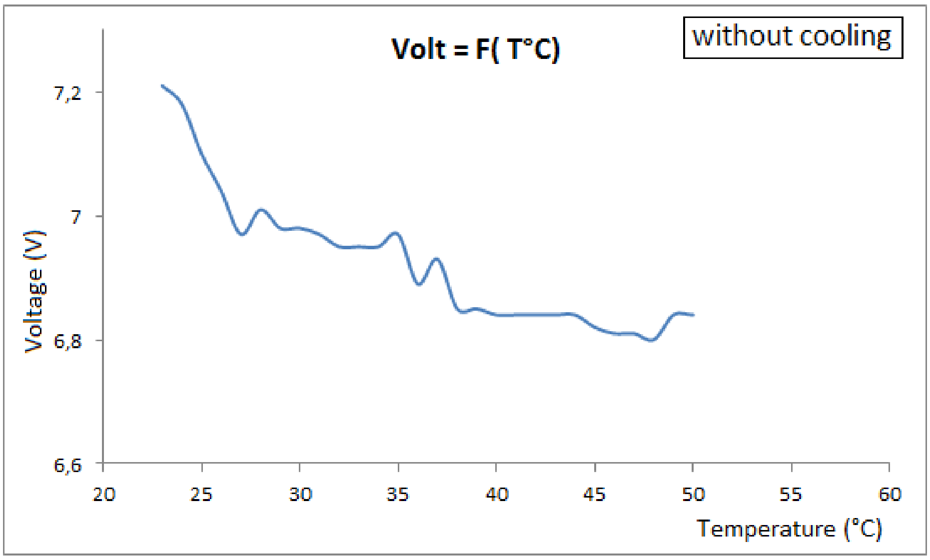


Figure III.8. Variation in voltage (U(V)) as a function of temperature (T(°C)).

Figure III.8. Demonstrates the voltage changes U(V) in the in function of temperature. It is clear that when the temperature rises the voltage of the solar panel is decrease from 7.21 V at T = 23°C to 6.84 V at T = 50°C. So from the graph, we conclude that the voltage is strongly influenced by the increase in temperature.

III.3.1.3. Variation of Power in function of temperature.

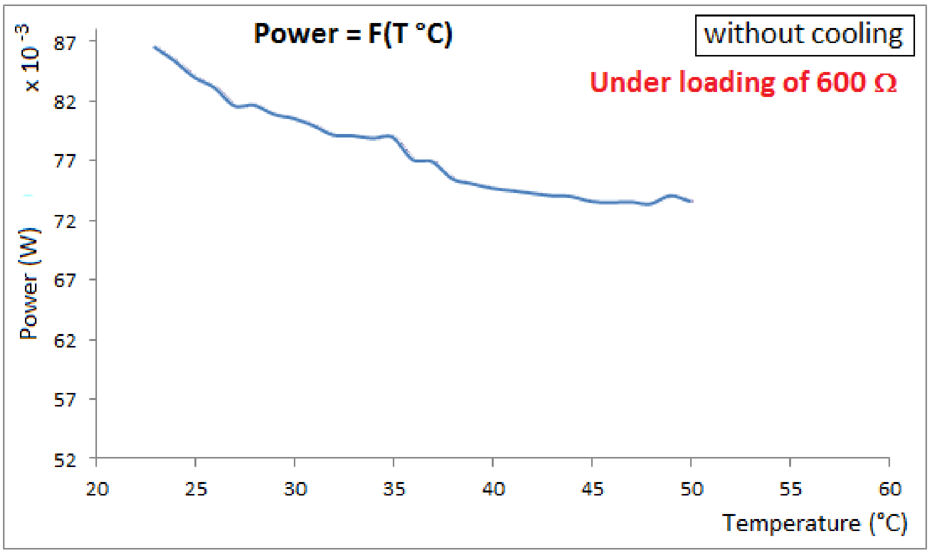


Figure III.9. Variation in power (P(W)) as a function of temperature (T(°C))

Figure III.9. Presents the changes in the output power P(W) of the solar panel with variation of temperature. Following the combined drop in the current and voltage with increasing temperature, solar panel power output is also decreasing thus the output power changes from 86.52mW at T = 23°C to 73.59mW at T = 50°C, under a resistive load of 600Ω.

III.3.2. Tests with water cooling

III.3.2.1. Variation of current in function of temperature

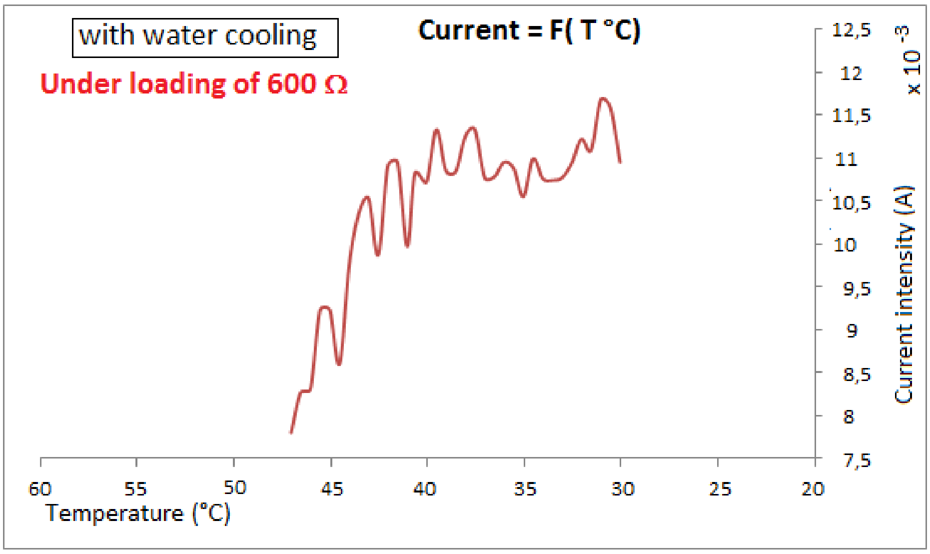


Figure III.10. Variation in electric current intensity (I (A)) as a function of temperature T(°C)

Figure III.10. Shows the Electric current intensity (I (A)) variations induced by temperature. It can be seen that when the temperature goes down by means of a cooling system which is based on water spraying on the underside of the photovoltaic panel, the electric current caused by the solar panel goes up from 7.97 A at T = 47°C to 10.94 A at T = 30°C, under a resistive load of 600 Ω.

III.3.2.2. Variation of voltage in function of temperature

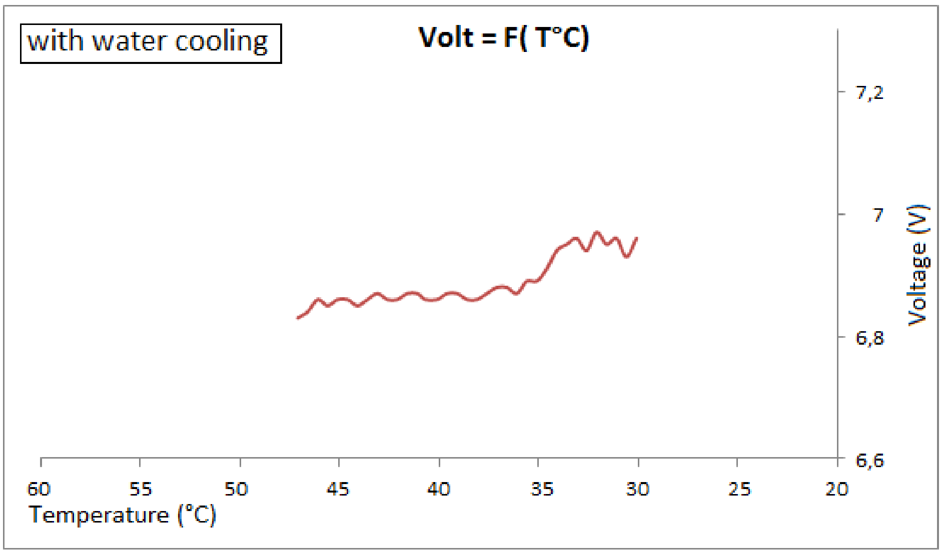


Figure III.11. Variation in voltage (U(V)) as a function of temperature (T(°C))

Figure III.11. Depicts how voltage (U(V)) changes with variation of temperature. It is noticed that the temperature abatement by activating a cooling system (that is spraying water on the underside of the photovoltaic panel) leads the solar panel voltage to raise from 6.83 V at T = 47°C to 6.96 V at T = 30°C.

III.3.2.3. Variation of power in function of temperature

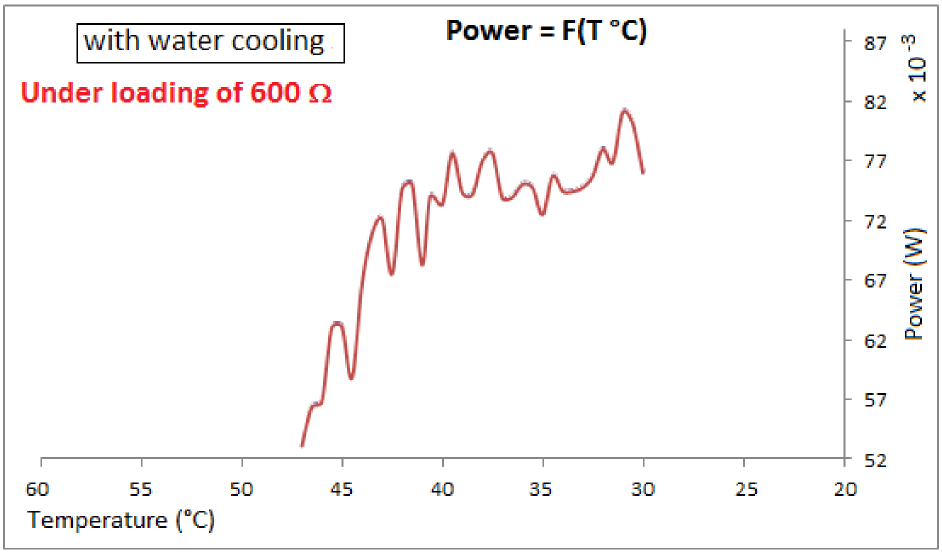


Figure III.12. Variation in power (P(W)) as a function of temperature (T(°C)).

Figure III.12. Shows the power output (P(W)) variation of the solar panel with respect to temperature. Since the current and voltage were simultaneously enhanced after the cooling (water-based) of the solar panel, the power output of the solar panel also follows the same trend, going from 53.2057 W at T = 47°C to 76.1424 W at T = 30°C, under a resistive load of 600 Ω. This is a major part of the power generated.

III.3.3. Tests with ethylene glycol $C_2H_6O_2$ cooling

III.3.3.1. Variation of current in function of temperature.

Figure III.13. Variation in electric current intensity (I (A)) as a function of temperature (T(°C))

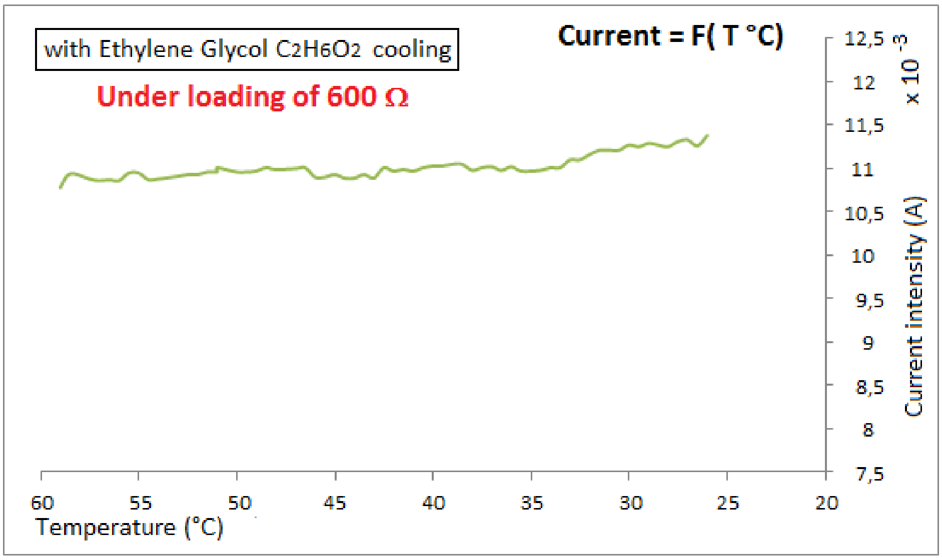


Figure III.13. Variation in electric current intensity (I (A)) as a function of temperature T(°C).

Figure III.13. The curve of electric current I (A) are presented as a function of temperature. The experimental data indicate that when the temperature lowers because of the working cooling system that is carried out by spraying a cooling liquid on the underside of the photovoltaic panel the current that solar panel generates increases from 10.78 A at T = 59°C to 11.38 A at T= 26°C, under the resistive load of 600 Ω.

III.3.3.2. Variation of voltage in function of temperature

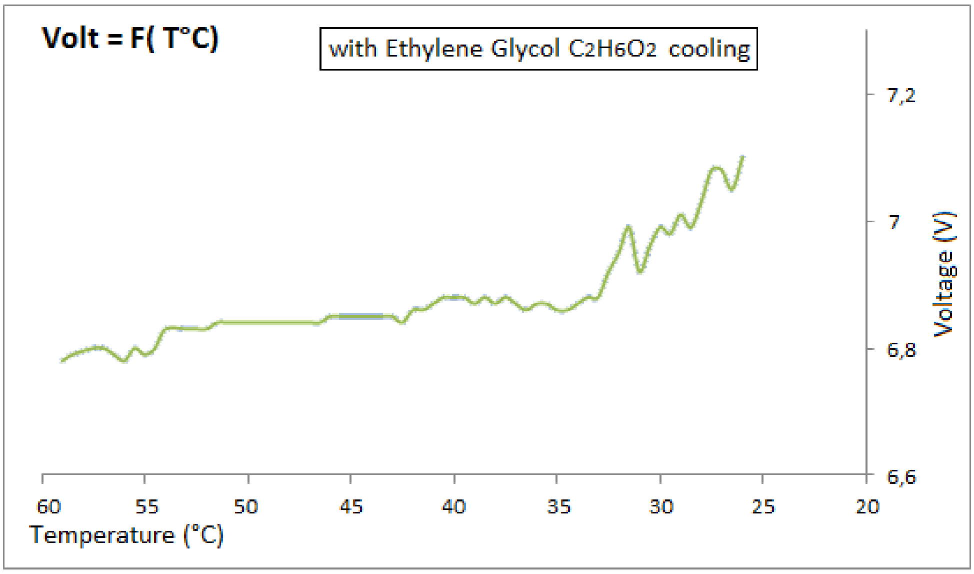


Figure III.14. Variation in voltage (U(V)) measurements as a function of temperature (T(°C))

Figure III.14. Shows the changes in the voltage (U(V)) with the variation of temperature. The experimental data indicate that when the temperature decrease by the effect of cooling system that is carried out by spraying a cooling liquid on the underside of the photovoltaic panel the voltage that the solar panel generates increases from 6.78 V at T = 59°C to 7.1 V at T = 26°C.

III.3.3.3. Variation of power in function of temperature

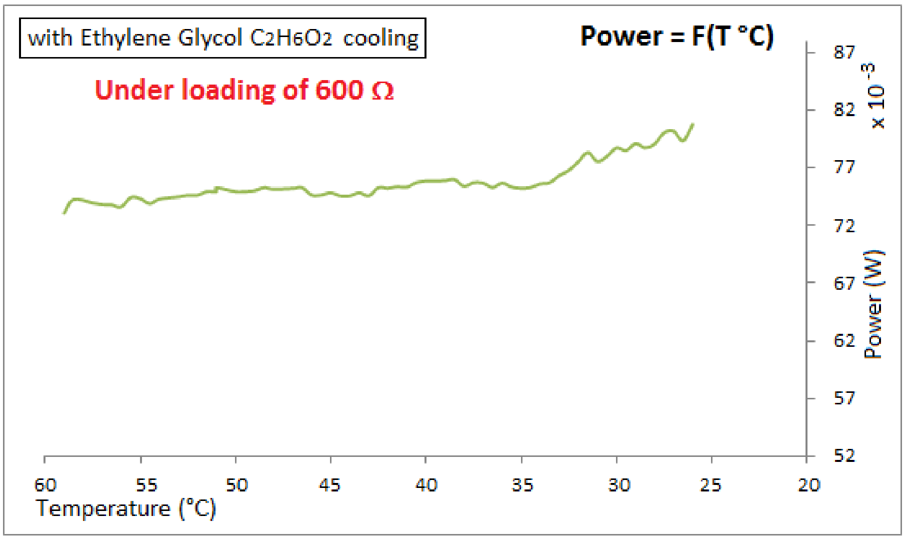


Figure III.15. Variation in power (P(W)) as a function of temperature

Figure III.15. Shows the data regarding the power output of the solar panel P(W) that depends on temperature. Because of the simultaneous increase of both current and voltage after the decrease of temperature by using a cooling system that is based on a cooling liquid the power output of the solar panel also goes up, rising from 73.08 W at T = 59°C to 80.79 W at T=26°C, under the resistive load of 600 Ω. This portion of the generated energy is quite considerable.

III.3.4. Comparison of current values without cooling, water cooling and ethylene glycol cooling

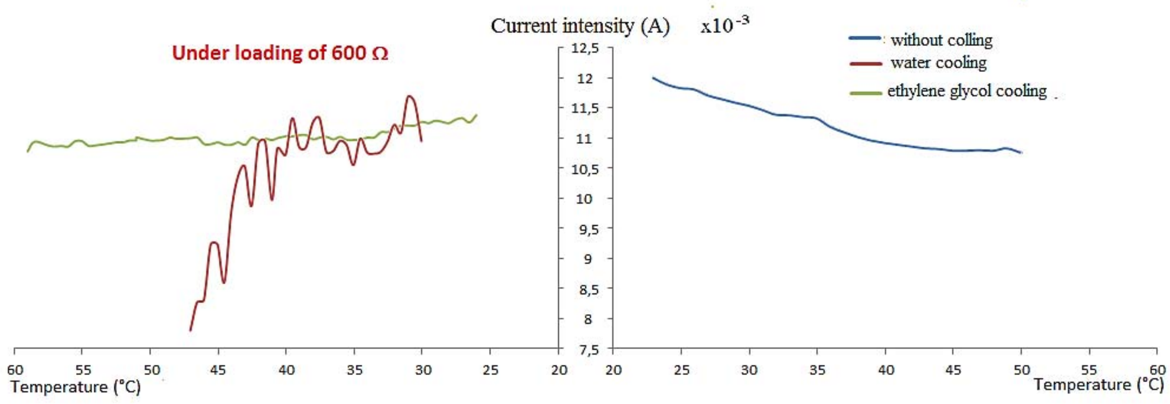


Figure III.16. Comparison of current values without cooling, water cooling and ethylene glycol cooling

The graph shows the current in relation to temperature characteristics of a pannel that is under load of 600Ω and is cooled with different methods water cooling, ethylene glycol cooling.

Observations:

Without cooling : The current falls from 12.2mA to 10.76mA when temperature goes up 23°C to 50°C, thus demonstrating that the system suffers from performance deterioration.

Water cooling: The current values display an abrupt change that is identified as the measurement equipment's instability. However, the instrumental data that are measured with water cooling are higher than those without cooling at overlapping temperature intervals.

Ethylene glycol cooling (green): Provides a very steady and strong current of about 11.38mA to 10.78mA in a wide range of temperature 26°C to 59°C.

Current Increase: Even with the measuring apparatus' disturbances accounted for, water cooling can still be used to keep a higher current intensity than that of the non-cooling situation, thus implying that the cooling is beneficial in energizing the system.

Current Increase and Stability: It is evident that ethylene glycol cooling dominates in this category, not only can it keep the current value at a far higher level than the "without cooling" case, but it also guarantees excellent performance consistency.

III.3.5. Comparison of Voltage values without cooling, water cooling and ethylene glycol cooling

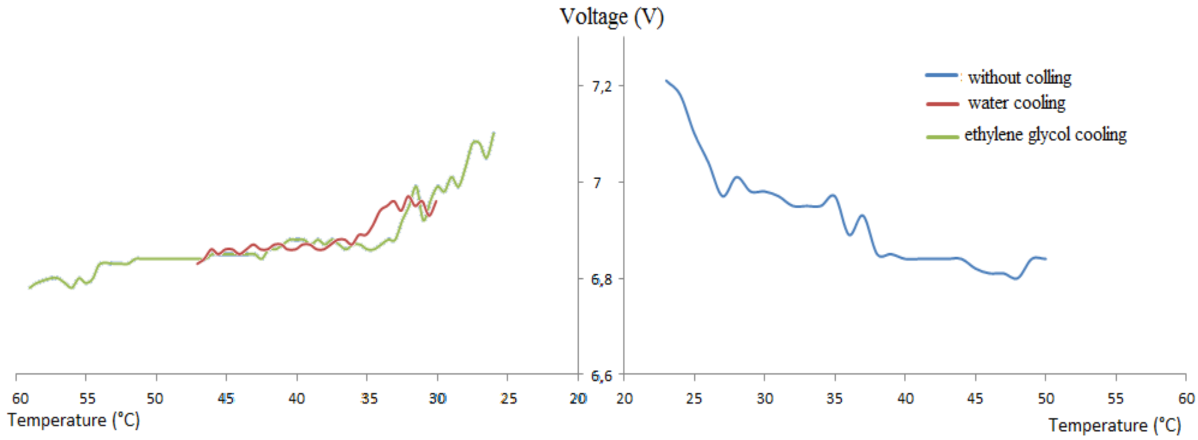


Figure III.17. Comparison of Voltage values without cooling, water cooling and ethylene glycol cooling.

The graph shows the voltage (V) in relation to temperature (T) characteristics of a system that is cooled by different methods, water cooling and ethylene glycol cooling.

Observations:

Without cooling: The voltage initially was very high ,around 7.21 V at 23°C then it declined drastically and in an irregular manner as the temperature increased up to about 6.84V at 45°C. This drop clearly shows that the capability of the system has been deteriorated.

Water cooling: The voltage value is increase from 6.3V at 47°C reaching 6.96V at 45°C, The values with water cooling, within the common temperature range, are equivalently stable or a bit higher than the case of "without cooling."

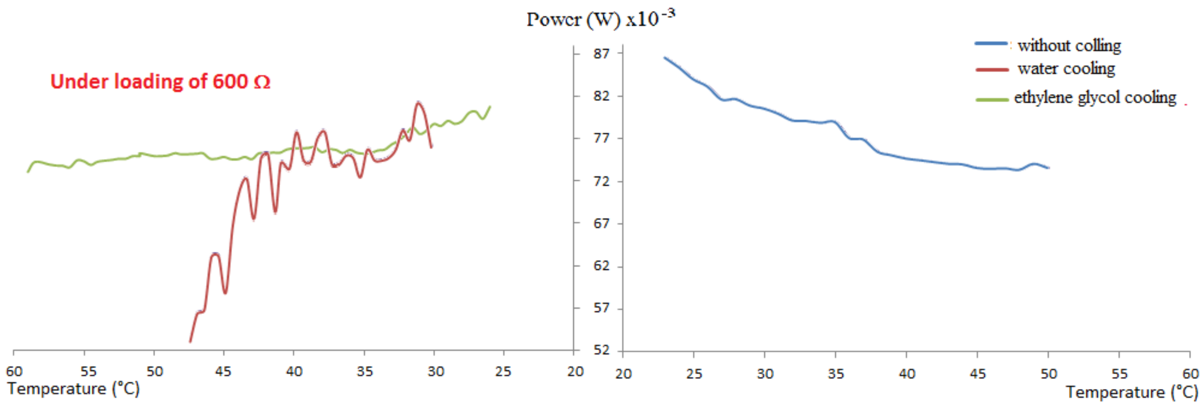
Ethylene glycol cooling: The voltage is The voltage value increase from 6.78V at 59°C reaching 7.1V at 26°C, Its behavior is comparable to that of water cooling in the higher temperature range.

Water cooling is a facilitator for higher and more stable voltage values at some temperatures than no cooling, where voltage goes down substantially. This means that water cooling supports the voltage-producing component to keep the better performance.

Voltage Maintenance and Stability: Ethylene glycol cooling is very good at keeping the voltage at the highest and most stable level compared to the "without cooling" case. Within the common temperature range, the voltage with ethylene glycol cooling is higher and more stable than the voltage in the uncooled state.

Concerning component performance at increased temperatures, the two cooling modes (ethylene glycol and water) not only share the same trend in the rising and smoothing of voltage levels, but also they signal as being among the most efficient ones.

III.3.6. Comparison of Power values without cooling, water cooling and ethylene glycol cooling



III.18. Comparison of Power values without cooling, water cooling and ethylene glycol cooling

The graph shows the power (P) in relation to temperature (T) characteristics of a system that is cooled by different methods, water cooling and ethylene glycol cooling.

Observations:

Firstly, if a power device is not cooled, the power value restarts at a peak value (around 86.52mW at 23°C, then it drops immensely and inconsistently as the temperature increases and reaches around 73.59mW at 50°C. The drop is basically a sign of a degradation of the unit.

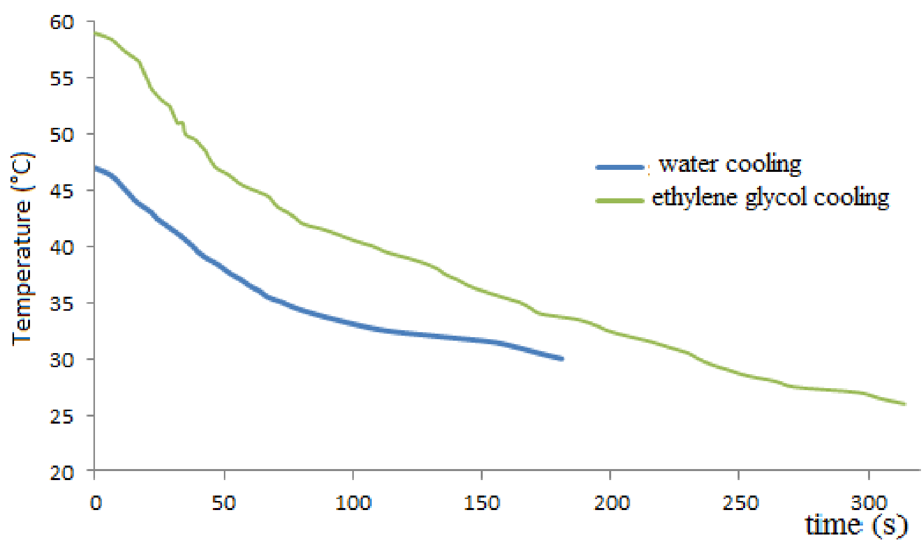
Water cooling: shows power having sharp ups and downs (ranging from about 53.2Mw to 81.22mW) throughout the temperature domain checked. These changes are signs of instability in performance that can be caused by trouble in the cooling process or measuring devices as pointed in the last paragraph. However, there are instances during the range where power value with water cooling is even higher than the "without cooling" at similar temperatures (e.g., around 35°C).

Ethylene glycol cooling (green): Power demonstrates a remarkable steadiness of high values (around 73.08mW– 80.79mW) in a broad temperature range (26°C to 59°C), with a small inclination to rise at the low end of the range.

Cooling Effect: Though the data points are more of a wave-like pattern, the cooling curve of the water nevertheless indicates that this approach can be the way to keep a power level even higher or to boost it in comparison with the case where there is no cooling, and the performance of the whole system generally goes down with the rise of temperature.

Power Increase and Stability: Among all the other ones, the ethylene glycol cooling is the best performing; it not only allows a power level that is visibly higher than the "without cooling" case but also makes sure that the power generated is of excellent stability in a wide range of temperatures. This indicates its high ability to keep the system efficient.

III.3.7. Comparative evaluation of the thermal efficiency of water and ethylene glycol



III.19. Comparative evaluation of the thermal efficiency of water and ethylene glycol

The graph illustrates a comparative evaluation of the thermal efficiency of water and ethylene glycol as heat removal media in a photovoltaic cell.

Ethylene Glycol Cooling

- At the start of the system running and the commencement of the cooling process, the cell's initial temperature was roughly 59°C.

- Following 60 seconds, the temperature of the cell dropped to about 47°C (a reduction of 12°C).
- At 120 seconds temperature was close to 42°C.
- Then it went down to around 37°C after 180 seconds which is a decrease of 22°C from the initial temperature.
- The cooling process kept going and at 314 seconds (the end of the graph) it reached about 26°C.

Conclusion regarding the operation: It follows from this that the cooling system has to be operated only for 4 minutes every 15 minutes, and it is not necessary for it to run continuously.

Water Cooling

- At the moment of the cooling system operation commencement, the cell's initial temperature was around 47°C.
- The temperature within the first 60 seconds fell approximately 10°C (from 47°C to around 37°C).
- After 120 seconds it went down to about 32.5°C.
- At the point of 180 seconds the temperature got to about 30°C and the curve seems to be horizontal at this value. This indicates that the temperature has stabilized at this level (possibly reaching thermal equilibrium with the water's temperature or ambient temperature.(

Conclusion about performance: Thus, it can be stated that to enhance the electrical efficiency of the photovoltaic device it is sufficient to run the cooling system only for the short duration of 3 minutes every 10 minutes.

III.4. Discussion

For high temperatures.

- Band gap narrowing: The vibrations caused by heat in the chemical panel material of the silicon are increased, which, in turn, reduces the energy of the band gap.
- Decreased Open-Circuit Voltage (V_{oc}): This is the most important effect; band gap narrowing causes the voltage, which the cell can produce, to go down.

- Increased Reverse Saturation Current (RSC): This parasitic current becomes higher, thus leading to a decline of the efficiency.
- Increased Recombination Rates (IRR): As the random movement of electrons becomes more, the possibility of electrons and holes recombining before getting to the electrodes thus, resulting in current being generated, becomes higher.
- Reduced number of effective charge carriers: The fraction of electrons and holes that really make the electric current is reduced.
- Increased Internal Resistance: This is due to the fact that the vibrations within the material's crystal lattice are increased, thus impeding the movement of electrons, which consequently will have a harder time moving freely in the lattice, therefore, the resistance to the flow of electrons will be increased.
- Overall Efficiency Decrease: Because of all these factors mentioned above, the conversion efficiency of solar power into electrical power is very low.

For low temperatures (cooling):

- Band gap widening: The vibrations caused by heat are decreased, thus the energy of the band gap of silicon is increased.
- Increased Open-Circuit Voltage (V_{oc}): The voltage that the cell produces because of band gap widening is higher, and this is the main reason for the efficiency rise.
- Decreased Reverse Saturation Current: The parasitic current that is present here is less than before and thus the cell’s performance will be better.
- Reduced Recombination Rates: The decrease of random electron movement gives a lower probability of recombination of electrons and holes as well as increasing the number of electrons available for current.
- Increased number of effective charge carriers: More electrons and holes get to the electrodes and those that contribute to the electric current are increased.
- Maintained Low Internal Resistance: As cooling reduces atomic vibrations, it makes electron movement easier and helps maintain low internal resistance, which in turn reduces losses.

  ☒ **Recovered Power (R P),** that is the increase in electrical output power achieved from a solar cell or module as result of reducing its operating temperature, the real values of our work are presented in table III.1

	Temperature	Power temperature coefficient (α)	Reference Power	Reference Temperature	R P(W)	RP %
Without cooling	20-50	-0.495%/°C	0,08652	25		
Water Cooling	30-47	-0.244%/°C	0,0761424	30	0.0046	6,04
Ethylene Glycol Cooling	26-59	-0.288%/°C	0,080798	25	0.0058	7,17

Conclusion

This experimental study serves as a signature of the journey undertaken to quantify the performance of the electrical system in photovoltaic (PV) modules aided by cooling from water and ethylene glycol under real working conditions. The findings obtained from the experimental tests are clearly shown in the diagrams, which present an important negative correlation between the PV panel's temperature and its electrical output in the absence of any cooling system. A substantial drop in the produced current, voltage, and electrical power was always seen when the panel temperature was raised.

On the other hand, the cooling systems being tested have not only proven to be instrumental in lessening the temperature problem but also have given a significant boost to the electrical performance of PV panels. The figures are quite clear that the facilitated cooling via water or ethylene glycol resulted in a remarkably higher current, voltage, and electrical power than the uncooled case. This confirms the main conjecture of the research: managing the temperature of the PV panel constitutes a key issue of energy conversion efficiency.

Concretely, the check of the two fluids presented huge distinctions in the results with each one embodied specific virtues. The water cooling method demonstrated the highest capacity to bring the panel's temperature down rapidly and efficiently, especially at the beginning. This direct influence of the fast reaction on the case of current, voltage, and power is the more and the quicker the reaction is accomplished, the longer the energy is accumulated. This fast reaction makes water a perfect choice for quick and effective heat dissipation when rapid temperature reduction is needed. The fact that it is highly efficient suggests that running it for short periods of time "h" (e.g., every 10 minutes for 3 minutes) can keep the panel temperature at an ideal level, as it is continuously electrically efficient.

On the other hand, ethylene glycol showed a slower initial cooling rate but had some unique advantages which could make it a better choice in certain situations. The test also proved that it has a capacity beyond just a rapid cooling ability, and the performance was improved for a longer time period. The resultant information from supplementary data points highest at ethylene glycol. The system can be run discontinuously (for instance, 15 minutes and then 4 minutes) without losing much power, which means that the system can continue to be running without overloading or running inefficiency. Such instances might be the use of anti-freeze or corrosion protection (though these aspects were not part of the study) which could offer a stable and strong solution, even if the initiation cooling is less aggressive and not the main feature.

The work presented here underscores the critical role of cooling devices in the design and installation of photovoltaic modules in hot areas and provides planners and solar engineers with clues for navigating the difficult decision whether or not to deploy a cooling system. The paper further establishes that the selection of an appropriate coolant is influenced by a mixture of factors, such as the needed reaction velocity, the environmental conditions, and the particular difficulties of the intermittent operation. This study powerfully illustrates the potential for the continuation of this work, focusing on the identification of the most effective cooling systems and devising more intelligent operational plans to harness solar energy power to the maximum extent possible.

Conclusion

This work of research is at least one of the conditions that cooling systems are among the most effective and necessary options for the enhancement of photovoltaic (PV) solar energy conversion efficiency. It has been discussed in the preceding chapters that excessively high temperatures continue to be a stumbling block to the efficient work of solar panels and thus continual effort in innovative ways of mitigating this negative impact is still required.

Key Findings and Recommendations

The experimental part of our study that aimed at comparing the performance of a solar cell with no cooling, with water cooling, and with ethylene glycol cooling, gave unambiguous results consistent with the assumption that the cooling greatly promotes panel efficiency. Although the heat of the uncooled panel resulted in a decline in its efficiency, an evident improvement in the performance was seen in the case of the application of cooling systems.

Water cooling proved to be an effective means of lowering the panel's temperature which in turn caused the electrical energy generated from the panel to be significantly increased as compared to the non-cooled state.

Ethylene glycol was revealed to have better cooling performance than water and therefore, the panel's temperature was kept at the lowest possible level, this resulting in the highest efficiency among all three methods. This further shows that the use of cooling fluids having better thermal properties can play a more important role in the positive impact on performance in the future.

These results entirely reassure that deploying cooling systems for photovoltaic panels is not only a small improvement but also a necessity in order to get the maximum benefit from solar energy projects.

Future Prospects

With the progress of solar energy technology, more efficient, cheaper, and eco-friendly cooling devices are indispensable to be developed for both human and environment. Some of the future directions of the research in this area could be the search for new cooling materials, designing cooling systems with lower energy consumption, and utilizing other technologies such as thermal energy harvesting from the panel to improve the overall system efficiency while integrating cooling systems.

Concluding Remark

In conclusion, solar energy forms a cornerstone of a clean energy future. By adopting and developing innovative solutions like cooling systems, we can overcome existing technical challenges and fully harness the immense potential of this energy source, paving the way for a brighter and more sustainable future for generations to come.

ANNEX BMC

1. Introduction

In Algeria's sun-drenched environment, leveraging ample solar resources is key to meeting national renewable energy targets. Our prototype mission aligns with this context by combining photovoltaic (PV) panels with a novel cooling system. This cooling system is designed for direct application to the solar panels, advancing the goals for efficient power innovation in Algeria. The cooling fluid typically used is water or ethylene glycol, circulated to draw heat away from the panels and maintain optimal operating temperatures.

2. Project Presentation: Enhancing Photovoltaic Efficiency with Cooling Systems

The ambition of this project is to strengthen a sustainable system that maximizes electricity generation from photovoltaic panels. This is achieved by combating the inherent inefficiency of PV panels, which significantly lose power output as their temperature rises. Our project directly tackles this challenge by developing a specialized cooling system. This system is designed to improve the thermal performance of solar panels, leading to increased efficiency and an extended operational lifespan.

2.1.Goals and Objectives

The primary goals and objectives for this project revolve around developing and commercializing an efficient cooling solution for photovoltaic systems:

- Design and assemble an effective cooling system for PV panels, capable of maintaining optimal operating temperatures.
- Demonstrate feasibility with a working prototype, showcasing how the cooling system significantly improves the thermal performance and efficiency of solar panels.
- Support Algeria's power transition by developing technological know-how that optimizes the use of abundant local solar assets. The cooling system aims to minimize energy loss due to temperature rise, potentially increasing panel efficiency by 20-25%.
- Lay groundwork for commercialization by assessing technical performance, costs, and market viability of this cooling technology. This involves evaluating the low-cost cooling system that effectively enhances the thermal performance of solar panels.
- The value proposition of this cooling system includes offering a sustainable solution, increased efficiency, reduced energy loss, and a customized solution adaptable for various panel types and climatic conditions.

ANNEX BMC

3. Business Model Canvas

Customer Segments Targeted:	**Customer Relationship**	**Value Proposition**	**Key Activitie Planning**	**Key Partners**
- Companies installing solar energy systems - Large farms relying on solar power - Industrial businesses such as Ain Melh Municipality Station Potential: - Residential homes and housing complexes - Energy stations under construction, such as the solar power station in Batma, M'Sila - Municipalities, government buildings, educational, and	**Creating the Relationship:** - Offering trial demonstrations and free consultations - Providing reliable real-world results **Developing the Relationship:** - Regular system updates **Sustaining the Relationship:** -Long-term contracts -After-sales services -Providing reliable results and guarantees	This is a cooling system designed to enhance the efficiency of solar panels using cooling technologies. This project offers the following values: **Innovation:** - Providing a solution to the issue of rising solar panel temperatures, which reduces their efficiency. **Risk Reduction Value:** - Increasing the lifespan of solar panels. **Customization & Differentiation Value:** - Minimizing energy loss due to heat, as solar panels lose about 20–25% of their efficiency. **Comprehensive Service Value:** - A customized cooling system based on location, number of panels, and climatic conditions. **High-Performance Value:** - Offering a sustainable solution with a high return on investment. **Price Value:** - A low-cost cooling system that effectively improves the thermal performance of PV **Cost Reduction:** - Reducing the need to replace solar panels. **Ease of Use:** - The system operates semi-automatically after initial setup. - Does not require advanced technical expertise for	- Technical study of solar panels - Market and target customer analysis - Prototype design - Initial preliminary plan preparation - Initial marketing strategy development - Study of legal and regulatory aspects **Production:** - Manufacturing or assembling a cooling system - Testing the system under real conditions - Improving the design based on results - Producing small batches **Marketing:** - Market research - Identifying the target audience - Developing marketing messages - Direct promotion.	- Business incubator of M'Sila University - Companies manufacturing solar energy systems - Academic and research institutions

ANNEX BMC

<table>
<tr>
<td>healthcare
facilities</td>
<td>Channels
-Social media platforms
- Exhibitions and conferences related to renewable energy
- Sales through intermediaries and au thorized agents</td>
<td rowspan="2">operation or maintenance.</td>
<td>Key Resources

Physical:
- Equipment and technologies used in cooling systems

Human:
- Maintenance worker
- Engineers and researchers for development
- Security personnel
Financial:
- National Fund for Startups</td>
<td></td>
</tr>
<tr>
<td colspan="2">Revenue Streams
- Selling the cooling system (product) directly to customers
- Providing regular maintenance services for solar panels and the cooling system
- Licensing manufacturing rights to companies seeking to associate their brand with sustainability and clean energy</td>
<td colspan="2">Investment Costs:
-Purchasing solar panels
-Cost of the Sensors ,cooling and control system
-System design and installation
-Electrical and mechanical connections
Operational Costs:
- Regular maintenance of the cooling system and solar panels
- Energy consumption for the cooling system
- Replacement of spare parts
- Worker wages
- Daily operational expenses (e.g., water)</td>
</tr>
</table>

ANNEX BMC

3.1.Equipment purchases.

Item description	Quantity	Unit cost	Total cost	Funding source
Solar panel	1	400,000 DA	400,000 DA	
Water pump	1	220,000 DA	220,000 DA	
Large pipes	1	45,000 DA	45,000 DA	
Silicone &Tape	1	95,000 DA	95,000 DA	
Heat sensor	1	130,000 DA	130,000 DA	
Water outlet hose	1	22,000 DA	22,000 DA	
Engine cooling liquid	1	40 ,000 DA	40,000 DA	
Total		1,097,000 DA	1,097,000 DA	

3.2. Consumable materials.

Item description	Quantity	Unit cost	Total cost	Funding source
Engine cooling liquid	1	40,000 DA	40,000 DA	
Total	1	40,000 DA	40,000 DA	

3.3. Salaries.

position	Quantity	Monthly salary	Monthly total	Annual total
Project Manager	2	100,000 DA	200,000 DA	2,400,000 DA
Technical / Maintenance Engineer	1	70,000 DA	70,000 DA	840,000 DA
Sales /Marketing officer	1	60,000 DA	60,000 DA	7200,000 DA
Totalx	4	230,000 DA	330,000 DA	3,960,000 DA

3.4. Other recurring costs.

Description			
electricity	5,000 DA	5,500 DA	5,200 DA
water	1,500 DA	1,500 DA	1,550 DA
transportation	15,000 DA	20,000 DA	17,000 DA
Maintenance /tools	10,000 DA	8,000 DA	12,000 DA
Totale monthly	31,500 DA	35,000 DA	35,750 DA

3.5. Projected sales table.

product &client target	N-2	N-1	N	N+1	N+2	N+3	N+4
Quantity product A	--	--	20	50	100	150	200
Unit price product A	--	--	50,000 DA	50,000 DA	52,000 DA	52,000DA	55,000 DA
Sales product A	--	--	1,000,000DA	2,500,000DA	5,200,000DA	7,800,000 DA	11,000,000 DA
Totale revenue	--	--	1,000,000DA	2,500,000DA	5,200,000DA	7,800,000 DA	11,000,000 DA

References

References :

[1] Tahsin Bakirtas, Ahmet Gokce Akpolat, The relationship between energy consumption, urbanization, and economic growth in new emerging-market countries, Energy, Volume 147, 15 March 2018, Pages 110-121, DOI: 10.1016/j.energy.2018.01.011.

[2] Choudhary, P. and Srivastava, R.K. Sustainability Perspectives—A Review for Solar Photovoltaic Trends and Growth Opportunities. Journal of Cleaner Production, 227, 589-612. 2019. https://doi.org/10.1016/j.jclepro.2019.04.107

[3] Shiva Gorjian and Ashish Shukla, Photovoltaic Solar Energy Conversion, Technologies, Applications and Environmental Impacts, ISBN978-0-12-819610-6, 2020

[4] Mallikarjun Hudedmani , Vishwanath Mahantayya Soppimath, Chaitanya Jambotkar, A Study of Materials for Solar PV Technology and Challenges , European Journal of Applied Engineering and Scientific Research, 2017, 5(1):1-13

[5] International Renewable Energy AgencyRenewable Power Generation Costs in 2019(2020)

[6] A. M. A. Shaaban, M. A. Mosa, A. A. El-Samahy, K. A. Abed , Enhancing the Performance of Photovoltaic Panels by Cooling: a Review , International Review of Automatic Control (I.RE.A.CO.), Vol. 16, N. 1 ISSN 1974-6059 January 2023

[7] Tarak Salmi, Mounir Bouzguenda, Adel Gastli, Ahmed Masmoudi, MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell, International Journal Of Renewable Energy Research, vol. 2, pp. 213-218, 2012.

[8] Photovoltaics Report, 2016.

[9] Planning and Installing Photovoltaic Systems: A guide for installers, architects and engineers, second edition. Earthscan. 2008.

[10] Salim Makhloufi . CONTRIBUTION A L'OPTIMISATION DES INSTALLATIONS PHOTOVOLTAIQUES PAR DES COMMANDES INTELLIGENTES. Universite HADJ LAKHADAR BATNA .2015

[11] Mekhilef, S., Saidur, R. and Kamalisarvestani, M., Renewable and Sustainable Energy Reviews, 2012. 16(5): p. 2920-2925.

[12] Mitch, J., Chemical & Engineering News, 2016. 94(18): p. 30-35.

[13] Zeki, A., Hussein Kazem, A. and Sopian, K., Latest Trends in Renewable Energy and Environmental Informatics, 2013.

[14] A. El Hammoumi, S. Chtita, S. Motahhir et al. Solar PV energy : Fro mmaterial to use , and the most commonly used Techniques to maximize the power output of PV systems : A

focus on Solar trackers and floating solar panels . Energy Reports 8 (2022) 11992–12010 [11998 ; 11993]

[15] Joshua David Bollinger. Applications of solar energy to power stand-alone area and street lighting.(2007). Masters Theses. 5506. https://scholarsmine.mst.edu/masters_theses/5506

[16] S. Tennakoon, W. Keerthipala, W. Lawrance, "'Solar Energy for Development of a Cost-Effective Building Energy System:· International Conference on Power System Technology. Volume 1, Pg. 55-59. Dec 2000

[17] D. Mayer, M. Heidenreich, "Performance Analysis of Stand-alone PV Systems from a Rational Use of Energy Point of View," 3rd World Conference of Photovoltaic Energy Conversion. Pg. 2155-2158. May 2003.

[18] H.G. Teo, P.S. Lee, M.N. Hawlader, An active cooling system for photovoltaic modules, Appl. Energy, 90 (2012), pp. 309-315.

[19] S. Wu, C. Xiong, Passive cooling technology for photovoltaic panels for domestic houses, Int. J. Low Carbon Technol., 9 (2014), pp. 118-126

[20] M. Salih, Performance enhancement of P.V. array based on water spraying technique, International Journal of Sustainable and Green Energy, (2014)

[21] Zeyad A. Haidara, Jamel Orfib, Zakariya Kaneesamkandi. Experimental investigation of evaporative cooling for enhancing photovoltaic panels efficiency. Results in Physics 11 (2018) 690-697.

[22] Khaled Teffah, Youtong Zhang, Modeling and experimental research of hybrid PV-thermoelectric system for high concentrated solar energy conversion, Solar Energy, vol. 157, pp. 10-19, 2017.

[23] K.A. Moharram, M.S. Abd-Elhady, H.A. Kandil, H. El-Sherif, Enhancing the performance of photovoltaic panels by water cooling, Ain Shams Engineering Journal, vol. 4, pp. 869–877, 2013.

[24] Amirhosein Hadipour, Mehran Rajabi Zargarabadi, Saman Rashidi, An efficient pulsed-spray water cooling system forphotovoltaic panels: Experimental study and cost analysis,Renewable Energy, vol. 164, pp. 867-875, 2021.

[25] K.A. Moharram, M.S. Abd-Elhady, H.A. Kandil, H. El-Sherif,Enhancing the performance of photovoltaic panels by water cooling, Ain Shams Engineering Journal, vol. 4, pp. 869–877,2013.

References

[26] Li-Hao Yang, Jyun-De Liang, Chien-Yeh Hsu, Tai-Her Yang, Sih-Li Chen, Enhanced efficiency of photovoltaic panels by integrating a spray cooling system with shallow geothermal energy heat exchanger, Renewable Energy, vol. 134, pp. 970-981, 2019.

[27] Sajan Preet, Brij Bhushan, Tarun Mahajan, Experimental investigation of water based photovoltaic/thermal (PV/T) system with and without phase change material (PCM), Solar Energy, vol. 155, pp. 1104–1120, 2017.

[28] Hamidreza Najafi, Woodbury Keith, Optimisation of a cooling system based on Peltier effect for photovoltaic cells, Sol. Energy 91 (2013) 152–160, https://doi. org/10.1016/j.solener.2013.01.026.

[29] D.S. Borkar, S.V. Prayagi, J. Gotmare, Performance evaluation of photovoltaic solar panel using thermoelectric cooling, Int. J. Eng. Res. 3 (2014) 536–539.

[30] M. Benghanem, A. Al-Mashraqi, K. Daffallah, Performance of solar cells using thermoelectric module in hot sites, Renew. Energy 89 (2016) 51–59.

[31] H. Moshfegh, M. Eslami, A. Hosseini, Thermoelectric cooling of a photovoltaic panel, in: S. Nizetic, A. Papadopoulos (Eds.), The Role of Exergy in Energy and the Environment. Green Energy and Technology, Springer, Cham, 2018.

[32] LUCUQUIN B, PIRONNEAU OIntroduction au Calcul Scientifique. Masson, 1997. Introduction to Scientific Computing for Engineers (Wiley). (Traduit du français) 1998.

[33] JEANNOT Y, Cours transfert thermique cours 2ème année, École des Mines, Nancy, France,

[34] Faghri, A , Heat Pipe Science and Technology, Second edition, Global Digital Press. 2016,

[35]"Thermal conductivity of common metals, metallic elements and Alloys". www.engineeringtoolbox.com. Retrieved October 15, 2020.

[36] Praful, S; Prajwal Rao, V; Vijeth, V; Bhagavath, Skanda V; Seetharamu, K N; Narasimha Rao, R ,(2020). "On the operating temperature of heat pipes". Journal of Physics: Conference Series.1473(1):012025.Bibcode:2020JPhCS1473a2025P.doi:10.1088/1742 6596/1473/1/012025. ISSN 1742-6588

[37] Jim Danneskiold, Los Alamos-developed heat pipes ease space flight. Los Alamos News Release, April 26, 2000.

[38] "Incompatible Heat Pipe Fluid/Envelope Pairs". www.1-act.com. Archived from the original on 2018-07-08. Retrieved 2014-11-03.

[39] "Heat Pipe Materials, Working Fluids, and Compatibility". www.1-act.com.

References

[40] L. Zhu, A. Raman, K.X. Wang, M.A. Anoma, S. Fan, Radiative cooling of solar cells, Optica 1 (2014) 32.

[41] L. Zhu, A.P. Raman, S. Fan, Radiative cooling of solar absorbers using a visibly transparent photonic crystal thermal blackbody, Proc. Natl. Acad. Sci. U.S.A. 112 (2015) 12282–12287.

[42] Z. Rostami, M. Rahimi, N. Azimi, Using high-frequency ultrasound waves and nano-fluid for increasing the efficiency and cooling performance of a P.V. module, Energy Convers. Manag. 160 (2018) 141–149.

[43] H. A. Hussien, M. Hasanuzzaman, A. H. Noman, and A. R. Abdulmunem, "Enhance photovoltaic/thermal system performance by using nano-fluid," In 3rd IET International Conference on Clean Energy and Technology (CEAT) 2014, Kuching, Malaysia, November 2014.

[44] A.M. Sardarabadi, M. Passandideh-Fard, Experimental and numerical study of metal-oxides/water nano-fluids as coolant in photovoltaic thermal systems (PVT), Sol. Energy Mater. Sol. Cell. 157 (Dec 2016) 533–542.

[45] M. Lucas, F. Aguilar, J. Ruiz, C. Cutillas, A. Kaiser, P. Vicente, Photovoltaic Evaporative Chimney as a new alternative to enhance solar cooling, Renew. Energy 111 (2017) 26–37.

[46] X. Han, D. Xue, J. Zheng, S. Alelyani, X. Chen, Spectral characterisation of spectrally selective liquid absorption filters and exploring their effects on concentrator solar cells, Renew. Energy 131 (2019), 938e45, https://doi.org/10.1016/j.renene.2018.07.125.

[47] R. Taylor, T. Otanicar, G. Rosengarten, Nanofluid-based optical filter optimisation for PV/T systems, Light Sci. Appl. 1 (2012) e34, https://doi.org/10.1038/ lsa.2012.34.

[48] SandeepS. Joshi, Ashwinkumar S. Dhoble, Experimental Investigation of solar photovoltaic thermal system using water, coconut oil and silicone oil as spectrum filters, J. Braz. Soc. Mech. Sci. Eng. 39 (8) (August 2017) 3227–3236, https://doi.org/10.1007/s40430-017-0802-0. Springer.

[49] SandeepS. Joshi, Ashwinkumar S. Dhoble, et al., Performance analysis of photovoltaic thermal system using silicone oil spectrum filter, Appl. Sol. Energy -Springer 54 (Issue-01) (2018) 4–9, https://doi.org/10.3103/S0003701X18010061.

[50] SandeepS. Joshi, Ashwinkumar S. Dhoble, Analytical approach for performance estimation of BSPVT system with liquid spectrum filters, Energy 157 (2018) 778–791, https://doi.org/10.1016/j.energy.2018.05.204.

References

[51] Ali Hassan, Abdul Wahab, Muhammad Arslan Qasim, Muhammad Mansoor Janjua, Muhammad Aon Ali, Hafiz Muhammad Ali, Tufail Rehman Jadoon, Ejaz Ali, Ahsan Raza, Noshairwan Javaid, Thermal management and uniform temperature regulation of photovoltaic modules using hybrid phase change materials nanofluids system, Renew. Energy 145 (2020) 282–293, https://doi.org/10.1016/j.renene.2019.05.130.

[52] N. Karami, M. Rahimi, Heat transfer enhancement in a hybrid microchannel-photovoltaic cell using Boehmite nano-fluid, Int. Commun. Heat Mass Tran. 55 (2014) 45–52.

الملخص

تتناول هذه المذكرة تحسين كفاءة الألواح الكهروضوئية باستخدام أنظمة التبريد لمواجهة تراجع الأداء الناتج عن تأثير درجة الحرارة وارتفاعها. البحث مقسم لثلاثة فصول: الأول يوضح مبادئ الألواح الكهروضوئية وتأثير الحرارة عليها. الثاني يستعرض تقنيات إدارة الحرارة. والثالث، وهو تطبيقي، يقارن الكفاءة بدون تبريد، بالتبريد بالماء، وباستخدام الإيثيلين غليكول. النتائج أظهرت تحسنًا كبيرًا في الكفاءة بفضل التبريد. توصي المذكرة بدمج أنظمة التبريد في محطات الطاقة الشمسية لمضاعفة الإنتاجية وتعزيز الاستدامة.

الكلمات المفتاحية: الألواح الكهروضوئية، كفاءة الألواح الكهروضوئية، أنظمة التبريد، التبريد بالماء، الإيثيلين غليكول، الطاقة الشمسية، تأثير درجة الحرارة.

Abstract

This dissertation focuses on enhancing photovoltaic panel efficiency through cooling systems to combat performance degradation from the temperature effect. It's structured in three chapters: Chapter One covers photovoltaic panels' principles and heat's impact. Chapter Two surveys heat management techniques. Chapter Three, the applied section, compares efficiency without cooling, with water cooling, and using ethylene glycol. Results unequivocally show significant efficiency gains with cooling. The dissertation recommends integrating cooling systems into solar energy plants to maximize output and promote sustainability.

Keywords: Photovoltaic Panels, Photovoltaic Panel Efficiency, Cooling Systems, Water Cooling, Ethylene Glycol, Solar Energy, Temperature Effect.

Résumé

Cette memoire aborde l'amélioration de l'efficacité des panneaux photovoltaïques via les systèmes de refroidissement pour contrôler la baisse de performance due à l'effet de la température. Elle est répartie sur trois chapitres scientifiques plus une annexe: la première partie présente les panneaux photovoltaïques et l'impact de la chaleur. Le deuxième chapitre explore les techniques de gestion thermique. Alors que la troisième, la partie appliquée, compare l'efficacité sans refroidissement, avec refroidissement par eau, et avec éthylène glycol. Les résultats ont montré une amélioration notable de l'efficacité grâce au refroidissement. La thèse recommande d'intégrer des systèmes de refroidissement dans les centrales d'énergie solaire pour optimiser la production et la durabilité.

Mots-clés: Panneaux photovoltaïques, Efficacité, Systèmes de refroidissement, Refroidissement par eau, Éthylène glycol, Énergie solaire, Effet de la température.