الجمهورية الجزائرية الديمقراطية الشعبية

Peoples Democratic Republic of Algeria

وزارة التعليم العالي والبحث العلمي

Ministry of Higher Education and Scientific Research

جامعة غرداية

University of Ghardaïa

Registration Number

/…../…../…../…../…..

كلية العلوم والتكنولوجيا

Faculty of Science and Technology

قسم الالية والكهروميكانيك

Department of Automation and Electromechanics

Dissertation submitted in partial fulfilment of the requirements for the award of the degree of

Professional Bachelor's Degree

Field: Science and Technology

Major: Renewable Energy

Specialization: Renewable Energy and Environment

Topic

Performance analysis of Hybrid CPV systems via the solar techniques: case study of Annaba, Algeria

Presented by :

- **GUERZIZ ILYAS**
- **BOUCHAIR SAMI**

Defended publicly on :21/05/2025

Before the jury composed of:

Salah Cherif	Assistant Professor	University of Ghardaïa	President
Mansouri Anfal	Assistant Professor	University of Ghardaïa	Supervisor
Azzouzi Ahmidet	Instructor in Renewable Energies	Innovation Center of Annaba	Co-supervisor 1
Barkat Fadila	Assistant Professor	University of Ghardaïa	Co-supervisor 2
Kaddour Abdelmadjid	Full Professor	URAER of Ghardaïa	Examiner

University Year : 2024/2025

Acknowledgements

In the Name of Allah, the Most Gracious, the Most Merciful

At the conclusion of this work, we would like to begin by expressing our sincere and deepest gratitude to **God Almighty**, whose mercy, strength, and guidance have accompanied us throughout our years of study and the realization of this project. Without His divine support, patience, and blessings, we would not have been able to reach this stage. We are truly thankful for the gift of knowledge, the resilience to persevere, and the countless moments of clarity and strength He granted us. We humbly pray that this work is accepted and serves a beneficial purpose.

I would like to extend my heartfelt gratitude to my beloved family — the **Guerziz family** — for their unconditional love, constant encouragement, and unwavering support throughout every step of this journey. Their faith in me, their patience, and the many sacrifices they made have been the foundation of my perseverance and success. I owe them my deepest thanks and lasting appreciation.

I would like to sincerely thank my dear family — the **Bouchair family** — for their boundless love, steady support, and continuous encouragement throughout this academic journey. Their belief in me, along with their enduring patience and sacrifices, gave me the strength and confidence to keep moving forward. I am deeply grateful and forever indebted to them.

.

We would like to extend our profound gratitude to **Dr. Mansouri Anfal** for her invaluable support, wise guidance, and unwavering encouragement throughout the development of this project. Her insightful feedback and thoughtful supervision were instrumental in shaping the quality and direction of our work. Beyond her academic input, her patience, availability, and belief in our potential served as a constant source of motivation and confidence. We are deeply honored to have had her as our supervisor and sincerely thank her for her dedication and trust.

Acknowledgements

We would also like to express our heartfelt thanks and deep gratitude to the esteemed **Mr. Azzouzi Ahmidet** for his exceptional support, sincere dedication, and constant availability throughout all stages of this project. His generous contribution and wise guidance had a profound impact on the smooth progress of our work, helping us overcome challenges and move forward effectively. His valuable assistance was a cornerstone in the success of this project, and we remain truly appreciative of the time, effort, and unwavering support he offered us.

I would like to express my sincere gratitude to **Dr. Barkat Fadila** for her generous support and kind presence during the presentation of my thesis. Her guidance, encouragement, and unwavering support played a vital role in helping us present our work with confidence and clarity.

We would also like to thank **Dr. Mazouzi Houria** for her kind encouragement and thoughtful support during our academic journey.

We would like to express our highest appreciation and sincere gratitude to **Dr. Salah Cherif**, who graciously served as the President of the Jury. We are truly grateful for the time and attention he devoted to thoroughly reviewing our work. His insightful observations and thoughtful guidance greatly enriched the academic quality of our study. We deeply value his presence and the professionalism with which he provided constructive and objective feedback.

We also extend our heartfelt thanks to **Prof. Kaddour Abdelmadjid**, who served as Examiner of this dissertation. His careful reading and valuable remarks reflected a deep understanding and a genuine commitment to academic excellence. His precise scientific feedback and wise suggestions contributed significantly to the improvement and refinement of our research.

We are truly honored by their involvement and evaluation, and we deeply appreciate their essential contribution to the success of this project.

Acknowledgements

we extend our thanks to **All the Professors** of the **Department of Automation and Mechatronics Engineering at the University of Ghardaïa**, who have contributed to our academic and personal development, as well as all the educators who played a role in shaping our education.

Finally, To **Our Dear Friends**, we would like to express our heartfelt appreciation for your sincere friendship, unwavering moral support, and constant presence throughout this journey. In times of doubt and difficulty, your words of encouragement uplifted us; and in moments of joy, your companionship made our success even more meaningful. Your belief in us, your shared laughter, and your solidarity lightened the weight of our challenges and reminded us that we were never alone. For all of this and more, we thank you deeply and sincerely.

Abstract

Solar energy is one of the most promising renewable resources, playing a vital role in addressing environmental challenges and meeting the growing global electricity demand. However, the performance of photovoltaic (PV) systems remains constrained by various environmental factors. This study investigates the impact of three integrated solar techniques on enhancing PV panel performance: the solar concentrator, the aerovoltaic system, and the solar oven. Experiments were conducted in **Annaba, Algeria (geographic coordinates: 36.9° N, 7.77° E)**.

The adopted methodology involved designing, building, and testing functional prototypes. Results showed that the aerovoltaic system achieved a net power output of **86.07 W**, compared to **84.36 W** in the standard setup, while performance dropped to **23.76 W** without ventilation—highlighting the role of active cooling. The solar concentrator reached a peak power of **0.403 W** under **715 W/m^2** irradiance with **22.5%** efficiency, rising to **28%** under **510 W/m^2**. The solar oven allowed for stress testing at extreme temperatures up to **117°C**, providing insights into PV thermal durability. These findings confirm the effectiveness of the studied techniques in improving photovoltaic efficiency and reliability under diverse environmental conditions.

Keywords:
Solar energy, photovoltaic systems, solar concentrator, aerovoltaic system, solar oven, energy efficiency, Annaba.

الملخص

تُعَدُّ الطاقة الشمسية من أبرز مصادر الطاقة المتجددة، نظرًا لأهميتها في مواجهة التحديات البيئية وتلبية الطلب المتزايد على الكهرباء. غير أن أداء الأنظمة الكهروضوئية يظل محدودًا بسبب تأثيرات العوامل البيئية المختلفة. في هذا السياق، تهدف هذه الدراسة إلى تحليل أثر ثلاث تقنيات شمسية متكاملة على تحسين أداء الألواح الكهروضوئية، وهي: المركز الشمسي، النظام الهوائي الكهروضوئي، والفرن الشمسي. وقد تم إجراء التجارب في مدينة **عنابة (الجزائر)، الواقعة عند الإحداثيات الجغرافية: 36.9° شمالاً، 7.77° شرقاً**.

اعتمدت المنهجية على تصميم، تصنيع واختبار نماذج أولية وظيفية. أظهرت النتائج أن النظام الهوائي الكهروضوئي أدى إلى زيادة القدرة الكهربائية الصافية إلى **86.07واط** مقارنة بـ **84.36واط** في الوضع التقليدي، بينما انخفضت إلى **23.76واط** عند غياب التهوية، مما يبرز أهمية التبريد النشط. أما المركز الشمسي، فقد حقق قدرة قصوى بلغت **0.403واط** عند إشعاع مباشر **715واط/م^2** بكفاءة **22.5%**، وصلت إلى **28%** عند إشعاع **510واط/م^2**. أما الفرن الشمسي، فمكن من اختبار الألواح في ظروف حرارية قاسية وصلت إلى **117°C**، ما وفّر مؤشرات هامة حول متانتها. تؤكد هذه النتائج فعالية التقنيات المدروسة في تحسين مردودية ومتانة الأنظمة الكهروضوئية في ظروف تشغيل متنوعة.

الكلمات المفتاحية:

الطاقة الشمسية، الأنظمة الكهروضوئية، المركز الشمسي، النظام الهوائي الكهروضوئي، الفرن الشمسي، الكفاءة الحرارية، عنابة.

Résumé

L'énergie solaire figure parmi les sources renouvelables les plus prometteuses, notamment pour répondre aux défis environnementaux et à la demande croissante d'électricité. Toutefois, la performance des systèmes photovoltaïques reste limitée par divers facteurs environnementaux. Cette étude vise à évaluer l'impact de trois techniques solaires intégrées sur l'amélioration du rendement des panneaux photovoltaïques : le concentrateur solaire, le système aérovoltaïque, et le four solaire. Les essais ont été réalisés à **Annaba (Algérie), située aux coordonnées géographiques : 36.9° N, 7.77° E**.

La méthodologie adoptée repose sur la conception, la fabrication et le test de prototypes fonctionnels. Les résultats montrent que le système aérovoltaïque a permis d'atteindre une puissance nette de **86.07 W**, contre **84.36 W** dans le cas standard, alors qu'elle a chuté à **23.76 W** sans ventilation, soulignant l'importance du refroidissement. Le concentrateur solaire a généré une puissance maximale de **0.403 W** sous un éclairement direct de **715 W/m²** avec un rendement de **22.5%**, atteignant **28%** sous **510 W/m²**. Le four solaire a permis de simuler des températures extrêmes jusqu'à **117°C**, révélant la résistance thermique des panneaux. Ces résultats confirment l'efficacité des solutions proposées pour améliorer la performance et la fiabilité des systèmes PV dans divers environnements.

Mots-clés:

Énergie solaire, systèmes photovoltaïques, concentrateur solaire, système aérovoltaïque, four solaire, rendement énergétique, Annaba.

List of Figures :

List of Tables:

List of Abbreviations :

AC:	Alternating Current.
Aa:	Aperture Area.
A:	Ampere.
CPV:	Concentrated Photovoltaic.
CNRS:	Centre National De La Recherche Scientifique.
DC:	Direct Current.
EVA:	Ethylene-Vinyl Acetate.
ENS:	Solar Energy.
F:	Focal Length.
FF:	Fill Factor.
FLUKE:	Brand Of Measurement Logger (Hydra Series II).
G:	Solar Irradiance (W/M^2).
H:	Height.
I:	Current.
Icc:	Short-Circuit Current.
I-V:	Current-Voltage Curve.
Id:	Direct Irradiance.
Kw:	Kilowatt.
KWh:	Kilowatt-Hour.
KWp:	Kilowatt-Peak.
L:	Length.
MPPT:	Maximum Power Point Tracking.
m^2:	Square Meter.
m^3:	Cubic Meter.
Mylar:	Polyester Film Used For Insulation.
NIR:	Near-Infrared.
NOCT:	Nominal Operating Cell Temperature.
P:	Power.
P(V):	Power As A Function Of Voltage.
Pmax:	Maximum Power Output.
PCM:	Phase Change Material.

PV:	Photovoltaic.
PVT:	Photovoltaic Thermal.
ROI:	Return On Investment.
STC:	Standard Test Conditions.
T°C /°C:	Temperature In Degrees Celsius.
Tedlar:	Polyvinyl Fluoride (PVF) Used As Module Back Sheet.
U:	Voltage.
Up:	Pyranometer Output Voltage.
UV:	Ultraviolet.
V:	Volt.
Vco:	Open-Circuit Voltage (Voc).
VMC:	Controlled Mechanical Ventilation.
W:	Watt.
W/m^2:	Watt Per Square Meter.
η:	Efficiency.
ΔT:	Temperature Difference.

General Introduction

General Introduction:

Over the past few decades, global energy consumption has risen sharply, driven by rapid industrialization, urbanization, and population growth. This increased demand has placed enormous strain on conventional energy resources, primarily fossil fuels such as coal, oil, and natural gas. These resources are not only finite but also major contributors to environmental degradation, air pollution, and climate change.

In response, the global transition toward renewable energy sources have become a top priority for governments, researchers, and industry stakeholders. Among the diverse renewable options, solar energy is particularly attractive due to its vast availability, geographic accessibility, and versatility in both centralized and decentralized applications. Photovoltaic (PV) technology, which directly converts sunlight into electricity without greenhouse gas emissions during operation, has become a cornerstone of this transition.

Despite its clear advantages, PV systems face several performance challenges. Environmental and operational factors—including ambient temperature, solar irradiance variability, panel orientation, dust accumulation, and thermal stress—can significantly reduce energy conversion efficiency and system longevity. Addressing these challenges is essential to maximize the potential of solar energy.

This study investigates three advanced solar techniques designed to enhance the performance and reliability of PV systems:

- **Solar Concentrators (CPV systems):** These devices increase the solar radiation intensity focused onto PV cells, improving power output but potentially increasing thermal loads.
- **Aerovoltaic Systems:** Hybrid systems combining photovoltaic electricity generation with thermal energy recovery and ventilation mechanisms to cool PV panels, thereby enhancing efficiency and lifespan.
- **Solar Ovens (Thermal Simulation Setups):** Utilized experimentally here to simulate high-temperature conditions and evaluate the thermal resistance and durability of PV modules under extreme heat stress.

To illustrate the rapid development and growing deployment of Concentrated Photovoltaic (CPV) systems worldwide, this thesis includes several figures and tables that highlight global capacity growth, regional market trends, efficiency improvements, and key technological advancements over the last two decades. These visuals provide context on the increasing importance of CPV in the global renewable energy landscape.

The primary objective of this study is to analyze the influence of these complementary solar techniques on photovoltaic panel behavior and efficiency under varying operational conditions. This includes both theoretical analyses and practical experimentation, offering a comprehensive evaluation of their real-world effectiveness.

The thesis is structured as follows:

- **Chapter I** presents a broad overview of renewable energy technologies, focusing on photovoltaic systems. It details their fundamental components, operating principles, and environmental factors affecting their performance.
- **Chapter II** delves deeper into the selected solar enhancement techniques. It discusses their working mechanisms, theoretical impact on PV system behavior, and reviews relevant literature. This chapter also integrates data-driven insights and graphical representations showing the evolution of CPV systems globally, demonstrating their technological and commercial progress.
- **Chapter III** focuses on the experimental setup and results. It describes the design, construction, and testing of a hybrid aerovoltaic solar dryer, a solar oven for thermal testing, and a parabolic solar concentrator. The collected data are analyzed to assess how each configuration affects PV panel efficiency, thermal stability, and overall energy yield.

By combining theoretical study, practical design, and experimental validation, this research aims to contribute valuable knowledge towards optimizing photovoltaic technologies through innovative solar techniques that enhance performance, durability, and energy output.

CHAPTER I: General Overview of Photovoltaic Systems.

I.1 Introduction:

With the global shift towards renewable energy sources, photovoltaic (PV) systems have become a key solution for generating clean and sustainable electricity. This chapter provides a comprehensive overview of these systems, starting with an introduction to renewable energy and its importance, followed by an exploration of PV system components, their operating principles, and the factors influencing their performance. Additionally, it presents emerging technologies such as solar concentrators, aerovoltaic systems, and solar ovens. The chapter also briefly highlights the role of diagnostic procedures in enhancing the reliability and efficiency of PV systems, a topic that will be explored in greater detail in the following chapters [1].

I.2 Renewable energies:

Renewable energies naturally regenerate and never run out. They are key to moving away from fossil fuels and fighting global warming, while protecting health and the environment. Globally, their development is growing fast as countries seek cleaner, more sustainable energy. In Algeria, abundant solar radiation (over 3000 hours per year) and wind resources offer a strong potential to expand renewables, reduce fossil fuel dependence, and support sustainable growth. The main sources of renewable energy are:

- solar energy [2].
- wind energy [3].
- Hydropower [4].
- biomass energy [5].

Renewables are destined to become the most advantageous source of electricity for the planet and for economic development. Because renewable energy, when produced thanks to an integrated vision that spans the entire value chain – from the production site to the suppliers – and with a commitment to mitigating the impacts on local areas and communities, ends up being truly, totally sustainable [6].

Figure I.1: Different types of renewable energies [1].

I.3 Solar energy:

To convert solar energy into electrical energy, we need a photovoltaic cell, the assembly of cells creates a photovoltaic module or a panel [7].

I.3.1 Solar photovoltaic:

The term "photovoltaic" can refer to the physical phenomenon (the photovoltaic effect discovered by Alexandre Edmond Becquerel in 1839) or the associated technology.

Photovoltaic solar energy is electricity produced by transforming part of the solar radiation by means of a photovoltaic cell. Schematically, a photon of incident light allows under certain circumstances to set an electron in motion, thus producing an electric current [8].

I.3.1.1 Module photovoltaic components:

I.3.1.1.1 Glass:

It is a 4 mm thick tempered glass with a low iron content in order to allow better optical transmission. Its characterization with a spectrophotometer (Varian Cary 500 UV-VIS-NIR) shows a transmission greater than 95% in the useful range of the solar spectrum 380 nm to 1200 nm [9].

I.3.1.1.2 EVA (EthyleneVinlyAcetate):

EVA is a transparent resin coating photovoltaic cell. It is a transparent, heat-sensitive resin, formed from chains of copolymers of ethylene and vinyl acetate. EVA, heat-treated between 150 and160 C, has great dielectric, thermal and sealing adhesive properties [10].

The four characteristics that have made EVA a material of choice for encapsulation are:

- it's very high electrical resistivity classifies it as a very good electrical insulator,
- its relatively low melting and polymerization temperatures,
- it's very low water absorption rate,
- its good optical transmission.

I.3.1.1.3 Mylar:

Mylar is a transparent polymer film used to electrically insulate the output connections from the back of cells, is a transparent polymer film [11].

I.3.1.1.4 Tedlar:

TEDLAR is a fluoropolymer. The back of the module is made of a multilayer tedlar-aluminum film, whose role against humidity and mechanical shocks is proven, sandwiched between two 180 µm thick tedlar sheets called fluorinated polyvinyl (PVF). To improve the electrical performance of the module [12].

I.3.1.1.5 Junction box: It includes [13]:

- **Bypass diodes**: The bypass diode operates when the sum of the voltage of the cells it protects is negative and it is blocked in the opposite case.
- **A non-return diode**: The first use: is to prevent the batteries from discharging into the shunt resistor of the solar modules at night. This function can be performed globally by the regulator's switching transistors. This non-return is not the only function of the series diodes? The second function is to prevent modules in the sun from discharging into modules possibly in the shade. This is absolutely not serious (apart from additional losses) in very small installations, but could become so in larger installations, or under high voltages (solar pumps). Furthermore, in the event of an accident on one or a group of solar modules, the non-return diodes prevent the phenomenon from spreading to the entire installation.
- **Connection cable:** The electrical cables equipping the photovoltaic modules generally, have sections of 2.5 to 4 mm² for an assigned voltage of 1000 V.

I.3.1.2 Operating principle of a photovoltaic cell:

A photovoltaic cell is a sensor made of a semiconductor material that absorbs light energy and transforms it directly into electric current. The operating principle of this cell uses the properties of absorption of light radiation by semiconductor materials. Thus, the choice of materials used to design PV cells is based on the physical properties of some of their electrons that can be released from their atoms when excited by photons from the solar spectrum and having a certain amount of energy depending on their wavelengths. Once released, these charges move in the material, forming an overall direct current (DC). The flow of this current then gives rise to an electromotive force (emf) at the terminals of the semiconductor, thus corresponding to the physical phenomenon called the photovoltaic effect. [14]

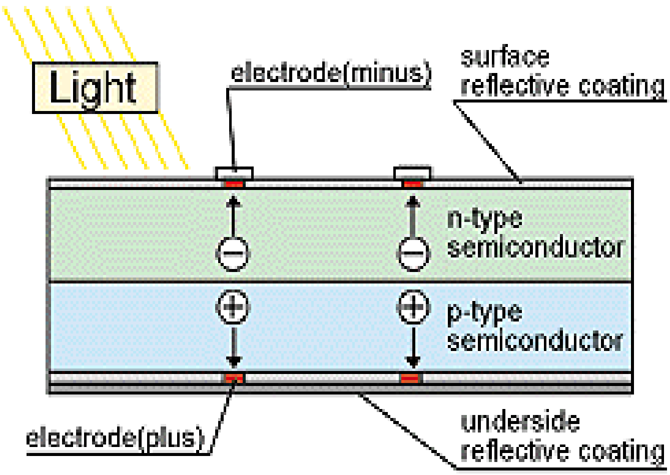


Figure I.2: principle of a photovoltaic cell [2].

I.3.1.3 The main factors influencing the PV performance:

I.3.1.3.1 Ambient Temperature:

The performance of solar panels is strongly influenced by temperature. High temperatures generally reduce the efficiency of solar panels, while low temperatures tend to increase it. However, the impact differs depending on the type of solar cell. Thin-film cells are less sensitive to temperature changes than crystalline silicon cells. In hot weather, thin-film panels will produce more electricity than crystalline silicon photovoltaic panels. In cold weather, it's the opposite.

If you live in an area where temperatures fluctuate, it may be more advantageous to opt for thin- film panels. If you live in a warm climate, it may be more appropriate to opt for crystalline silicon panels. Temperature can significantly affect the efficiency of solar panels, so choosing the right panel for your climate is essential [15].

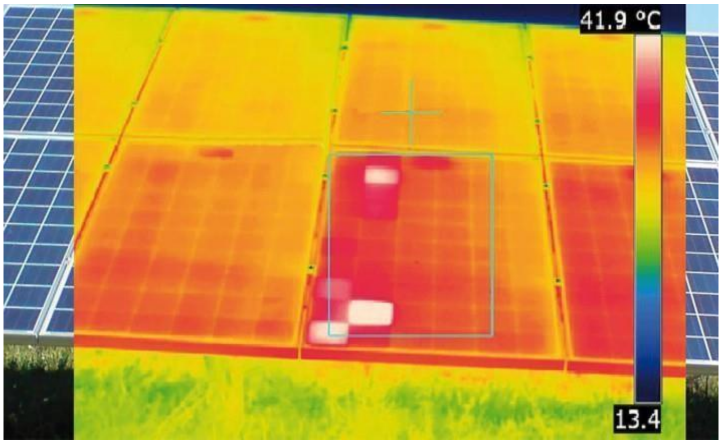


Figure I.3: Thermal Inspection of Solar Panels Showing Hotspots [3].

I.3.1.3.2 The intensity of sunlight:

Sun intensity is a factor that affects the efficiency of solar panels. Solar panel cells are devices that convert sunlight into electricity. Sun intensity can affect the efficiency of these cells. Photovoltaic cells are most efficient when exposed to moderate sunlight. The amount of electricity produced by the cells is reduced when sunlight is too strong or too weak. Solar panel systems are equipped with shading devices to keep the cells in the optimal range. This helps ensure their efficiency. These devices can greatly improve the efficiency of solar panels by ensuring consistent levels of sunlight [16].

I.3.1.3.3 Shading:

Solar panel cells are most efficient when exposed to direct sunlight. Shading from trees, buildings, or other objects can reduce the amount of sunlight that reaches the cells. This reduces the amount of electricity produced. Shading can sometimes cause hot spots to appear in the cells, which can lead to permanent damage. To ensure your solar panels get enough sunlight throughout the day, it is essential to choose their location carefully. If it is not possible to avoid shading, using specialist solar panels can help reduce the impact of shading [17].

I.3.1.3.4 Climatic conditions:

The efficiency of solar panels is greatly influenced by weather conditions. Solar panels are most efficient when placed perpendicular to the sun's rays. Solar panels are most efficient when the sun is directly overhead, which is not the case in most parts of the world.

The efficiency of solar panels is affected by the angle of the sun. When the sun is lower in the sky, its light must travel further through the atmosphere to reach the panels. The efficiency of solar panels can be reduced when some of the sunlight is scattered or absorbed before reaching the panels. Clouds can also have a similar effect, although it is less significant. Solar panels are partially shaded by trees, reducing the amount of sunlight they receive. However, the shade also helps cool the panels, making them more efficient [18].

I.3.1.3.5 Duration of use of solar panels:

The efficiency of a solar cell is influenced by the lifespan of a solar panel. Solar panels are made of semiconductor materials. However, over time, these materials degrade and their ability to convert sunlight into electricity decreases. Solar panels can become dirty and covered with debris, blocking light from reaching the cells and reducing their efficiency. To ensure optimal performance, it is essential to clean and maintain solar panels regularly. When deciding whether or not to replace aging solar panels, it is important to consider that they typically come with a 20– 25-year warranty. Solar panels can continue to produce clean, renewable energy for a long time if they are properly maintained [19].

I.4 Conclusion:

This chapter introduced the fundamentals of renewable energy, with a focus on photovoltaic solar energy, detailing its main components, operating principles, and key environmental factors such as irradiance, temperature, and shading that affect panel performance. This overview provides the necessary foundation to understand the real-world behavior of PV systems.

In the following chapter, we will examine complementary solar techniques such as solar concentrators, aerovoltaic systems, and solar ovens, and analyze their impact on improving photovoltaic system performance [20].

Chapter II: Impact of selected solar technologies on photovoltaic systems performance.

II.1 Introduction:

Solar energy remains one of the most promising sustainable solutions to today's environmental and energy challenges, driving increased focus on optimizing the performance of photovoltaic systems under real operating conditions.

In this context, this chapter explores the role of complementary solar techniques that may directly or indirectly affect the efficiency of solar panels. The study focuses on three specific technologies: solar concentrators, aerovoltaic systems, and solar ovens each analyzed in terms of their principles, characteristics, and potential impact on photovoltaic system performance [21].

II.2 Effect of Solar Concentrators on the Efficiency of Photovoltaic Panels:

Higher solar radiation is required to improve the performance of solar energy systems by increasing the amount of focused sunlight on the surface of photovoltaic panels or thermal receivers using solar concentrators. It enhances the conductivity of solar power received over a given area. But this effect is affected by many factors, such as solar radiation intensity, temperature, and materials manufacturing properties of both panels and concentrators [22].

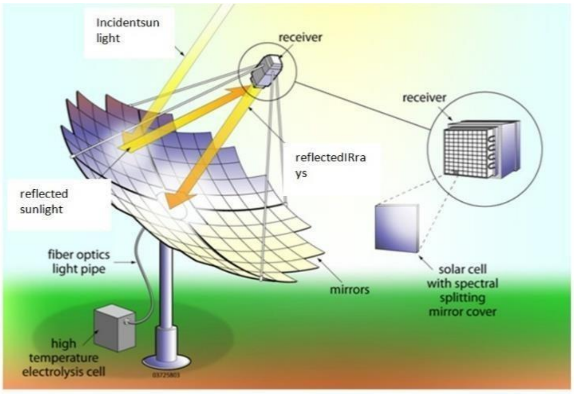


Figure II.1: Concentrated Photovoltaics [4].

II.2.1Increase in Received Solar Radiation:

Solar concentrators aim the sunlight onto a smaller area of photovoltaic panels in order to increase the amount of light that falls on the cells. This can be done with lenses or mirrors that gather and concentrate solar rays on a point or line. Having said that, with the increase in the intensity of radiation this gives rise [23]:

Increased Photons Impact: On a single photovoltaic cell, an increased number of photons falling generates a greater amount of electron-hole pairs, which causes an increase in generated electrical current [24].

Current Enhancement is More Significant: This effect is indeed present, but less intense than the one produced by the increase in current that produces partial voltage increase [25].

Improved Energy Conversion Efficiency: As the panels capture higher solar energy, the overall electricity generation rate is greater, increasing total conversion efficiency of the system [26].

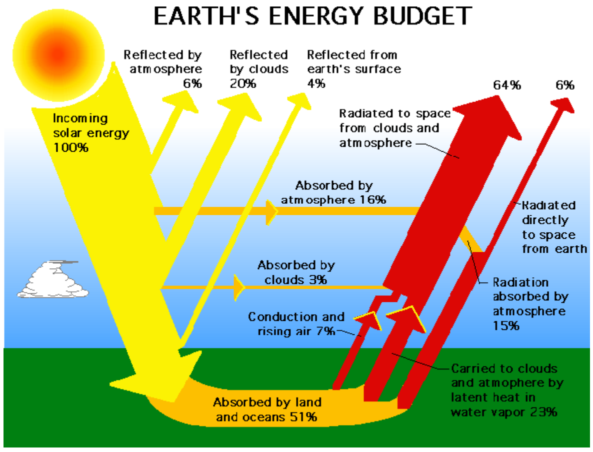


Figure II.2: Understanding Solar Radiation [5].

II.2.2Effect of Temperature Increase on Solar Panel Efficiency:

While solar concentrators increase the quantity of received radiation, they also cause an increase in the temperature of photovoltaic panels, thus reducing their performance. These effects can be condensed into [27]:

Increased Recombination: Higher temperature leads to an increase in the mobility of the charge carriers (electrons and holes), as higher temperature means higher thermal energy, which in some cases leads to increase of recombination events, reducing the cell voltage difference and energy conversion efficiency [28].

Solar Cells Resistance Increase: Solar cell internal resistance rises as temperatures increase, resulting in reduced performance [29].

Solution: Implementing Effective Cooling Systems:

Cooling systems such as those below that can lower these impacts of rising temperatures [30]:
Passive Cooling: Using air flow surrounding the panels [31].

Water Cooling: You can also circulate water over the surface of solar cells to evaporate heat [32].

Phase Change Materials (PCM) cooling: Utilizing materials that absorbs extra heat and stabilizes panel temperatures [33].

II.2.3Enhancing Energy Conversion Efficiency with Solar Concentrators:

In this article, we will discuss several ways solar concentrators improve photovoltaic system performance [34]:

- **Lower cost per active material:** Conventional panels require more mass of active materials (e.g. silicon), but in concentrators, sunlight will be focused on a relatively smaller surface area, reducing the amount of active material in every panel and thus reducing costs [35].
- **Increased Electricity Generation per m2:** Due to the intense incoming radiation, it generates much more electricity than traditional systems of the same area [36].
- **Maximized Output in Areas with High Direct Irradiation:** Solar concentrators can operate in direct sunlight and maximize their performance, therefore; it is best suited for its implementation in sunny or desert regions [37].

II.2.4 Comparison Between Traditional and Concentrated Photovoltaic Systems [38]:

Table II.1: Energetic Comparison between the both PV and CPV systems.

Criterion	Traditional Photovoltaic Systems	Concentrated Photovoltaic Systems (CPV)
Received Solar Radiation	Depends on natural sunlight intensity	Radiation is concentrated and intensified
Temperature	Low to moderate temperatures	High temperatures requiring active cooling
Conversion Efficiency	Lower due to standard radiation distribution	Higher due to optimized radiation concentration
Active Material Cost	High due to the need for a large surface area	Lower due to reduced active cell area
Solar Tracking Requirements	Not always necessary	Essential for precise alignment with the sun
Rendement (Overall Efficiency)	- Commercial efficiency: 15% – 22% - Theoretical maximum: up to ~30%	- Commercial efficiency: 35% – 45% - Theoretical maximum: up to ~70%

II.2.5 The Importance of Solar Concentrators in Enhancing PV Panel Efficiency:

How Solar Concentrators Can Help Solve the Shortcomings of PV Panels If the effects of temperature rise are tackled, this new technology, so called as solar concentrators, can be a very effective solution for improvement of efficiency ratio of photovoltaic panels. These tips can be helpful in getting the most out of the system [39]:

- Adopt proper cooling technology to avoid efficiency drop at high temperatures [40].
- Choosing solar panel and concentrator construction materials that have high thermal resistance to promote long-term performance sustainability [41].
- Designing tracking systems that can optimally orient the panels always towards the sun during the day [42].
- Incorporation of thermal storage units while the concentration is integrated into hybrid systems to provide a constant electrical power supply even after sunset [43].

❖ Photovoltaics can be established efficiently in plants under solar concentrators, which increase the amount of absorbed solar radiation. However, they do need managing heat well to excelício performance. By utilizing these technologies appropriately, it can then become possible to strike a trade-off between the performance enhancement and the reduction of the thermal disadvantages. This helps increase renewable energy manufacturing and decreases operational expenses in the long term [44].

II.3. Contribution of the AeroVoltaic System to Efficiency Improvement and temperature Reduction:

It is a concept and an aerovoltaic solution that provides not only electricity generation capacity but also utilizes heat—they used this from the air heated by solar panels. The key to this system is in solving one of the issues plaguing traditional solar panels: the fact that they become increasingly warmer when in use, ultimately leading to a gradual loss of their electrical efficiency [45].

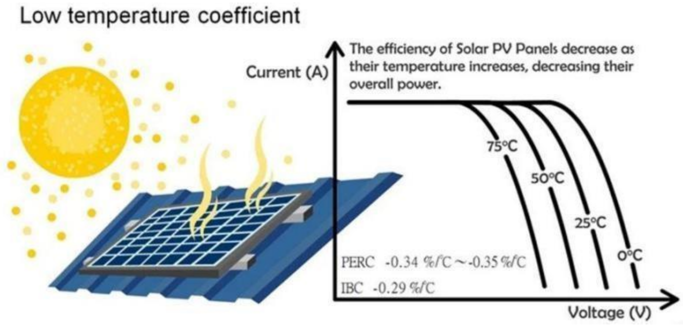


Figure II.3: Aerovoltaic System [6].

II.3.1. Advantages and Disadvantages of the AeroVoltaic System:

The hybrid solar panel offers numerous advantages while presenting some drawbacks.

Firstly, its energy efficiency is significantly higher compared to traditional photovoltaic solar panels. Additionally, it optimizes space usage by integrating two complementary technologies within the same surface area [46].

II.3.1.1 Advantages of the AeroVoltaic Solar Panel [47]:

- **High energy efficiency:** Ranges between 70% and 90%, compared to only 12% to 20% for conventional photovoltaic panels.
- **Greater energy production:** A hybrid solar panel can generate up to twice the energy for a single-family home and up to four times more for a collective building.
- **Optimized space utilization:** By combining electricity and heat production in a single unit, space is saved.
- **Eco-friendly technology:** Photovoltaic electricity generation does not produce pollution, making it a fully sustainable and environmentally friendly solution.
- **Unlimited energy source:** Solar energy is inexhaustible, free, and naturally available.
- **Long-term economic savings:** The hybrid solar system allows financial savings for up to 20 years, which corresponds to the lifespan of the panel.
- **Competitive energy costs:** As government subsidies for solar energy decrease, the selling price of electricity by producers also becomes more competitive.

II.3.1.2 Disadvantages of the AeroVoltaic System [48]:

- **Sensitivity to temperature variations:** The higher the temperature, the lower the panel's efficiency, which can impact overall performance in extremely hot conditions.

II.3.2 Enhancing Solar Panel Efficiency Through Cooling:

Photovoltaic cells in solar panels absorb heat when exposed to sunlight for extended periods, resulting in increased panel temperatures that diminish their solar electricity generation efficiency. At this juncture, the aerovoltaic system activates its functionality, this process translates into enhanced electricity production specifically in warm regions. The system avoids excessive energy dissipation by maintaining optimal panel temperature control, which results in consistent performance and prolonged panel lifespan [49].

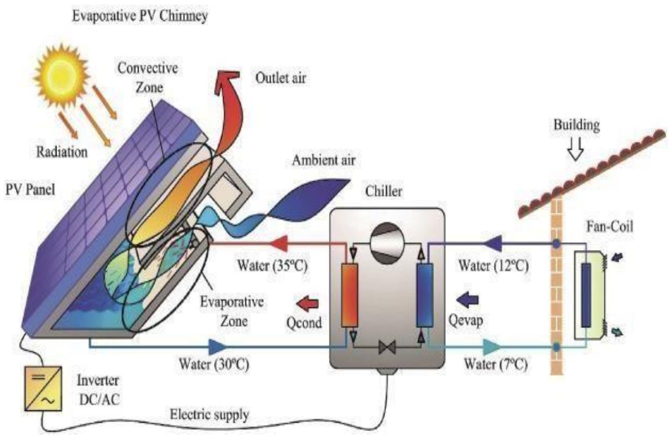


Figure II.4: Advanced Cooling Techniques of P.V Modules [8].

II.3.3 Potential Applications of Waste Heat Recovery in Aerovoltaic Systems:

Apart from improving photovoltaic efficiency, the aerovoltaic system can also be used to recover the heat produced for productive use, and thus is an inexpensive and green technology. Key uses include [50]:

- Hot air from behind the solar panels is blown into the buildings, which drastically lowers the amount of heating systems used during the winter and therefore reduces energy consumption.
- Cooling in summer: The system accomplished thermal comfort in summer with leaving conditioning use is as small as possible via airflow manufacturing.
- Food product solar drying: Warm air can be utilized to efficiently and naturally dry fruits, vegetables, and other agricultural products to facilitate sustainable food production.
- Industrial uses: Recovered heat may be utilized in a range of industrial processes requiring hot air or hot water, such as drying in factories or heating water for other uses.
- Ventilation enhancement: The system can work in conjunction with mechanical ventilation (VMC) to help improve indoor air quality and provide more even heat distribution in buildings.

II.3.4 The Dual Advantages of Aerovoltaic Technology in Energy Generation:

The aerovoltaic system is a major advancement in solar energy technology, combining higher photovoltaic efficiency with new applications for heat recovery. This combination of generating electricity and utilizing thermal energy makes it a smart and sustainable solution to meet energy needs for homes and businesses while maximizing the use of available natural resources [51].

II.4 The Parabolic Solar Oven: An Efficient and Sustainable Solution for Cooking and Sterilization:

The parabolic solar oven is an innovative outdoor cooking solution that harnesses solar energy to heat food, beverages, and sterilize medical equipment. It operates without the need for any fuel, making it an economical and sustainable option that helps reduce air pollution and curb deforestation.

This device functions by converting sunlight into thermal energy, which is then utilized for cooking and sterilization. The solar collector, designed in a parabolic shape and coated with a reflective layer, concentrates solar rays onto an evacuated tube positioned at the parabola's focal point. The collector is manufactured with a diameter of 600 mm and a depth of 150 mm, while the inner surface of the evacuated tube is coated with aluminium to enhance heat generation within the cavity.

To maximize efficiency, aluminium foil is used as a reflective layer with a reflectivity of up to 90%, significantly increasing heat concentration inside the evacuated tube. The materials to be heated, such as food, water, or medical equipment, are placed inside the evacuated tube through a designate

tray. Thanks to this design, the maximum temperature inside the tube can reach up to 302°C, making it a highly effective and reliable solution for cooking and sterilization [52].

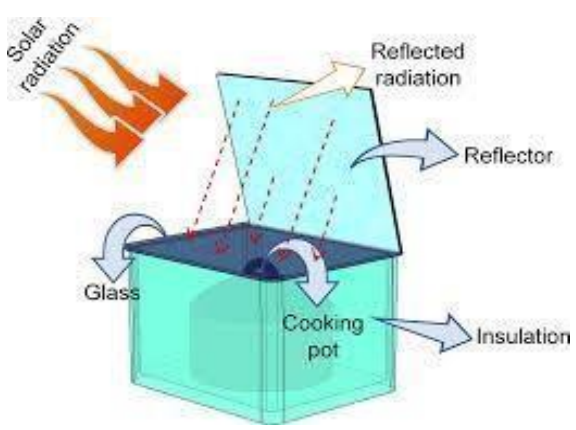


Figure II.5: Solar Cooking Systems [9].

II.4.1 Thermal Resistance Assessment of Panels Using Solar Oven Testing:

The testing of panels' thermal resistance using a solar oven is a valid method for assessing the thermal safety of panels at high temperatures and identifying possible failures. This method is achieved by providing temperature exposure to the panels that simulates an extreme operating environment where performance evaluation and indications of salient failures may be monitored [53].

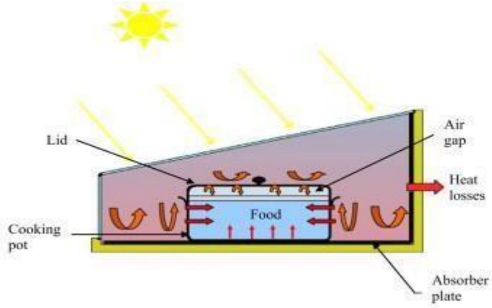


Figure II.6: Solar Cooking- an Overview [10].

II.4.2 Testing Principles [54]:

- Heating Up the Panels: The panels are placed at a high temperature within the solar oven for a defined time.
- Observing Changes: The panels are monitored both electrically and physically during and post-testing for characteristics such as cracking, thermal growth, and efficiency degradation. Objectives of the Test:
- Thermal Durability: Evaluate the panels and their functionality under thermal degradation.

II.5 Conclusion:

This chapter explored the influence of selected solar techniques on the performance of photovoltaic systems. The analysis focused on solar concentrators, aerovoltaic systems, and solar ovens, each offering different approaches to enhancing energy conversion or evaluating panel resilience under specific conditions.

These technologies were examined for their potential to either improve system efficiency or simulate operational stress, contributing to a better understanding of performance variation. The next chapter will present the experimental implementation of these concepts through the development and testing of practical solar applications [55].

Chapter III: Experimental study of solar technique.

III.1 Introduction:

Experimental validation plays an essential role in confirming the effectiveness of solar energy technologies under real conditions. After addressing the theoretical aspects in the previous chapters, this part focuses on evaluating the impact of selected solar techniques on photovoltaic performance through practical experiments.

Three systems were tested: an **aerovoltaic setup**, a **solar oven**, and a **solar concentrator**. This chapter presents their construction, testing procedures, and the analysis of collected data to assess their influence on the electrical and thermal behavior of PV panels.

III.2 Hybrid aerovoltaic solar dryer:

III.2.1 Principle of the System:

The goal of our work is to design a solar dryer that recovers heat generated by a solar panel to dry food or medicinal herbs. This approach increases the panel's efficiency compared to traditional photovoltaic systems.

The hybrid solar panel consists of a box mounted beneath a standard solar panel, tilted at 41° (an angle optimized for the Annaba region). This box captures waste heat from the panel's underside, simultaneously acting as a cooling system. It is connected to a drying chamber via a pipe. The chamber is constructed from a refrigerator's freezer compartment due to its superior thermal insulation.

III.2.2 Materials and components:

III.2.2.1 Box beneath the solar panel:

- **Primary Material :** Wood.
- **Internal Dimensions:**
    - Length: 1.02 m.
    - Width: 0.667 m.
    - Height: 0.05 m.
- **Insulation:**
    - Polystyrene (for thermal insulation).
    - Aluminium foil (for heat reflection).
- **Useful volume :** 0.0340 m^3.
- **Drying surface area :** 0.6803 m^2.
- **Surface-to-volume ratio :** 20.0088.

III.2.2.2 Drying Chamber :

- **Material:** Repurposed freezer compartment (from a refrigerator).
- **External Dimensions :**
    - Height: 0.48 m | Width: 0.70 m | Depth: 0.62 m.
- **Internal Dimensions :**
    - Height: 0.335 m | Width: 0.59 m | Depth: 0.425 m.
- **Insulation :** Refrigerator-grade thermal insulation.
- **Useful Volume :** 0.0840 m^3.
- **Drying Surface Area :** 0.1976 m^2.
- **Surface-to-Volume Ratio :** 2.3523.

III.2.2.3 Ventilation System :

Two fans are incorporated :

- **Heat Recovery Fan :**
    - Location: Box beneath the solar panel.
    - Specifications : 1A / 12V.
    - Function: Panel cooling and waste heat recovery.
- **Air Circulation Fan :**
    - Location : Drying chamber.
    - Specifications : 2.5A / 12V (turbine-type).
    - Function: Ensuring uniform hot air distribution.

III.2.3 Solar Dryer Construction:

III.2.3.1 Heat Recovery Box Fabrication:

The box was constructed using:

- **Materials:** Recycled wood scraps and plywood remnants sourced from a local carpentry workshop.
- **Construction Process:** The manufacturing steps were executed as follows:

1. Wooden boards were arranged inside the box to form a serpentine air channel.

- **Purpose:**

- Maximize heat recovery.
- Ensure efficient hot air circulation.

Figure III.1Formation of a Serpentine Air Channel Using Wooden Boards.

2. The outer surface of the box is painted black to maximize heat absorption and seal the pores (see Figure III.2).

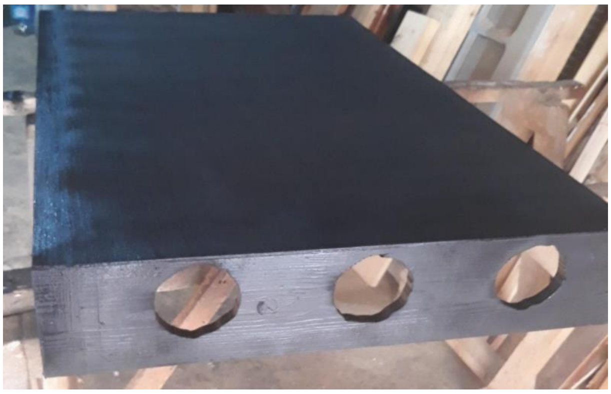


Figure III.2 Black Coating for Heat Absorption and Sealing.

3. The inner wall of the box is lined with polystyrene (Figure III.3), and aluminum foil is glued onto it to enhance thermal insulation (Figure III.4).

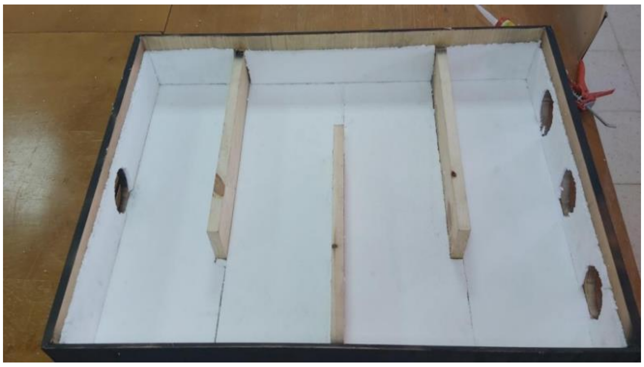


Figure III.3 Polystyrene Lining for Thermal Insulation.

Figure III.4 Aluminum Lining for Thermal Insulation.

4. A fan (salvaged from a computer) is placed opposite the lower openings of the box to draw hot air into the drying chamber (Figure III.5).

Figure III.5 Computer Fan Installed to Draw Hot Air into Drying Chamber.

5. The solar panel is mounted on top of the box, as shown in Figure III.6.

Figure III.6 Installation of the Solar Panel on Top of the Box.

III.2.3.2 Construction of the Drying Chamber

1. A defective refrigerator is cut open to separate the freezer compartment, which will be repurposed as a drying chamber.
2. A 4.5 cm radius hole is drilled in the lower section of the freezer to install a fan (typically used for cooling light vehicles). This fan circulates hot air inside the freezer, preventing food spoilage during the drying process (Figure III.7).

Figure III.7 Fan Installation for Preventing Food Spoilage During Drying.

3. The exterior surface of the freezer is painted black to:

- Completely prevent light from entering the drying chamber (Figure III.8)
- Avoid light-induced degradation of the products' composition

This preventive measure ensures better preservation of the food's properties during the dehydration process.

Figure III.8 Black Coating of Freezer to Prevent Light and Preserve Food Composition.

4. The box is connected to the drying chamber via a flexible aluminium duct. Finally, both fans are wired in parallel to the solar panel, each featuring an independent cut-off switch for easier operation of the solar dryer. Figure III.9 shows the final configuration of our solar dryer.

Figure III.9 Box Linked to Drying Chamber via Aluminum Duct; Fans Wired in Parallel with Cut-off Switches.

III.2.4 Experimental Results:

Once the dryer was completed, the following measurements were taken:

- Ambient temperature.
- Voltage and current output from the solar panel (without the heat recovery system).
- Generated power (calculated).

The results are shown in **Table III.1**, which summarizes the measurements taken with the panel alone (without the heat recovery system).

Table III.1: Table Illustrating Photovoltaic Panel Behavior Without Cooling or Heat Recovery Systems.

Time (min)	Ambient Temperature T(C°)	Voltage U(v)	Current I(A)	Measured output power P(w)
8:30	26.9	19.80	3.85	76.46
9:00	24.6	18.73	4.16	77.91
9:30	35.7	18.52	3.24	60.00
10:00	34.2	18.3	4.61	84.36
10:30	34.8	18.40	4.56	83.90
11:00	35.2	18.33	4.51	82.66
11:30	35.6	18.1	4.36	78.91
12:00	37.6	18.28	4.12	75.31
12:30	37.5	18.17	4.42	80.31
13:00	35.3	18.19	4.3	78.21
13:30	35	18.28	4.6	84.08
14:00	36.7	18.38	2.74	50.36
14:30	35.6	18.42	4.42	81.41
15:00	34.1	18.16	2.16	39.22

The data presented in this table detail the behavior of the photovoltaic (PV) panel operating under natural environmental conditions, without the implementation of any active cooling or heat recovery systems. Throughout the morning hours, the power output of the panel exhibits a steady increase, driven primarily by the rising solar irradiance as the sun ascends. The power output reaches its maximum level between approximately 10:30 and 11:30 AM, which corresponds to the period of optimal solar exposure.

However, following this peak, the power output begins to decline even though solar irradiance remains relatively high. This performance degradation is largely attributed to the thermal effects on the PV panel. Specifically, the accumulation of heat on the panel's surface elevates its temperature beyond optimal operating levels. Since PV cells typically exhibit reduced efficiency at higher temperatures, this thermal buildup causes a drop in electrical output despite the continuous availability of solar energy.

The figure below illustrates this behavior, with a noticeable sharp peak in power output corresponding to the morning increase, followed by a gradual but consistent decline as the panel temperature rises. This trend highlights the critical influence of thermal management on the performance of PV systems. Without effective cooling or heat dissipation methods, the efficiency of photovoltaic panels can be significantly compromised, reducing overall energy yield and system effectiveness.

These findings underscore the importance of integrating thermal control strategies, such as passive cooling, forced air circulation, or heat recovery, to mitigate the adverse effects of overheating and optimize the operational performance of PV installations.

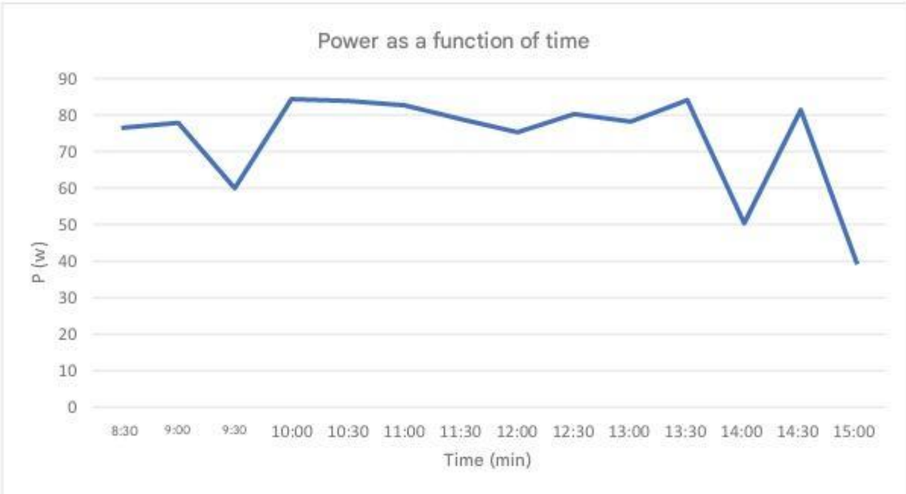


Figure III.10: Power output curve of the solar panel without heat recovery system as a function of time.

The second experiment involves measuring:

1. Temperatures (ambient and drying chamber).
2. Voltage and current output from the solar panel connected to the cooling system (chamber inactive, fans off).

   The panel's power output is then calculated.

Table III.2: Measurements with panel linked to the heat recovery system (fans disabled).

Time (min)	Ambient Temperature T(C°)	Temperature in drying box T(°C)	Voltage U(v)	Current I(A)	Measured output power P(w)
8:30	24	33.7	18.87	3.98	75.10
9:00	24.8	32.8	18.7	4.37	81.71

9:30	35.8	33	18.66	4.58	85.46
10:00	33	33.8	18.4	4.66	85.74
10:30	36.1	38.1	18.22	4.55	82.90
11:00	35.1	37.8	18.32	2.44	44.70
11:30	32.7	34.3	18.3	3.47	63.50
12:00	36.5	32.9	18.2	2.83	51.50
12:30	36.2	34.2	17.83	1.50	26.74
13:00	35.9	36.6	18.00	1.32	23.76
13:30	34.8	33.1	18.12	2.18	39.50
14:00	37.9	33.2	18.40	4.60	84.64
14:30	33.8	35.8	18.49	4.49	83.02
15:00	35.5	34.6	18.56	4.37	81.10

This table presents the results of the second experiment, where the PV panel is connected to the heat recovery box but the fans remain turned off. Initially, the panel's performance closely matches that of the baseline test, reaching a peak power output of 85.74 W at 10:00 AM. However, the decline in output occurs earlier and more sharply compared to the previous experiment. By 1:00 PM, the power has dropped significantly to only 23.76 W, despite ambient temperatures remaining relatively high.

This indicates that without active airflow, the heat recovery system acts as a thermal trap, causing heat to accumulate underneath the panel and consequently reducing its electrical output. The lack of ventilation leads to heat buildup, which adversely impacts both the voltage and current generated by the panel. Therefore, although this setup is conceptually designed to improve energy efficiency, it can have the opposite effect and reduce overall performance if not coupled with sufficient thermal management.

The following graph illustrates greater fluctuations and an earlier decline in power output compared to the previous test, confirming that passive heat accumulation without proper ventilation degrades PV panel performance.

Figure III.11: Power output curve of the solar panel connected to the heat recovery system as a function of time.

The third experiment involves :

1. Extracting hot air from the heat recovery chamber.
2. Channeling this air into the drying compartment.
3. Recording measurements after 15 minutes of fan operation:
   - Temperatures (ambient and recovery chamber).
   - Panel voltage and current.
4. Calculating the panel's power output.

Table III.3: Measurements with panel connected to the thermal energy recovery system and air flow directed to the drying chamber.

Time (min)	Ambient Temperature T(C°)	Temperature In box T(C°)	Voltage U(V)	Current I(A)	Measured output power P(w)
8:45	34	35.3	18.61	4.44	82.62
9:15	34	35.3	18.66	4.44	82.85
9:45	33.8	35.7	18.55	4.64	86.07
10:15	37.8	38.3	18.34	4.65	85.28
10:45	34.1	38.8	18.20	3.90	70.98
11:15	34.3	39.6	18.2	2.50	45.5

11:45	34.3	38.00	18.04	1.06	19.12
12:15	36.1	42.1	18.2	3.12	56.78
12:45	36.2	43.2	18.16	4.5	81.72
13:15	41.8	36.6	18.08	1.87	33.80
13:45	33	39.3	17.35	0.99	17.17
14:15	37	42.1	18.26	4.53	82.71
14:45	36.1	48.8	18.52	4.28	79.26
15:15	34.8	42.5	18.32	2.13	39.02

This table presents the results of the third experiment, in which the fans were activated to extract hot air from behind the solar panel and channel it into the drying chamber. The power output showed a noticeable increase during the early morning hours, reaching a peak of 86.07 W at 9:45 AM, indicating an improvement compared to the previous experiments. This enhanced performance is attributed to the partial cooling effect provided by the airflow, which helped reduce surface overheating of the panel.

However, as both ambient and internal temperatures continued to rise, reaching 48.8°C at 2:45 PM, the cooling system became insufficient to cope with the thermal load, and the power output declined to 39.02 W by 3:15 PM. This suggests that the ventilation setup cannot fully manage the heat stress during peak midday hours, leading to a drop in panel performance.

The following figure illustrates a relatively stable power output during the morning, followed by a gradual decrease in the afternoon. These results confirm that while fan-assisted ventilation can improve early-morning efficiency, it is inadequate to maintain optimal operating conditions under intense solar radiation.

Figure III.12: Power output curve of the solar panel connected to the thermal energy.

Remark:

Comparative analysis of the experimental results indicates:

1. **Power reduction** between Experiments 1/2 and Experiment 3 due to:
    - Solar panel heating.
    - Inadequate fan capacity for effective cooling.
2. **Power fluctuations** caused by :
    - Environmental factors (cloud cover, temperature variations).
    - Measurement uncertainties (temperature sensors).

- The implemented system operates as a heat recovery unit but fails to perform as an active photovoltaic cooling mechanism.

❖ **Impact on PV Performance:**

The aerovoltaic system demonstrated its effectiveness in improving the cooling of the PV panel, helping to stabilize voltage output and reduce thermal stress during peak sun hours. This cooling effect can enhance electrical efficiency and extend panel lifespan under high irradiance conditions.

III.3 Solar Oven:

The solar box oven is a thermally insulated chamber, equipped with a transparent lid and reflective interior surfaces. Sunlight passes through the glass and is reflected by the internal walls until it strikes the dark surface of the container. The energy from these rays is then converted into heat. To enhance solar radiation capture, aluminum-coated reflectors are installed on either side of the box, directing light toward the glass at a more perpendicular angle to the sun's rays. The solar oven operates solely with direct sunlight: the presence of clouds, fog, or dust reduces radiation intensity and consequently extends the cooking time.

Figure III.13: The solar box oven.

III.3.1 Solar Oven Fabrication:

III.3.1.1 The Box:

III.3.1.2 The Frame:

The construction process begins with building the frame. Wooden pieces are cut to specific dimensions for this purpose.

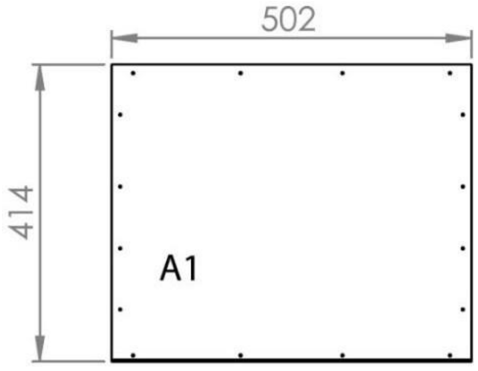
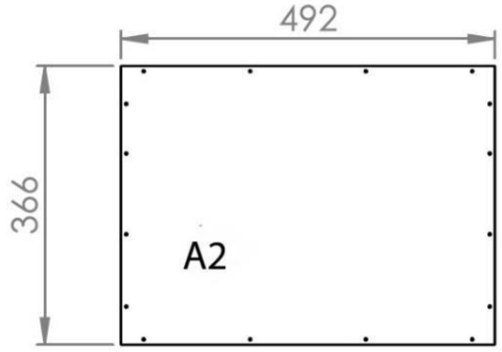


Figure III.14: Rear Wall.



FigureIII.15: Front Wall.

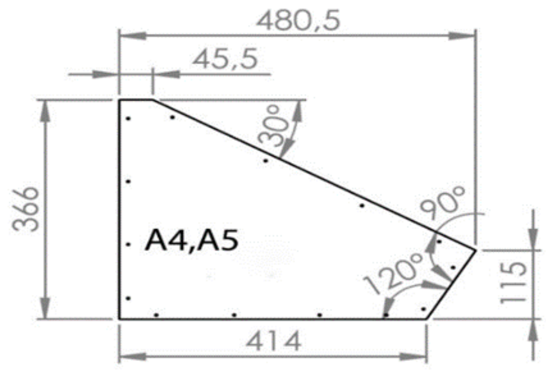


Figure III.16: Left and Right Walls.

III.3.1.3 Box Walls and Assembly onto the Frame:

The box is made up of five walls, as shown in Figure III-17.

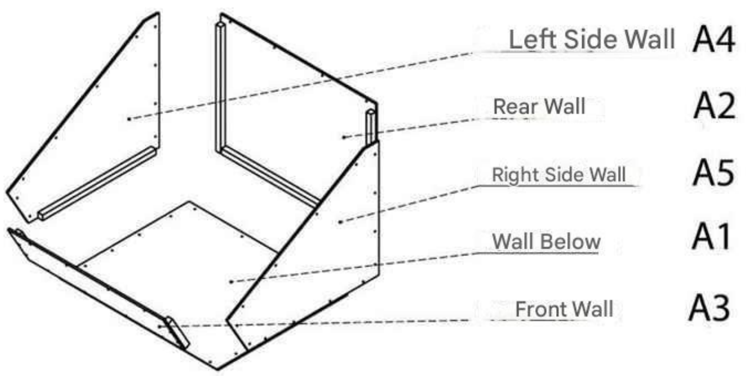


Figure III.17: Representation of the Box Walls.

III.3.1.4 The Oven Basin in Aluminum

The oven basin is made from a 0.3 mm thick aluminum sheet, which is cut and folded to precisely match the interior shape of the box.

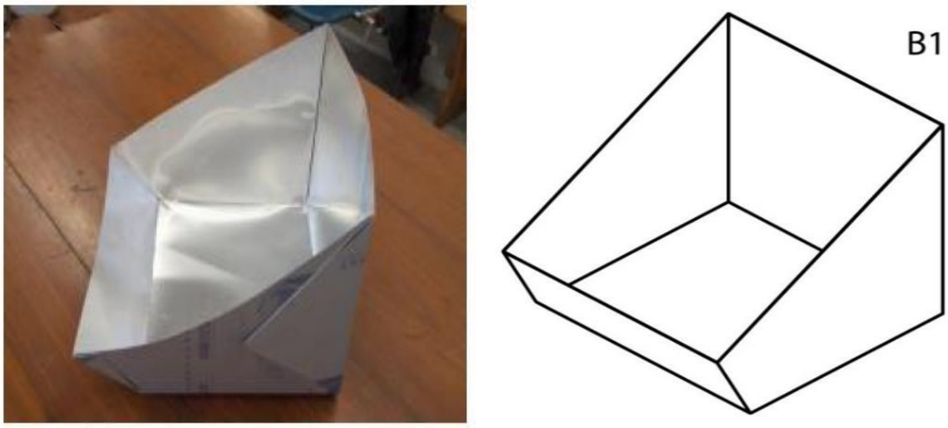


Figure III.18: Folded Aluminum Basin.

III.3.1.5 Assembly of the Box and Aluminum Basin:

The aluminum basin is placed inside the wooden box, ensuring optimal insulation between the basin and the box using mineral wool or polystyrene foam.

Figure III.19: Assembly of the Box and Basin [11].

III.3.1.6 Glazed Door and Reflector:

III.3.1.6.1 The Frame of the Glazed Door:

The frame of the glazed door is fabricated as shown in the following figure.

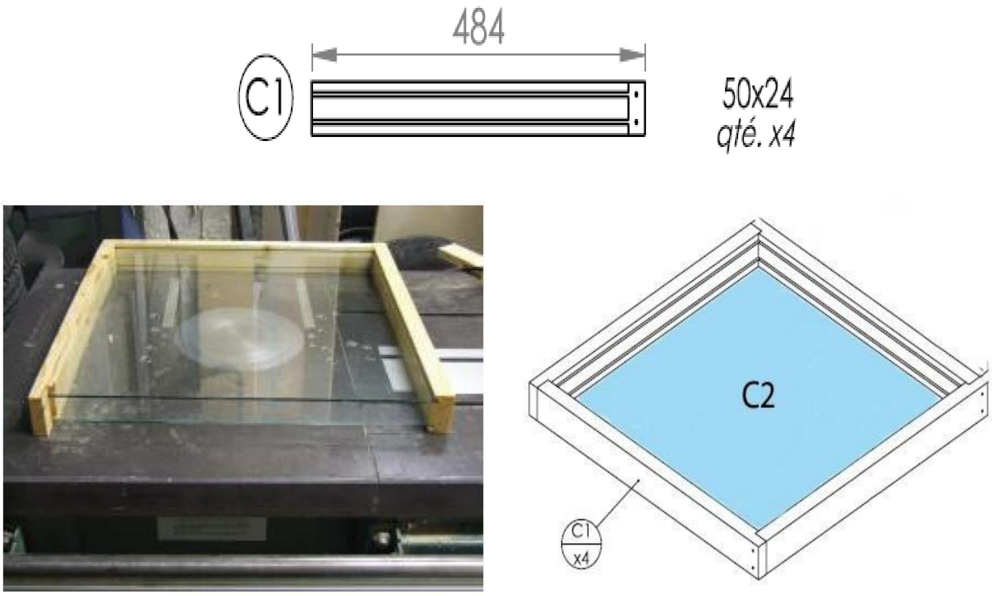


Figure III.20: Glazed Door Frame.

III.3.1.6.2 The Reflector:

The wooden piece is cut to the specified dimensions below, and then a self-adhesive mirror paper is applied to its surface.

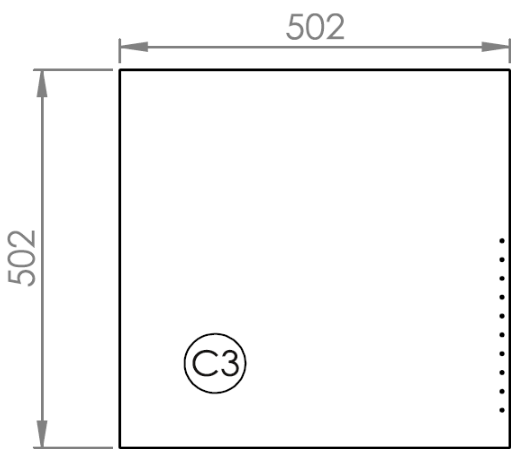


Figure III.21: Reflector.

III.3.1.6.3 Assembly of the Reflector and Glazed Door:

The assembly of the reflector with the glazed door is carried out as shown in the following figure.

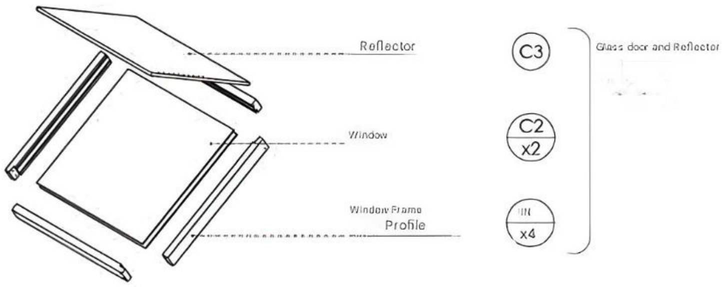


Figure III.22: Assembly of the Reflector and Glazed Door.

III.3.1.7 Final Assembly

The final assembly is carried out in eight steps, as illustrated in Figure III.23.

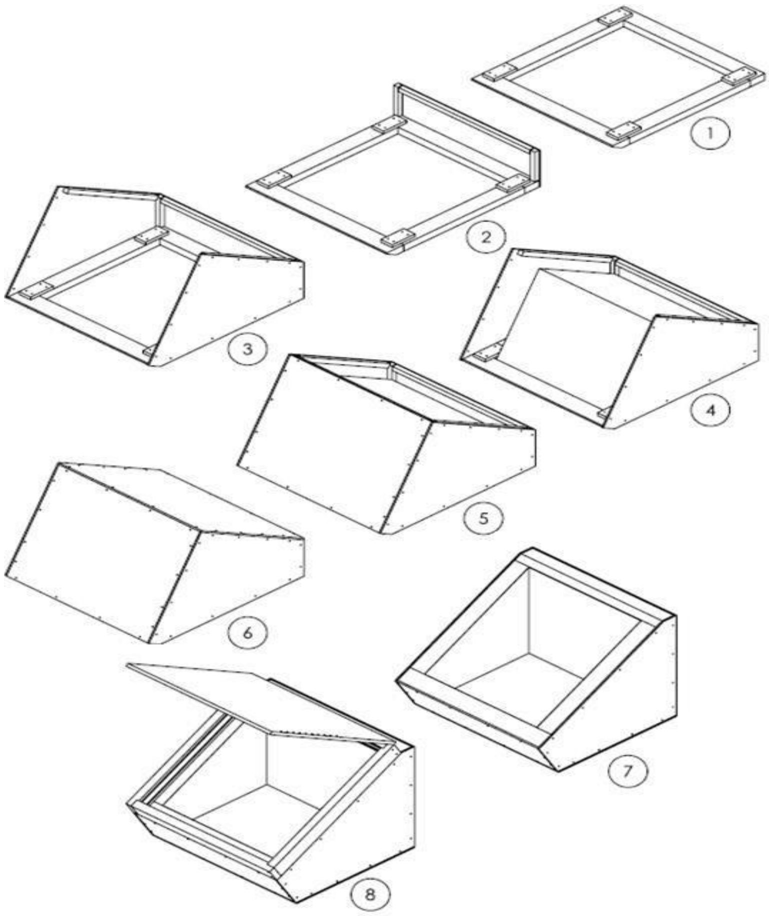


Figure III.23: Final Assembly.

III.3.2 Experimental Tests:

Table III.4: Results of the Tests Conducted on the First Day of testing, January 27, 2025.

Time (h)	Global radiation (W/m²)	Climate Temperature (°C)	Oven Temperature (°C)
8:30	420	17	0
8:45	630	17	50
9:00	840	18	55
9:15	660	18	60
9:30	1245	18	75
9:45	1230	19	82
10:00	1200	19	93
10:15	1410	20	100
10:30	435	20	95
10:45	435	20	87
11:00	390	21	85
11:15	780	21	80
11:30	900	21	87

This table illustrates the evolution of the oven's internal temperature in response to increasing solar irradiance. Starting from 0°C at 8:30 AM, the oven temperature rose steadily, reaching a peak of 100°C by 10:15 AM, which coincided with the maximum recorded solar irradiance of 1410 W/m². This strong correlation indicates that the oven effectively harnesses solar energy during the early hours of the day.

However, after reaching this peak, the oven temperature began to decline, despite relatively stable ambient conditions. This unexpected decrease may be attributed to several factors, such as temporary cloud cover reducing solar input, heat losses through the oven's structure, or the limitations of thermal insulation at high internal temperatures.

Table III.5: Results of the Tests Conducted on the Second Day of testing, January 28, 2025.

Time (h)	Global radiation (W/m²)	Climate Temperature (°C)	Oven Temperature (°C)
8:30	1140	19	0
8:45	1200	22	96
9:00	1230	23	102
9:15	1290	23	105
9:30	1290	23	106
9:45	1260	23	109
10:00	1245	24	110
10:15	1215	24	114
10:30	1215	24	114
10:45	1230	24	115
11:00	1230	24	116
11:15	1290	24	117
11:30	1305	24	117

On the second day, the solar oven demonstrated improved performance. Beginning at 0°C at 8:30 AM, the internal temperature rose rapidly, reaching 117°C by 11:30 AM, under stable solar irradiance levels exceeding 1200 W/m². This enhanced efficiency is attributed to more favorable weather conditions and slightly higher ambient temperatures compared to those observed on the first day.

The following figure illustrates a clear correlation between the intensity of absorbed solar radiation and the resulting oven temperature, confirming the oven's strong dependence on solar input for thermal performance.

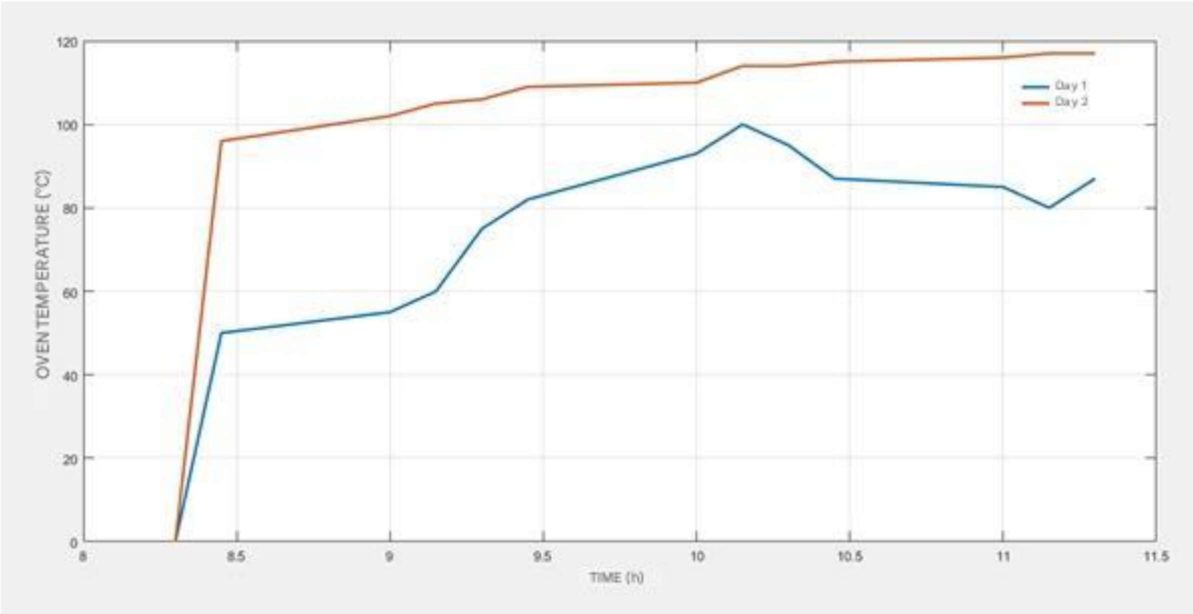


Figure III.24: Variation of the Oven Temperature Over Two Days.

This graph illustrates the power output of the solar panel operating without any heat recovery or cooling system. The curve displays a gradual increase in electrical output during the early morning hours, reaching a peak between 10:30 and 11:30 AM. Following this peak, a noticeable decline occurs, even though solar irradiance remains consistent.

This downward trend reflects the adverse impact of thermal accumulation on the panel's performance. As the surface temperature of the panel increases, its electrical efficiency diminishes due to the temperature sensitivity of photovoltaic cells. The shape of the curve clearly confirms that in the absence of active or passive cooling strategies, the panel suffers from overheating, leading to a significant reduction in power output.

❖ **Impact on PV Performance:**

Although the solar oven is primarily a thermal application, it enabled simulation of extreme temperatures, providing useful insights into the thermal tolerance and material behavior of PV modules under harsh conditions. This test environment helps assess how PV systems respond to high thermal loads, contributing to durability analysis

III.3.2.1 Tests on the Oven's Operation:

III.3.2.1.1 The Procedure:

To test the proper functioning of the oven, the following experiment was conducted: a glass container containing water and an egg is placed in the center of the oven, and checks are made every 15 minutes.

Figure III.25: Container Containing an Egg.

Figure III.26: Container Inside the Oven.

Figure III.27: The Egg Prepared After 30 Minutes.

III.3.2.1.2 Observation:

It was observed that after the first 15 minutes, the egg white is cooked, and after 30 minutes, the egg is fully cooked.

III.3.2.1.3 The Result:

From this experiment, it can be concluded that the solar oven is capable of cooking food. However, compared to an electric wave oven or traditional cooking, the cooking time with a solar oven is much longer.

III.4 solar concentrators:

We will examine the various stages involved in the development of the offset-type parabolic solar concentrator. This type was chosen due to its availability and its effectiveness in avoiding the shadow effect on the reflector.

Figure III.28: General overview of the prototype.

III.4.1 Description of the different parts of the prototype:

The test bench consists of an offset parabolic dish covered with a highly reflective film, with monocrystalline solar cells placed at its focal point.

III.4.1.1The Reflector:

The reflector is made from an old satellite dish, which was first covered with glossy paper to smooth out surface irregularities and reduce roughness. A self-adhesive aluminum reflective film was then applied to the surface to create the reflector, with the film’s shiny side oriented toward the sun.

To minimize optical imperfections on the reflective surface, the aluminum film was cut into small strips before being applied. Figure (III-29) illustrates the main construction steps.

Figure III.29: The steps for constructing the reflector.

The aluminum reflector is made of Mylar type material with a reflectivity coefficient greater than 0.85. The geometric characteristics of the parabola are provided in the following table:

Table III.6: Geometric Characteristics of the Reflector.

Geometric Characteristics of the Reflector	
Diameter	D=1.81m
Size	H=0.26m
Focal length	F=0.78m
Aperture area	Aa=2.57m²

Once the parabola is completed, a mounting frame must be constructed on which it will be placed, as shown in Figure III.30.

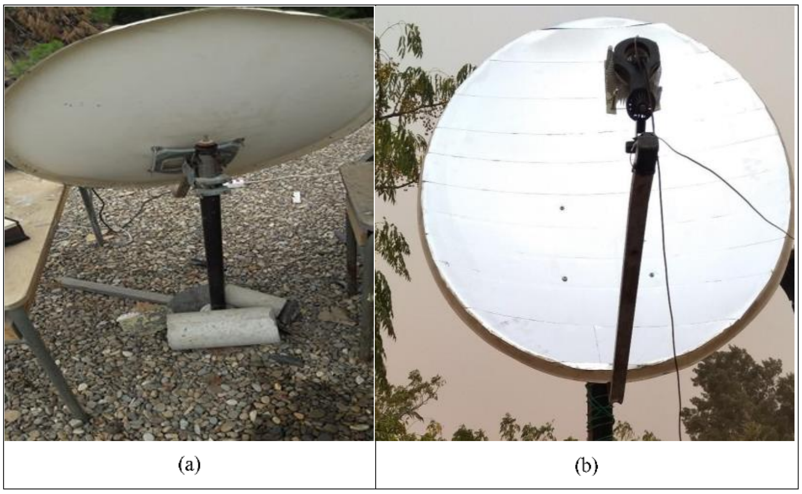


Figure III.30: a) Rear view of the prototype, b) Front view of the parabola before the start of the experiment.

III.4.1.2 Description of the Receiver:

Four basic solar cells are connected in parallel to increase both current and voltage, resulting in higher electrical power output.

These cells are mounted on a heat sink to effectively dissipate heat and are protected by a transparent glass cover on the front surface to shield them from external elements.

Figure III.31: The placement of the cells on the heat sink.

III.4.2Experimentation:

III.4.2.1 Determination of the focus of the dish:

Remember that the role of the parabola is to concentrate all the solar radiation received towards a point (focus). It should be noted that our parabola is not quite round. We found a focal length equal to 0.78 m.

We will also proceed to the experimental determination of this distance by proceeding to the localization of the luminous point resulting from the light reflected by the curved surface of the parabola figure III.32.

Figure III.32: Determination of the focus of the dish

III.4.2.2 Measuring the temperature of the fireplace

The test consists of evaluating the distribution of the concentrated flux at the focus of the dish. This can be achieved by the temperature distribution in the focal spot. The measurement of the different temperatures at the focus of the dish is provided by thermocouples of type K figure III.33. This measurement allows us to precisely locate the position of the focus by placing thermocouples at different radial distances at the focus from the center.

Figure III.33: K-type thermocouple

The photos in Figure III.34 show the location and binding of the thermocouples to the data acquisition.

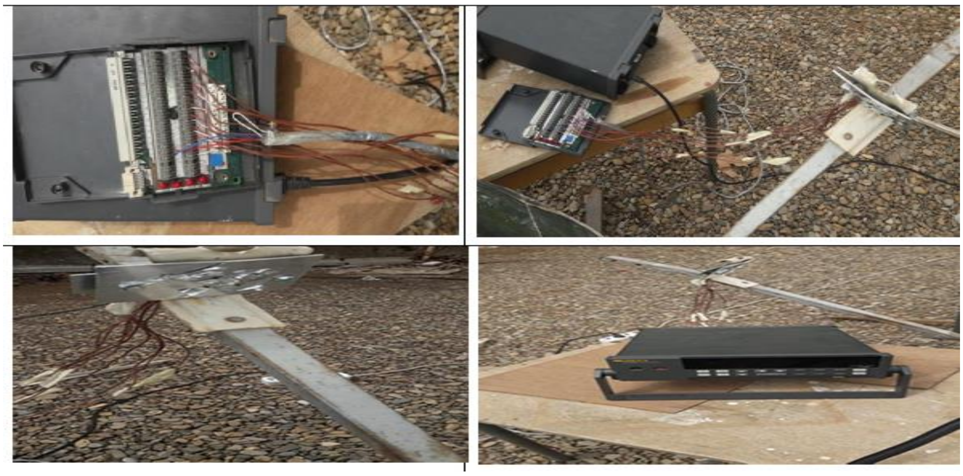


Figure III.34: The location of thermocouples in data acquisition

To determine the temperature at the hearth, tests were carried out under varying metrological conditions and for different periods.

III.4.2.3 Data acquisition:

A Fluke Hydra Series II type logger is used for data acquisition. It allows the reading of the various parameters, namely: the ambient temperatures and that of the cells placed at the focus as well as the solar irradiance and the voltage delivered by the cells, see figure III.35.

Figure III.35: Data logger type FLUKE HYDRA SERIES II.

III.4.2.4 Installing the hub:

We know that the parabolic concentrator works when the sun's rays are parallel to its axis. So, it must be placed in a bright and well-ventilated environment, with a clear sky, avoiding shady areas around the equipment. The system is directed towards the sun, and the measuring devices (pyranometers and thermocouples) are installed to measure the illuminance and temperature at the receiver. The sun is tracked manually to always obtain a good focal spot.

III.4.2.5 Solar radiation measurement:

The measurement of the incident global illuminance on the surface of our concentrator is carried out using a pyranometer III.36. The latter is fixed on a bracket installed parallel to the surface of the hub. From the voltage Up measured at the output of the pyranometer (inµV), the value of the solar radiation E (W/m2) is determined by the relationship: E=Up/sensDevice sensitivity, for CM6B model, Sense = 10.60µV.

Figure III.36: Pyranometer for illuminance measurement.

A second pyranometer, whose sensitive surface is obscured, is used to measure diffuse illuminance. The value of the direct illuminance is obtained by difference.

Direct illuminance = Normal global illuminance – Diffuse illuminance.

III.4.2.6 Thermocouples:

A thermocouple is made up of two different conductors of material or assemblies at one end and subjected to a temperature gradient generated at their ends, a voltage dependent on the temperature and the choice of the two materials is then delivered.

III.4.3 Measurement technology and connections:

III.4.3.1 Principle:

If a temperature deviation is present along a metal wire, a load transfer occurs depending on the characteristics of the material. The energy conversion generates an emf within this conductor, the size and direction of which depend on the material, the direction, and the temperature gradient.

This is why the thermoelectric effect with 2 welded conductors is used together at one of their ends. A measurable voltage at the free ends is then obtained in the presence of a temperature gradient.

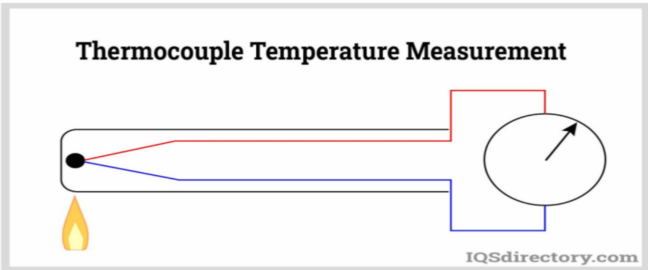


Figure III.37: Principle of operation of a thermocouple.

III.4.4 Data analysis and interpretation of the results obtained:

In this part, we will present the effect of solar concentration on the parameters of monocrystalline photovoltaic cells (4 cells placed in parallel), Voc, Icc and the variation of conversion efficiency as a function of illumination for different values of variable resistances. Finally, the simulation is carried out in Matlab/Simulink according to a program which is presented in Figure III.38:

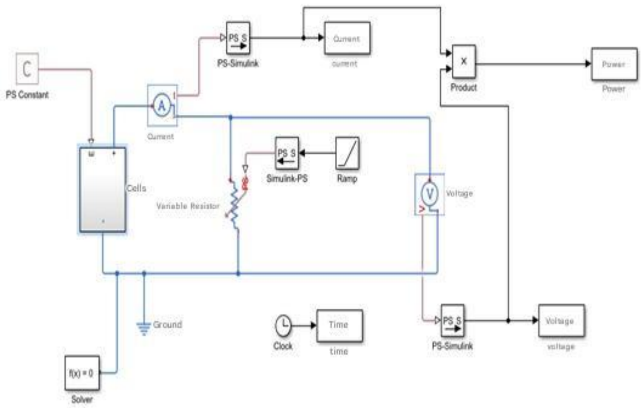


Figure III.38: Simulation program in Matlab/Simulink

III.4.4.1 Characteristic I (V) and P(V) under concentration:

- **1st experience :**

The test performed for direct illuminance Id=715 W/m² is shown in Table III.7 and the characteristics are shown in Figures III.39 and III.40.

Table III.7: measured values of the voltage and current generated by the cells under illumination Id=715w/m².

I(A)	0.46	0.38	0.4	0.35	0.32	0
V (v)	0	1.007	1.007	1.02	1.045	1.29

his table reflects the first test under high direct irradiance. The current reached 0.46 A and voltage 1.29 V, producing a peak power of 0.403 W. The cell temperature rose to 140°C, indicating intense heat buildup. While the electrical output is significant, this level of heat may lead to degradation if not controlled.

The next figures illustrate the I(V) and P(V) curves, showing strong performance under concentrated light with noticeable power gain. However, the thermal impact on the cells is evident and must be addressed.

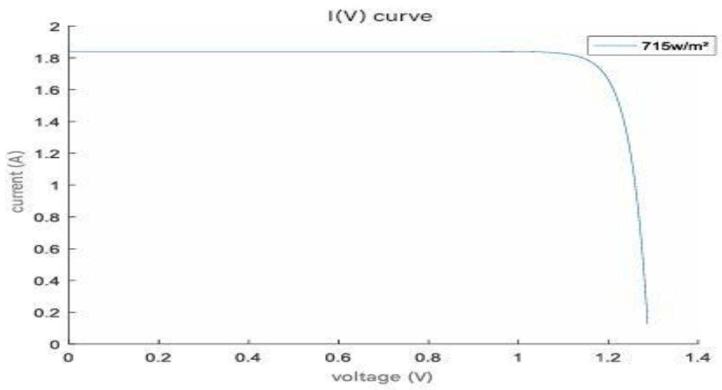


Figure III.39: the I(V) curve under concentration with Id=715W/m².

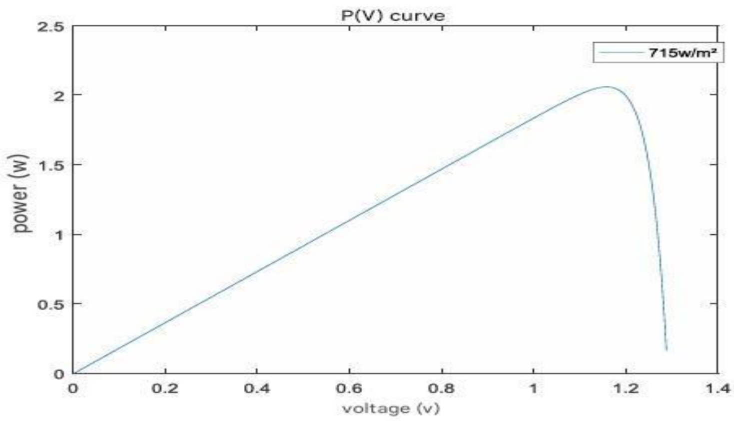


Figure III.40: The P(V) curve under concentration with Id=715W/m².

- **2nd experience**

This time the measurements are taken under direct illumination Id=510 W/m² as shown in Table III.8 and the characteristics are illustrated in Figures III.41 and III.42:

Table III.8 measured values of the voltage and current generated by the cells under illumination Id=510w/m²

I(A)	0.4	0.35	0.325	0.29	0
V (v)	0	1.022	1.0025	0.9375	1.027

This table presents the results of the second experiment using the solar concentrator under a direct irradiance of 510 W/m². The current values range from 0.4 A to 0 A, while the voltage varies between 0 V and 1.027 V. These values indicate a moderate level of electrical output, showing that the panel responded to the available light but without reaching its maximum potential.

The next curves demonstrate effective energy generation despite lower irradiance. The results underscore the importance of thermal management in maintaining high efficiency.

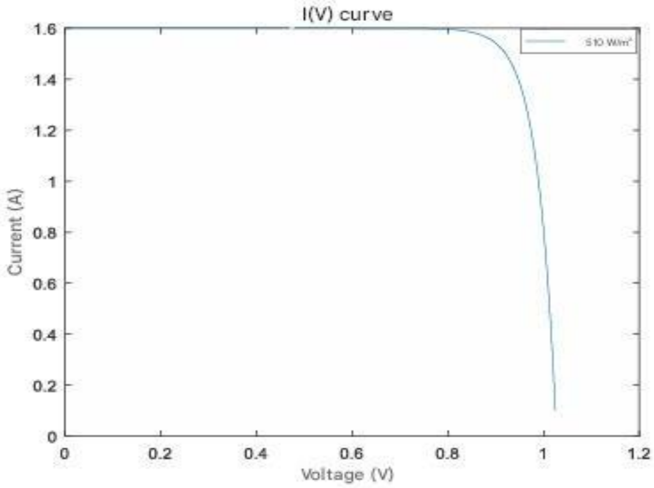


Figure III.41: The curve I(V) under concentration with Id=510 W/m²

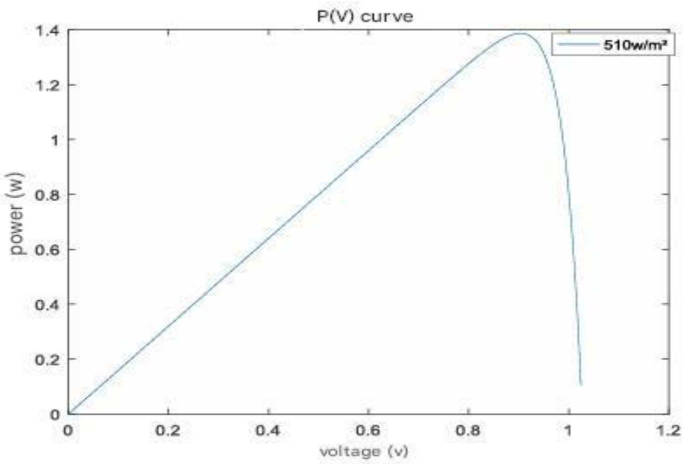


Figure III.42: The P(V) curve under concentration with Id=510W/m²

- **3rd experience**

The results of the last experiment, which is carried out under an overcast sky with an illuminance Id=194 W/m², are shown in the table and the characteristics are illustrated in Figures III.43 and III.44.

Table III.9: measured values of the voltage and current generated by the cells under illumination Id=194 W/m²

I(A)	0.3	0.175	0.125	0
V (v)	0	0.41	0.302	0.77

This table displays the third experiment's results, conducted under low irradiance conditions of 194 W/m², likely due to overcast skies. The current starts at 0.3 A and decreases to 0 A, while the voltage ranges from 0 V to 0.77 V. As expected, the resulting power output is quite low, not exceeding 0.0717 W.

The following curves reflect poor performance under low light, with significant reductions in both current and voltage. This confirms that solar concentration is ineffective in diffuse light conditions.

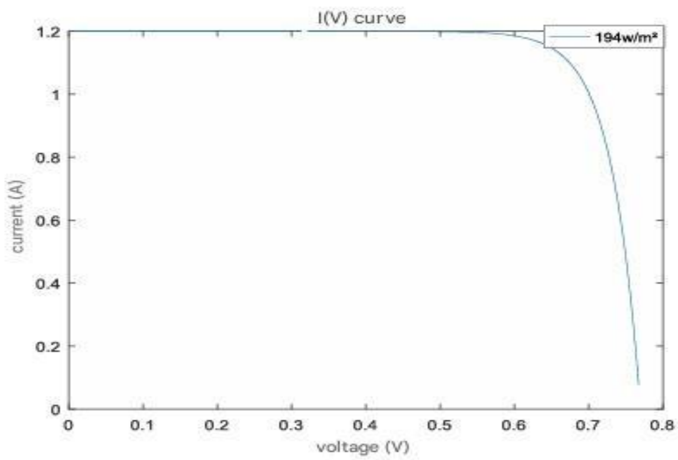


Figure III.43: the curve I(V) under concentration with Id=194 W/m²

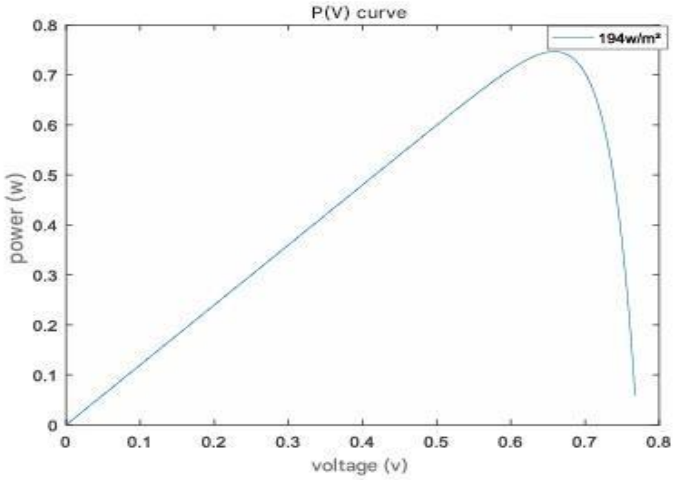


Figure III.44: The P(V) curve under concentration with Id=194w/m²

III.4.4 Comparative Analysis of Concentrated PV Performance:

The data presented in Table III.10 and the curves in Figures III.47 and III.48 provide a clear comparative view of the photovoltaic cell performance under different levels of concentrated solar irradiance. Three experimental conditions were tested: high irradiance (715 W/m²), moderate irradiance (510 W/m²), and low irradiance (194 W/m²).

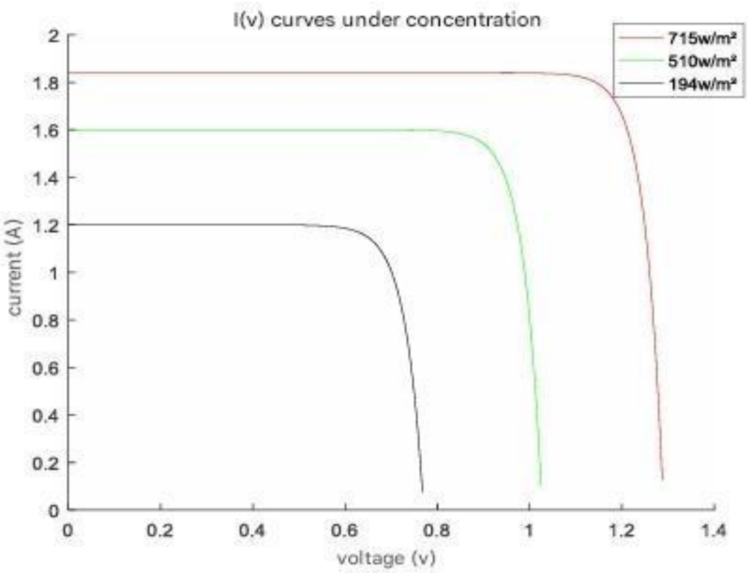


Figure III.45: The I(V) curves under concentration for the different illuminances

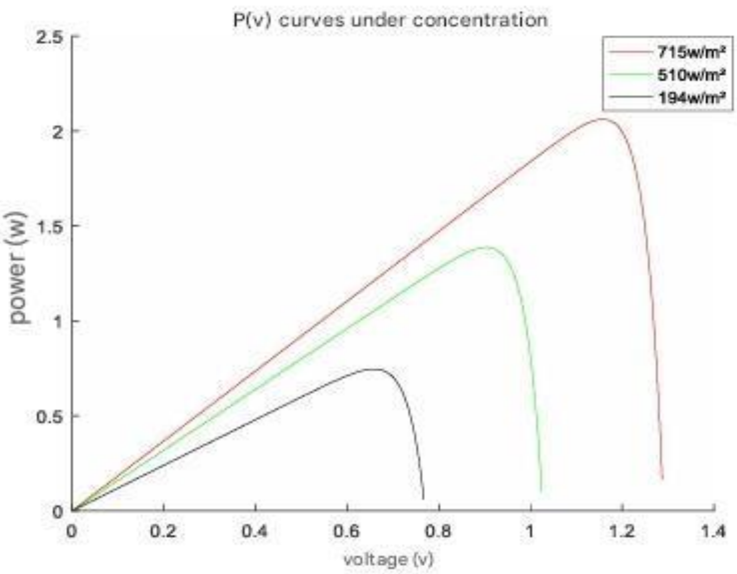


Figure III.46: P(V) curves under concentration for the different illuminances.

The following table presents the results of the characterization of all tests:

Table III.10: the results of the characterization of all tests

	Test 1	Test 2	Test 3
Icc(A)	0.46	0.4	0.3
Vco(v)	2.59	1.027	0.77
Tamb (°C)	38	31	29
Tcell (°C)	140	110	98
Id (w/m2)	715	510	194
Pmax (w)	0.403	0.357	0.0717
FF	0.68	0.87	0.31
η (%)	22.5	28	14.7

From the results, it is evident that higher irradiance generally leads to increased current, voltage, and maximum power output. However, it also causes a significant rise in cell temperature, which can negatively impact long-term performance if not properly managed. In contrast, under moderate irradiance, the system produced slightly lower electrical output but showed a more stable behavior, likely due to less thermal stress. The low irradiance test resulted in poor output, confirming that concentrated PV systems rely heavily on direct sunlight to be effective.

The I(V) and P(V) curves highlight this trend. As seen in Figures III.42 and III.43, both current and power curves shift noticeably depending on the irradiance level, showing clear performance degradation under cloudy or diffuse light conditions. These comparisons emphasize the importance of not only maximizing light input through concentration but also managing the resulting thermal load to maintain optimal photovoltaic efficiency.

III.4.5 Impacton PV performance:

The solar concentrator significantly increased localized irradiance and temperature. When applied to a PV cell, a notable improvement in electrical output was observed, validating its potential in performance enhancement, while also highlighting the need for effective thermal regulation to avoid overheating and degradation.

III.5 Conclusion:

This chapter highlighted the practical potential of solar energy through the development of three efficient systems: a hybrid aerovoltaic solar dryer, a box-type solar oven, and a parabolic solar concentrator. Experimental results demonstrated their effectiveness in thermal energy applications using only renewable sources. These systems offer sustainable, low-cost alternatives for agricultural and domestic use, reinforcing the role of solar technology in addressing energy and environmental challenges.

General Conclusion

General Conclusion

This thesis aimed to explore the influence of selected solar techniques on the performance of photovoltaic (PV) systems, focusing on practical integration and real-world experimentation within the geographical context of **Annaba, Algeria**. This region, characterized by an average solar irradiance of approximately **5.5 kWh/m²/day**, provides a favorable environment for solar energy applications, yet challenges such as high ambient temperatures can limit PV efficiency.

In the first part of this work, a theoretical foundation was laid, covering the principles of photovoltaic energy, key system components, and environmental variables influencing PV output—primarily temperature, irradiance, and heat accumulation. These factors directly impact voltage, current, and overall efficiency, underscoring the necessity for performance-enhancing solar techniques.

The second part examined three specific solar enhancement techniques: a **parabolic solar concentrator**, an **aerovoltaic system**, and a **solar oven**. The concentrator aimed to increase solar irradiance on PV cells, though it introduced additional thermal stresses. The aerovoltaic system combined electricity generation with air cooling, improving thermal regulation and thus enhancing system stability. The solar oven served as a test platform to evaluate the thermal resilience of photovoltaic materials under extreme heat conditions.

Experimental investigations, presented in the final part, demonstrated the practical benefits of these techniques under Annaba's climatic conditions. The **hybrid aerovoltaic solar dryer**, equipped with forced ventilation, achieved a peak power output of **86.07 W**, surpassing the baseline PV system output of **84.36 W**, and significantly outperforming the passive heat accumulation scenario, which only yielded **23.76 W**. This result highlights the crucial role of active air cooling in mitigating thermal degradation and boosting efficiency.

The **solar oven experiments** reached internal temperatures exceeding **117°C**, simulating harsh operating conditions to assess material durability. Meanwhile, the **parabolic solar concentrator** attained a maximum power output of **0.403 W** at an irradiance of **715 W/m²**, with an efficiency of **22.5%**, and showed improved efficiency of up to **28%** at **510 W/m²** irradiance. However, performance declined notably under diffuse or low-light conditions, emphasizing the need for effective thermal management and reliance on direct sunlight.

Overall, integrating these relatively simple solar enhancement systems led to measurable improvements in energy production, voltage stability, and thermal management of PV panels in Annaba's environment. The study provides valuable insights into the behavior of photovoltaic cells under varying thermal stresses and offers a solid foundation for future developments in energy efficiency optimization, performance monitoring, and fault detection.

Nonetheless, the study faced certain limitations, including the constrained scale of experiments due to material availability and time, as well as the absence of real-time sensor data and long-term performance monitoring, which could further strengthen diagnostic capabilities and system optimization.

References:

1. U.S. Department of Energy. (2022). Understanding Solar Photovoltaic System Performance. Retrieved from https://www.energy.gov/sites/default/files/2022-02/understanding-solar-photo-voltaic-system-performance.pdf

2. International Energy Agency (IEA). (2023). Solar Energy. Retrieved from https://www.iea.org/reports/solar-energy

3. International Renewable Energy Agency (IRENA). (2022). Wind Energy. Retrieved from https://www.irena.org/wind

4. International Renewable Energy Agency (IRENA). (2021). Hydropower. Retrieved from https://www.irena.org/hydropower

5. International Renewable Energy Agency (IRENA). (2020). Bioenergy. Retrieved from https://www.irena.org/bioenergy

6. International Energy Agency (IEA). (2023). Renewable Energy and Sustainability. Retrieved from https://www.iea.org/reports/renewable-energy

7. U.S. Department of Energy. (2021). Solar Photovoltaic Technology Basics. Retrieved from https://www.energy.gov/eere/solar/solar-photovoltaic-technology-basics

8. Fraunhofer ISE. (2020). Photovoltaics Report. Retrieved from https://www.ise.fraunhofer.de/en/publications/studies/photovoltaics-report.html

9. Green, M. A. (2000). Solar Cells: Operating Principles, Technology, and System Applications (Prentice Hall).

10. King, D. L., J. A. Kratochvil, and W. E. Boyson. Photovoltaic Module Encapsulation Materials and Processes—A Review. National Renewable Energy Laboratory (NREL), 1998, https://www.nrel.gov/docs/legosti/old/25198.pdf.

11. Jasinski, R. A. (2014). Polymer Films in Photovoltaic Applications. In Encyclopedia of Polymer Science and Technology (pp. 1-15). Wiley.https://doi.org/10.1002/0471440264.pst660

12. Kaiser, P. K., & Laing, M. (2017). "Durability and Performance of PV Module Backsheet Materials: Focus on Tedlar® PVF Films." Solar Energy Materials & Solar Cells, vol. 160, pp. 393-400. https://doi.org/10.1016/j.solmat.2016.10.034

13. Kalogirou, Soteris A. (2009). Solar Energy Engineering: Processes and Systems. Academic Press.

14. Nelson, Jenny. The Physics of Solar Cells. Imperial College Press, 2003.

15. Quaschning, Volker. Understanding Renewable Energy Systems. 3rd ed., Routledge, 2016.

16. Honsberg, Craig, and Stuart Bowden. Photovoltaics Education. The University of New South Wales, 2021, https://www.pveducation.org/pvcdrom/solar-cell-operation/illumination

17. King, D. L., et al. "Effects of Shading on Photovoltaic Modules." Progress in Photovoltaics: Research and Applications, vol. 7, no. 6, 1999, pp. 503–512. https://doi.org/10.1002/(SICI)1099-159X(199911/12)7:6<503:AID-PIP314>3.0.

18. Duffie, John A., and William A. Beckman. Solar Engineering of Thermal Processes. 4th ed., Wiley, 2013.

19. Jordan, Dirk C., and Sarah R. Kurtz. "Photovoltaic Degradation Rates—An Analytical Review." Progress in Photovoltaics: Research and Applications, vol. 21, no. 1, 2013, pp. 12–29. https://doi.org/10.1002/pip.1182

20. Boyle, Godfrey, editor. Renewable Energy: Power for a Sustainable Future. 3rd ed., Oxford University Press, 2012.

21. Kazmerski, Lawrence L. "Solar Photovoltaics R&D at the Crossroads: Progress, Challenges, and Opportunities." Solar Energy Materials & Solar Cells, vol. 90, no. 18-19, 2006, pp. 2789–2807. https://doi.org/10.1016/j.solmat.2006.05.016

22. Chandel, Surjeet S., et al. "A Comprehensive Review on Solar Photovoltaic Concentrator Systems." Renewable and Sustainable Energy Reviews, vol. 53, 2016, pp. 1282-1297. https://doi.org/10.1016/j.rser.2015.09.047

23. Duffie, John A., and William A. Beckman. Solar Engineering of Thermal Processes. 4th ed., Wiley, 2013.

24. Green, Martin A. Solar Cells: Operating Principles, Technology, and System Applications. Prentice Hall, 1982.

25. Nelson, Jenny. The Physics of Solar Cells. Imperial College Press, 2003.

26. Markvart, Tom, and Luis Castaner, editors. Practical Handbook of Photovoltaics: Fundamentals and Applications. 2nd ed., Elsevier, 2014.

27. Skoplaki, E., and J.A. Palyvos. "Operating Temperature of Photovoltaic Modules: A Survey of Measurement Techniques." Solar Energy Materials & Solar Cells, vol. 90, no. 2, 2006, pp. 155–181. https://doi.org/10.1016/j.solmat.2005.06.004

28. Rurali, Riccardo. "Decoherence and Recombination of Charge Carriers in Semiconductor Nanostructures." Journal of Computational Electronics, vol. 7, no. 3, 2008, pp. 377–391. https://doi.org/10.1007/s10825-008-0249-0

29. Radziemska, Ewa. "The Effect of Temperature on the Power Drop in Crystalline Silicon Solar Cells." Renewable Energy, vol. 28, no. 1, 2003, pp. 1–12. https://doi.org/10.1016/S0960-1481(02)00015-0

30. Touati, Fatima, et al. "Improvement of PV Panel Efficiency Using a Cooling System." https://doi.org/10.1016/j.egyr.2019.08.049

31. Hussein, A. K. "Applications of Passive Cooling Techniques in Buildings and Other Structures: A Review." Applied Energy, vol. 154, 2015, pp. 606–623. https://doi.org/10.1016/j.apenergy.2015.04.091

32. Chandrasekar, M., S. Suresh, and T. Senthilkumar. "Passive and Active Cooling Methods for Photovoltaic Panels—A Review." Renewable and Sustainable Energy Reviews, vol. 20, 2013, pp. 84–102. https://doi.org/10.1016/j.rser.2012.11.040

33. Hasan, A.M., et al. "Phase Change Material-Based Thermal Management for Photovoltaic Panels under Hot Climatic Conditions." Renewable Energy, vol. 89, 2016, pp. 51–59. https://doi.org/10.1016/j.renene.2015.11.033

34. García, A., et al. "Performance Analysis of Photovoltaic Systems with and without Solar Concentrators." Solar Energy, vol. 135, 2016, pp. 555–561. https://doi.org/10.1016/j.solener.2016.06.058

35. Luque, Antonio, and Steven Hegedus. Handbook of Photovoltaic Science and Engineering. 2nd ed., Wiley, 2011.

36. Coventry, J. S. "Performance of a Concentrating Photovoltaic/thermal Solar Collector." https://doi.org/10.1016/j.solener.2004.07.005

37. Wang, Y., et al. "Performance Evaluation of Concentrated Photovoltaic Systems in High Direct Normal Irradiance Regions." Renewable Energy, vol. 85, 2016, pp. 927–935. https://doi.org/10.1016/j.renene.2015.07.087

38. King, David L., et al. "Comparison of Concentrator Photovoltaic and Conventional Flat-Plate Photovoltaic Modules." Progress in Photovoltaics:https://doi.org/10.1002/(SICI)1099-159X (199911/12)7:6<449.

39. Kalogirou, Soteris A. "Solar Energy Engineering: Processes and Systems." 2nd ed., Academic Press, 2013.

40. Qu, M., and C. Li. "Cooling Techniques for Photovoltaic Panels to Improve Efficiency." Renewable and Sustainable Energy Reviews, vol. 82, 2018, pp. 2811–2826. https://doi.org/10.1016/j.rser.2017.10.022

41. Tian, Y., et al. "Thermal Stability and Durability of Materials Used in Concentrated Photovoltaic Systems." Solar Energy Materials and Solar Cells, vol. 150, 2016, pp. 144–150. https://doi.org/10.1016/j.solmat.2016.04.015

42. Kazem, H. A., et al. "A Review of Solar Tracking Systems and Their Impact on Photovoltaic Performance." Renewable and Sustainable Energy Reviews, vol. 65, 2016, pp. 430–442. https://doi.org/10.1016/j.rser.2016.06.060

43. Zhou, D., et al. "Thermal Energy Storage in Concentrated Photovoltaic/Thermal Hybrid Systems: A Review." Applied Energy, vol. 225, 2018, pp. 161–178. https://doi.org/10.1016/j.apenergy.2018.05.070

44. Chiradeja, P., and P. Aroonrat. "Performance Improvement of Photovoltaic Systems Using Solar Concentrators with Thermal Management." Energy Procedia, vol. 100, 2016, pp. 179–186. https://doi.org/10.1016/j.egypro.2016.10.177

45. Bahaidarah, H., et al. "Performance Evaluation of Aerovoltaic Systems for Combined Power Generation and Cooling." Energy Conversion and Management, vol. 171, 2018, pp. 1264–1274. https://doi.org/10.1016/j.enconman.2018.06.072

46. Rajoria, K., et al. "A Review on Aerovoltaic Systems: Integration, Advantages, and Challenges." Renewable and Sustainable Energy Reviews, vol. 138, 2021, 110594. https://doi.org/10.1016/j.rser.2020.110594

47. Kumar, S., and R. Kumar. "Performance Analysis and Economic Feasibility of Aerovoltaic Systems." Energy Reports, https://doi.org/10.1016/j.egyr.2021.08.064

48. Li, X., et al. "Thermal Effects on the Performance of Aerovoltaic Systems Under Extreme Conditions." https://doi.org/10.1016/j.solener.2020.08.037

49. Said, Z., et al. "Cooling Techniques for Photovoltaic Panels: A Review with a Focus on Aerovoltaic Systems." Renewable Energy, vol. 162, 2020, pp. 2016–2034. https://doi.org/10.1016/j.renene.2020.08.068

50. Chen, Y., et al. "Aerovoltaic Systems: Multifunctional Applications in Building Heating, Food Drying, and Industrial Processes." Energy Conversion and Management, vol. https://doi.org/10.1016/j.enconman.2019.05.065

51. García, M., and J. Martínez. "Aerovoltaic Systems: Integrating Electricity Generation and Thermal Energy Recovery for Sustainable Energy Solutions." Sustainable Energy Technologies and Assessments, vol. 48, 2021, 101568. https://doi.org/10.1016/j.seta.2021.101568

52. Singh, R., and A. Kumar. "Design and Performance Analysis of a Parabolic Solar Cooker for Cooking and Sterilization Applications." Renewable Energy, vol. 147, 2020, pp. 1084-1093. https://doi.org/10.1016/j.renene.2019.09.074

53. Zhang, L., et al. "Thermal Performance Testing of Photovoltaic Panels Using Solar Oven Simulation: A Method for Assessing Thermal Safety and Failure Modes." Solar Energy Materials and Solar Cells, vol. 230, 2021, 111243. https://doi.org/10.1016/j.solmat.2021.111243

54. Kumar, S., and P. Singh. "Thermal Durability Testing of Photovoltaic Panels Using Controlled High-Temperature Exposure." Journal of Renewable and Sustainable Energy, https://doi.org/10.1063/5.0012345

55. Green, Martin A., et al. Solar Energy: Fundamentals, Technology, and Systems. 2nd ed., Earthscan, 2015.

Figures References :

1. **https://miro.medium.com/v2/resize:fit:1400/1*pBKcKZ3Gyo3F9lwNlTetBw.jpeg.**
2. **https://content.cld.iop.org/books/10__1088_978-1-6817-4469-8/revision5/bk978-1-6817-4469-8ch7f1_hr.jpg.**
3. **https://static.wixstatic.com/media/c7c574_1de5f687ad084766b248f25e797b8ed5~mv2.jpg/v1/fill/w_980,h_551,al_c,q_85,usm_0.66_1.00_0.01,enc_avif,quality_auto/c7c574_1de5f687ad084766b248f25e797b8ed5~mv2.jpg.**
4. **https://ars.els-cdn.com/content/image/1-s2.0-S0098135422004367-gr6.jpg.**
5. **https://www.researchgate.net/publication/292141614/figure/fig1/AS:342700768415744@1458717638701/Fig-3-Typical-absorption-and-scattering-of-incident-solar-energy.png.**
6. **https://www.pv_magazine.fr/wp_content/uploads/sites/12/2023/11/957381_118558.jpg.**
7. **https://ars.els-cdn.com/content/image/1-s2.0-S0960148118313272-gr1.jpg.**
8. **https://encrypted_tbn3.gstatic.com/images?q=tbn:ANd9GcTRB56Xu_XTe1QhN4ABiup275dWnupxtqsvpNLbgmFkW-NF42gx.**
9. **https://www.researchgate.net/publication/308785865/figure/fig1/AS:412733011972096@1475414626137/Schema-representant-le-mecanisme-de-transfert-de-chaleur-vers-lalimentation-se-trouvant.png.**
10. **https://encrypted_tbn1.gstatic.com/images?q=tbn:ANd9GcSiyjm8sbb9ZsaYQkJ8vp0F8f48hA7QQk_tQ8nuQdDJ3IXu7cJ1.**
11. **https://www.systemed.fr/images/conseils/cuiseur-solaire-a-rotation-automatique-2036-p12-l330-h330-c.jpg.webp.**

الجمهورية الجزائرية الديمقراطية الشعبية
وزارة التعليم العالي والبحث العلمي

جامعة غرداية
كلية العلوم والتكنولوجيا

Université de Ghardaïa
Faculté des Sciences et de la Technologie

قسم: الآلية والكهروميكانيك
شعبة: الطاقات متجددة
تخصص: الطاقات متجددة وبيئة

غرداية في: 2025 /31/05

شهادة ترخيص بالتصحيح والايداع:

انا الاستاذ(ة): منصوري أنفال

بصفتي المشرف المسؤول عن تصحيح مذكرة تخرج (ليسانس/ماستر/دكتورا) المعنونة بـ:

Performance analysis of Hybrid CPV systems via the solar techniques : case study of Annaba, Algeria

من انجاز الطالب (الطلبة):

قرزيز الياس

بوشعير سامي

التي نوقشت/قويمت بتاريخ: 21/05/2025

اشهد ان الطالب/الطلبة قد قام /قاموا بالتعديلات والتصحيحات المطلوبة من طرف لجنة المناقشة وقد تم التحقق من ذلك من طرفنا وقد استوفت جميع الشروط المطلوبة.

امضاء المسؤول عن التصحيح

مصادقة رئيس القسم