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**Theme**

**Incorporation of a Glass Cover to Enhance  
the Performance of Solar Dryers in El-Oued  
Region**

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

# *Dedication*

First and foremost, thank God for my arrival at this distinguished stage in my life in which I went through the experiences of science and life together and raised me to a greater level of awareness.

I dedicate this work to:

My small and special family that brings joy to my existence in life and that I feel safe and warm with in my life.

My respected professor Hadj Ammar Mouhamed Ali , whose role was not limited to academic education only, but I benefited from his wisdom and teaching style .

To my friend, mentor and greatest supporter—myself—for unwavering commitment to achieving her goals and inspiring me to keep moving forward in my journey.

To every seeker for knowledge, with the hope that it inspires you to explore this field with passion and curiosity, motivating you to pursue knowledge and discovery.

**Nadjat Laggoun**

# *Dedication*

In the proudest moment of my life, I dedicate this work to the one who raised me and struggled for my sake—my beloved father.

To the angel in my life and the embodiment of love—my dear mother.

To my unwavering support, my steadfast companion—my sister, who was granted to me as both a refuge and a pillar.

To the one who cleared the thorns of failure from my path—my beloved sister.

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To everyone who taught me a letter and corrected the missteps in my journey—

I present to you this humble work, hoping that God may bring benefit through it and that it may be of benefit to others.

**ADAIKA Djoumana**

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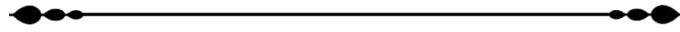
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# *Summary*



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*List of symbols*

<b>Symbol</b>	<b>Signification ( Unit )</b>
<b>Latin symbols</b>	
$A$	Surface area (m <sup>2</sup> )
$A_{nub}$	Annual net undiscounted benefits(\$)
$C_p$	Specific heat capacity (kJ/kg K)
$\dot{D}_r$	Dryer (gw/gP-s min)
$\dot{E}$	Energy (W)
$\dot{E}_X$	Exergy (W)
$E_{wr}$	Water removed from the potato (kg)
$E_{kwh}$	Electrical energy (kWh)
$I_{inv}$	Initial investment (\$)
$\dot{m}$	Mass (g)
$G$	Solar radiation (W/m <sup>2</sup> )
$M_c$	moisture content in the potato (gw/g P-s)
$\dot{m}_{air}$	mass flow rate of air (kg/s)
$P$	Power (W)
$\dot{P}_{CO_2}$	penalty cost (\$)
$T$	Air temperature (°C)
$\Delta t$ or $t$	resident time (s)
$V$	Volume (m <sup>3</sup> )
$V_{av}$	Average air velocity (m/s)
<b>Greek symbols</b>	
$\eta$	efficiency (%)
$\rho$	Density (kg/m <sup>3</sup> )
$\lambda$	Cost of unit CO <sub>2</sub> emission (\$)
<b>Subscripts</b>	
$a$	air
CO <sub>2</sub>	CO <sub>2</sub>
$ex$	exergy
$f$	fan or final
$G$	gained
$i$	initial
$in$	inlet
$loss$	loss
$Pipe$	pipe
$Out$	outlet
$Out$	outlet

## *List Of Symbols*

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<i>r</i>	rate
<i>Sc</i>	solar collector
<b><i>List of Abbreviations</i></b>	
<i>C<sub>OP</sub></i>	Coefficient of performance (-)
<i><math>\dot{C}_{mer}</math></i>	Specific moisture extraction rate (g/kWh)
<i>ISC</i>	Inverted solar collector
<i>S<sub>ml</sub></i>	Sample mass loss (g)
<i>toe</i>	Tonne of oil equivalent

# *General Introduction*



# GENERAL INTRODUCTION

Food waste is a huge problem we're dealing with today. According to the United Nations' Food and Agriculture Organization (FAO), about one-third of all the food grown or made around the world never makes it to our plates. That's a massive 930 million tons of food wasted every year [1]. Moreover, about a third of all human-caused greenhouse gas emissions are linked to food [2]. Researchers are increasingly looking for alternatives to fossil fuels such as solar energy in various industries including the food sector.

The most common way to preserve food a crop is by drying them using sunlight. This works because reducing the moisture content in food to a certain level slows down the activity of enzymes, bacteria, yeasts, and molds that can spoil it. Drying is a two-step process: first, heat is transferred from an energy source to the food, and then moisture moves from inside the food to its surface and eventually into the surrounding air. As the food heats up, the moisture evaporates and is carried away by the air [3]. Solar dryers are devices which use sunlight as the energy source for drying. Solar drying is considered environmentally friendly, clean, and highly reliable because it produces far fewer emissions compared to the greenhouse gases generated by fossil fuels [4]. Despite these multiple benefits, many studies have been conducted with the aim of reducing the energy consumption and drying time.

Das and Akpinar [5] designed a dual-direction tracking solar air collector (SAC) and combined it with a drying cabinet, comparing it to a fixed SACD. The moving SACD demonstrated higher thermal efficiency (75.7%) compared to the fixed one (51.7%), with improvements in heat transfer rates and moisture diffusivity values during the drying of apple slices. El Gamal et al [6] developed a solar tracking system to enhance the efficiency of solar air heaters made from recyclable aluminum cans for drying apple slices. Results showed that the tracking system increased thermal efficiency by 45%, reaching 87.1% at the highest air flow rate, and achieved a 17% higher drying rate compared to fixed systems. Khanlari et al [7] Developed tubular solar air heater (T-SAH) to heat the air in a greenhouse dryer (GD). The thermal performance of GD with the help of T-SAH was analyzed numerically. Experiments showed that the combination of T-SAH with GD significantly reduced the drying time of apricot samples, with the average efficiency of T-SAH ranging from 45.6% to 56.8%. Aoun and Naser [8] studied an inverted solar collector with copper fins (CF) for

## General Introduction

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drying Tomato in the Sahara region of Algeria (El-Oued City). Recently, Hadj Ammar et al. [9] developed a novel solar crop dryer design featuring an inverted absorber perforate-type collector with forced airflow.

This configuration was tested in El Oued City, Algeria, specifically for drying potatoes. The test indicated that the average air temperature in the drying chamber was 50°C, and the drying time for potatoes, starting from an initial moisture content (MC) of 84.17% to a final MC of 12.5% (wet basis), was 6 hours. Drying efficiencies ranged from 20.37% to 34.01%, with exergy efficiencies varying from 58.48% to 93.22%.

The literature review emphasizes the traditional use of solar collectors for drying various products, with a focus on evaluating dryer performance under diverse conditions. However, no research was conducted on the inverted solar dryer (ISD). Therefore, the development of ISD allows for providing the appropriate air temperature for the dried crop and is inexpensive and environmentally friendly. In this regard, for the first time, a novel design for drying crops has been tested in eastern Algerian, characterized by an abundance of Orange production. In 2024-2025, Algeria produced about 1.6 million qindar Orange [10]. Hence, the main aim of this research is to test an ISD for drying Orange and develop this type to introduce an alternative heating system to the electrical system and be environmentally friendly.

Thence, the main aim of this study was to develop an integrated glass cover (GC) and tracking mechanism to maximize the conversion efficiency of the dryer chamber by continually adjusting its direction to the optimum angle towards the sun during daytime hours. In order to compare the drying performance, the orange slices were dried simultaneously in the ISD with and without GC on tracking mechanism. The useful energy, mass, the moisture content, the drying efficiency, and drying rate values were calculated with the data obtained from the drying experiments performed in both systems. An ISD configuration was tested under weather conditions in El-Oued city (Algerian Sahara). We divided this dissertation into three chapters as follows:

**Chapter One:** This chapter presents a theoretical study that explains the concept of solar drying, its types and the key phenomena associated with the process, along with the factors that influence drying.

**Chapter Two:** This chapter discusses the types of solar drying systems, detailing their working principles, components and applications across various fields.

## General Introduction

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**Chapter Three:** This chapter covers the experimental work, focusing on the stages of experiment preparation as well as the analysis and discussion of the obtained results.

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# **CHAPTER I**

## **Generalities and Fundamentals of Drying**



## I.1 Introduction

Drying is a fundamental process used across various industries to remove moisture from materials, ensuring preservation, quality, and usability. To achieve efficient drying, four key factors must be considered (heat, drying surface, air flow and proximity to water). Understanding these fundamentals is essential for optimizing drying processes in food processing, textiles, pharmaceuticals, and more. This chapter discusses fundamental concepts of drying processes and explores the principles governing drying.

## I.2 Definition of drying

Drying is a method intended to partially eliminate water from moist materials by evaporate . This method involves both heat and mass transfer, wherein the liquid within the solid material is transformed into vapor in the drying air, and the provision of heat facilitates the phase transition of the liquid. The material to be dried may initially be in either a solid or liquid state; however, the final product is always in a solid form [1].

## I.3 Types of drying

### I.3.1 Natural drying

The conventional process of natural drying, used by our ancestors, involves directly exposing agricultural products to sunlight by spreading them on the ground [2]. This process is associated with several drawbacks that limit its effectiveness. A significant portion of crops is often lost due to the extended drying duration, which can lead to product degradation, susceptibility to fungal and animal infestations, and exposure to unfavorable climate conditions. Furthermore, Natural sun drying typically requires incurs high labor expenses and substantial space for spreading the products [3].



**Figure (I-1):** Natural Tomato[4] and Fish Drying [5].

### I.3.2 Industrial drying

In this drying process, the product is positioned on a perforated base inside the dryer, allowing hot air to flow through it. These dryers produce higher-quality outcomes than traditional drying approaches. While numerous industrial dryers are available, they generally share fundamental elements such as a heat source, a temperature regulation system, and an airflow distribution mechanism [6]



Figure (I-2): An Industrial drying [7].

### I.4 Objectives of drying

- Decreasing the water content,
- Suppression of chemical and biological processes,
- Enhancement of storage duration,
- Mitigation of dry substance degradation,
- Simplified and cost-effective product management,
- Preservation of the product's nutritional, biological, and technical attributes [8].

### I.5 The Fundamentals of Drying

Drying your home after a water damage loss can be difficult. It takes attention to detail and a scientific method. Nonetheless drying can become less difficult when you remember four items that affect the quality of your drying. The four points to pay attention to make up the fundamentals of drying. The four fundamentals are heat, drying surface, air flow and proximity to the water. Change any of these in a positive way and you will improve the drying. If you

are having issues reaching a dry standard, then this is where you should look first to help develop the situation.

- Heat: to speed up drying time you want to raise the temperature of the environment.
- Drying Surface: for maximum effect you want to dry the air at the wet surface.
- Air Flow: air flow is key the same way that drying surface is key.
- Proximity to the Water: this step is one of the harder ones to do. Proximity to the Water means that you need to try and do the other three things we just talked about as close to the actual water loss as possible [9].

## **I.6 Physical phenomena occurring during drying**

The drying process involves two interrelated physical phenomena: heat and mass transfer.

### **I.6.1 Heat transfer**

Heat transfer takes place when a temperature gradient exists between two objects. Thermal energy can be transmitted through three mechanisms: conduction, convection, and radiation [10].

### **I.6.2 Conduction**

Conduction or indirect dryers are particularly suitable for thin materials or solids with high moisture content. In these systems, heat required for evaporation is delivered via heated surfaces (either stationary or moving) integrated into the dryer to support, transport, or contain the solids. The moisture evaporated from the material is removed either through vacuum operation or by a stream of gas that primarily acts as a carrier for the moisture. Vacuum operation is especially recommended for heat-sensitive solids to prevent thermal degradation. Convective dryers tend to have lower thermal efficiency due to the significant enthalpy loss associated with the drying air. In contrast, conduction dryers exhibit higher thermal efficiency. Examples of indirect dryers include paddle dryers used for drying pastes, rotary dryers equipped with internal steam tubes, and drum dryers designed for drying thin slurries [11].

### **I.6.3 Convection**

Convection is widely regarded as one of the most prevalent methods for drying particulate, sheet-like, or pasty solids. In this process, heat is delivered by heated air or gas that flows across the surface of the solid material. The heat required for evaporation is transferred via convection to the material's exposed surface,

while the evaporated moisture is removed by the drying medium. Common drying agents include air (the most frequently used), inert gases (such as nitrogen, N<sub>2</sub>, for drying solids containing organic solvents), direct combustion gases, or superheated steam (or solvent vapors) in convective drying systems [11].

### **I.6.4 Radiation**

The energy utilized for drying the material is generated by electromagnetic waves, specifically through the application of either infrared radiation or microwaves [11].

### **I.6.5 Mass transfer**

Mass transfer is a critical factor in drying processes, where resistance to mass transfer often acts as the primary limiting factor. Although heat transfer and fluid flow play significant roles in encapsulation and preservation, the movement of moisture, vapors, gases, and aromatic compounds is essential in determining the quality of food products.

Challenges in applying mass transfer theories to food processing stem from the intricate physical structures and diverse chemical compositions of food materials. These properties can vary not only between different products but also within the same product, and they may further change during processing. Additionally, it is important to highlight that the migration of water, whether in liquid or vapor form, can occur via "filtration" through the porous structure of the product, driven by pressure gradients between the interior and the surface [12].

## **I.7 Influence of the parameters on drying kinetics**

### **I.7.1 Influence of air temperature:**

The temperature of the drying air has a significant influence on the drying speed. This influence is due to the heat input to the product that grows with the air temperature. It is also due to the temperature of the product which is all the more important than the temperature of the air. Consequently, the diffusion rates of water in the product increase with the temperature.

### **I.7.2 Influence of air velocity:**

The air speed has a positive effect on the drying kinetics, especially at the beginning of the operation. However, for products whose drying kinetics is

controlled by the internal migration of water, the influence of air drying speed becomes very low.

### I.7.3 Influence of air humidity

The water content of the air plays an important role in the behavior of the kinetics of drying of certain products. As for the air speed, this influence is more important at the beginning of drying and decreases when air temperature increases [13].

### I.8 Water activity in the product

The water found in the tissues and cells of plants is called "available water " and how easily this water can be used or removed is referred to as its availability  $A_w$ . However, some water is tightly bound and not easy to remove. Additionally, the presence of sugars and salts in the water can slow down the rate at which water is removed [14].

The activity of water ( $A_w$ ) in product is equal to the ratio of the partial pressure of water vapour on the surface of the product ( $P_{vp}$ ) to the saturated air vapour pressure ( $P_{vs}$ ) [15].

$$A_w = \frac{P_{vp}}{P_{vs}}$$

### I.9 Drying mechanism:

To dry a product, you need to blow hot, dry air over it. This air interacts with the wet product, exchanging heat and moisture.

The hot air transfers some of its heat to the product, causing the water on the product's surface to create a higher water vapor pressure compared to the surrounding air. This difference in pressure allows the water to move from the product's surface into the drying air. Essentially, the drying process depends on two key factors:

1. Heat transfer: Providing enough heat to turn the water in the product into vapor.
2. Moisture removal: Moving the water or water vapor from the product into the air.

The figure (I-3) shows a simple representation of a wet product. The solid has a film of water which adheres by surface forces to its outer surface [16].

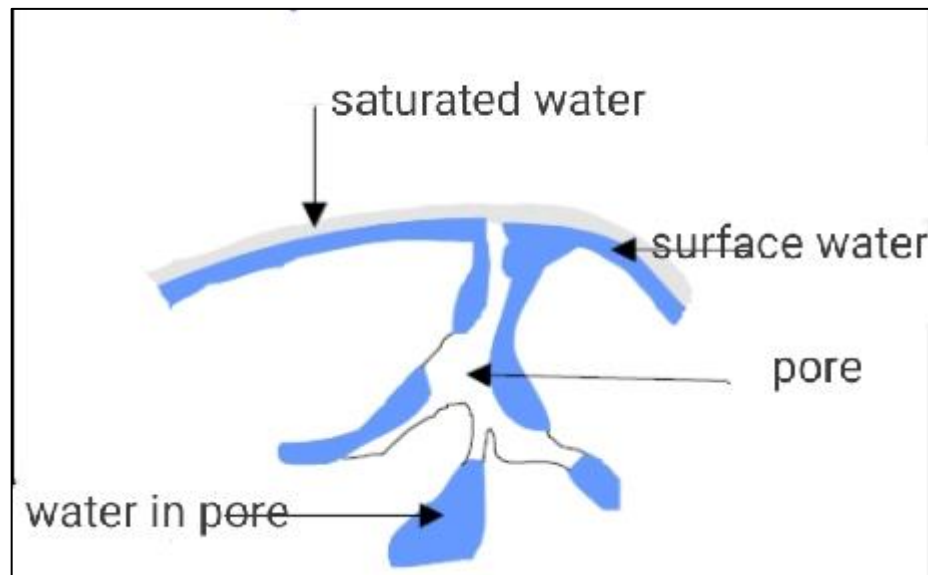


Figure (I-3): Schematic presentation of a wet product [14].

## I.10 The Three drying phases

### I.10.1 Warm-up period (AB):

This phase is usually very short and involves a quick increase in the drying rate as the product heats up to reach its equilibrium temperature. At the start, the product is cooler and has thermal inertia, so it takes some time to warm up. Once the product absorbs enough heat from the air to match the energy needed for water evaporation, it enters the vaporization phase. During this time, the drying rate increases because the heat transfer between the product and the air becomes more efficient.

### I.10.2 Constant drying rate period (BC):

In this phase, free water on the surface of the product evaporates. This water is continuously replaced by water moving from inside the product to the surface (similar to how transpiration works in plants). During this stage, the product's temperature stays constant because the heat energy is used for evaporation.

### I.10.3 Slow drying phase (CD):

This phase involves the evaporation of bound water. By this point, all the free water that moved from the inside to the surface of the product and turned into vapor has been removed. Only bound water remains, which is harder to remove because it's no longer freely available. Instead of evaporating at the surface, the water now evaporates inside the product, creating an "evaporation front" that

moves toward the core. As this front moves deeper, it becomes harder for the water vapor to escape to the surface. If the temperature and airflow remain the same as in earlier phases, the product's temperature will start to rise and get closer to the temperature of the incoming air [17].

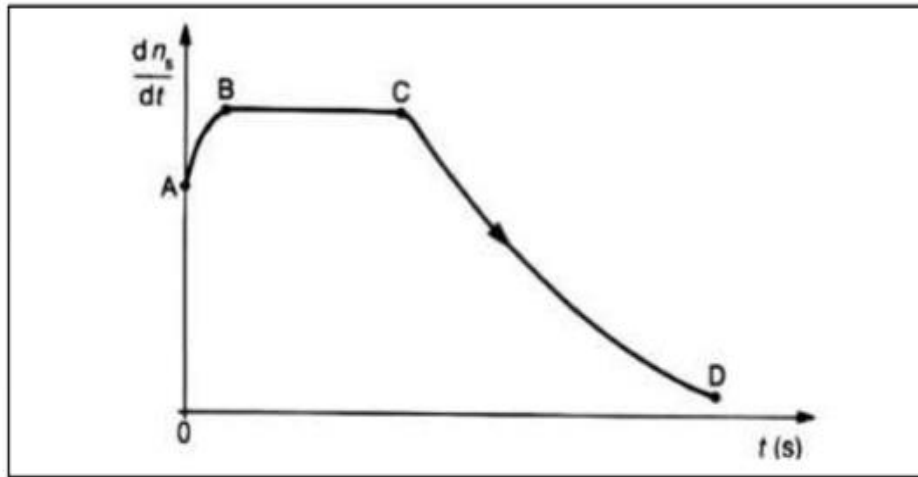


Figure (I-4) Drying curve [17].

### I.11 The Benefit drying of the products

Drying is crucial for sustainable global development. As one of the most energy-intensive industrial processes, it accounts for 7-15% of total industrial energy consumption in most countries. Given the enormous energy demand of drying and the relatively low energy efficiency of conventional dryers (only 25-50%), improving drying efficiency can significantly contribute to low-carbon development, sustainability, and climate change mitigation. Even minor enhancements in energy efficiency through process optimization, multi-stage drying, intermittent drying, and renewable energy integration can lead to substantial energy savings. As one of the oldest food preservation methods and a widely used industrial process, drying is often regarded as a mature and well-established technology. Beyond sustainability, drying is essential for global food security. By reducing moisture to safe levels, it inhibits microbial growth, slows deteriorative biochemical reactions, and lowers costs associated with packaging, transportation, storage and processing. This helps minimize postharvest losses, extend shelf life and enhance product value [18].

## **I.12 Conclusion**

In this chapter, we explored the general concepts related to the drying process in general, and solar drying in particular. We discussed the key phenomena that occur during the drying process, namely heat transfer and mass transfer. Finally, we addressed the main factors influencing the drying rate.

In the next chapter, we will examine various types of solar dryers, their working principles, components. Besides, their applications in different fields.

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# **Chapter II**

## **Solar Drying Systems**

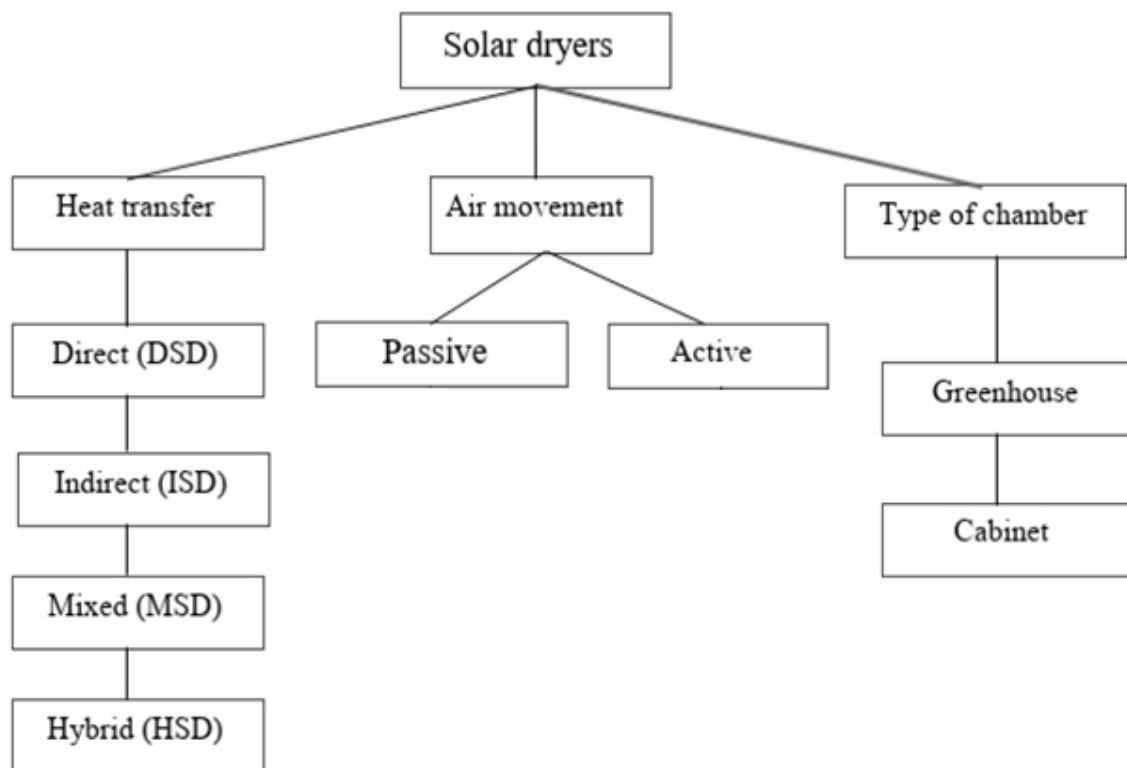


## II.1 Introduction

Solar dryers have garnered significant interest among researchers because they require less space and time for drying compared to artificial mechanical methods, while also being more cost-effective. Additional benefits include reduced relative humidity, lower moisture content in dried products, higher drying temperatures, and minimized spoilage during the process. As a result, solar drying technology can be seen as a viable solution to global food and energy challenges, offering a more efficient alternative to the limitations of traditional drying methods [1]. In this chapter, we will examine various types of solar dryers, their working principles, components. As well as, their applications in different fields.

## II.2 Classification of solar dryers

Solar dryers can be classified according to their mode of heat transfer, air movement and type of drying cabinet. Figure (II.1) shows an illustrative classification of solar dryers [2].



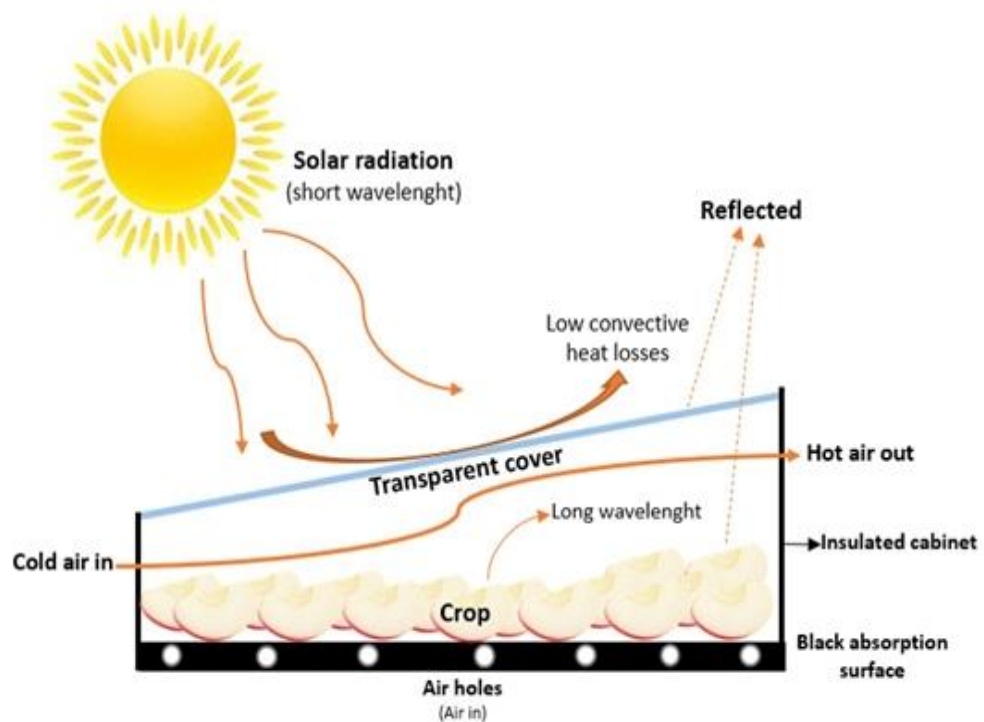
**Figure (0-1):** Schematic summary of the classification of solar dryers [2]

## II.2.1 Mode of Heat transfer

Based on mode of heat transfer, solar dryers are classified into four types as follows: Direct, Indirect, Mixed and Hybrid.

### II.2.1.1 Direct Solar Drying (DSD)

In this type, the material being dried is placed directly under sunlight inside an enclosed space with a transparent glass. The sunlight rays heat up the inside of the cabinet, creating a greenhouse effect trapping heat and raising the temperature higher than the outside air. The glass cover helps reduce heat loss from wind, keeping the chamber warmer. To make the most of heat absorption, the dryer's interior is often painted black. However, some heat and moisture still escape due to air movement and evaporation inside the chamber [3].



**Figure (0-2):** Schematic of working principle of direct drying method [3].

### II.2.1.2 Indirect solar dryer:

The Indirect Type solar dryers illustrated in Figure (0-3) has two primary parts: a drying cabinet and a solar collector setup. The drying cabinet holds materials on trays, while the solar collector includes a glass plate and an absorber plate. Hot air flows over the food in the cabinet, heating it and removing moisture. Inside the drying chamber, wire mesh trays hold the food that needs to be dried. The solar collector setup, connected to the drying chamber at a specific angle based on the location's latitude, features an absorber plate coated with black paint to absorb as much solar radiation as possible. When sunlight hits the glass cover, several heat transfer processes take place: some radiation is reflected back into the air, some passes through the glass, some is lost to the atmosphere, and some is absorbed by the absorber plate. Additionally, some energy heats the air that flows into the drying chamber through convection. The food in the cabinet absorbs this heat, causing it to lose moisture [4].

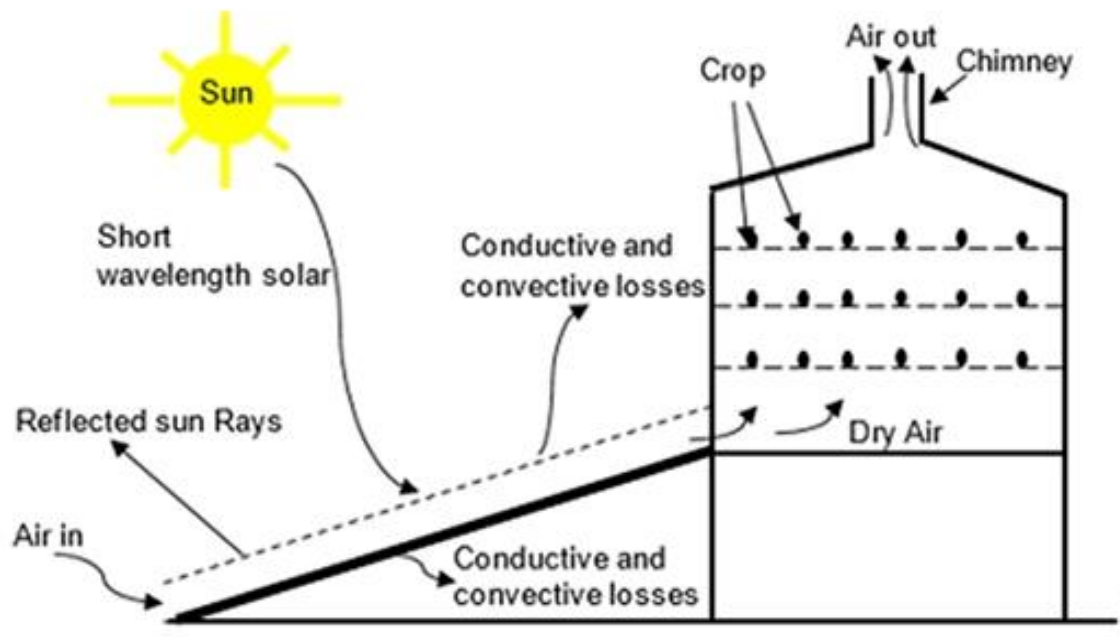


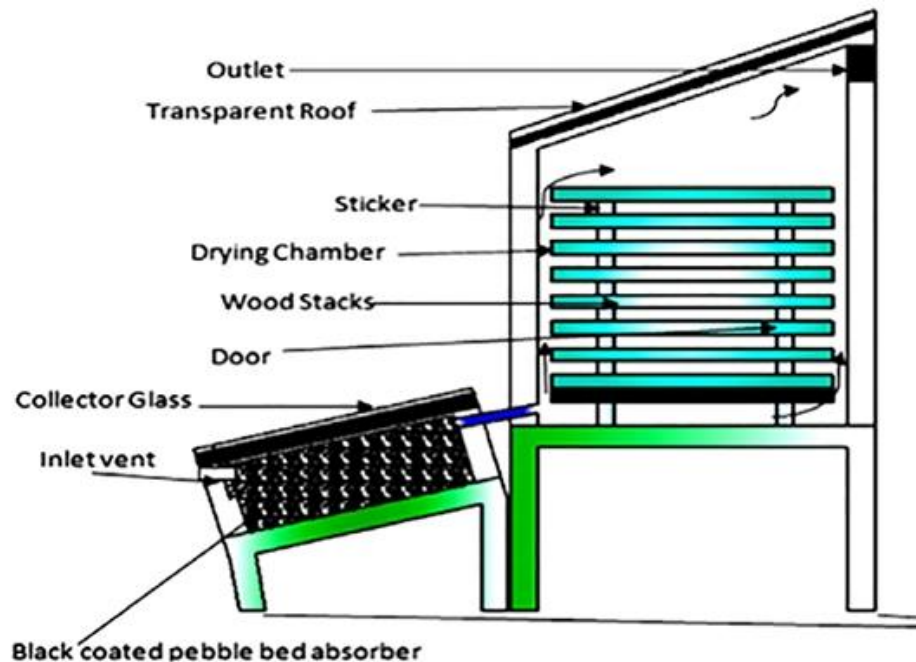
Figure ( 0-3): schematic view of the indirect type solar dryer [4].

### II.2.1.3 Mixed mode solar dryer:

Mixed mode dryers combine the principles of both direct and indirect solar dryers. A transparent panel allows the product to dry directly under sunlight, while air is preheated before entering the drying chamber. This design results in higher thermal efficiency compared to standalone direct or indirect solar dryers.

In these systems, heat transfer occurs through both convection and radiation within the drying chambers [2].

### II.2.1.4 Hybrid dryers



**Figure ( 0-4)** Schematic of Mixed mode dryer [5]

Hybrid dryers are essentially indirect solar dryers enhanced with additional energy sources to ensure continuous drying of agricultural products, even after sunset or during bad weather. These extra energy sources include biomass heaters, electrical heaters, and thermal storage systems. Among these, solar-biomass dryers are especially popular because both solar and biomass energy are easily available in rural areas and are highly effective for drying purposes .A thorough review of existing research shows significant progress in hybrid solar dryer technology, including the design, development, and testing of various configurations. Some of these innovative designs are:

1. Solar drying systems with thermal energy storage: These systems store thermal energy for use when sunlight is insufficient.
2. Solar drying systems with chemical heat pumps: These systems efficiently transfer heat energy to improve drying performance.
3. Solar drying systems with dehumidification systems: These systems control humidity levels inside the drying chamber to optimize drying conditions.

4. Solar drying systems with auxiliary heaters: These systems use additional heaters, such as biomass or electrical heaters, to provide extra heat during periods of low solar radiation [6].

❖ **Advantages and limitations of different solar dryers:**

The previous types of solar dryers have advantages and limitations are illustrated in the Table (II-1):

**Table ( 0-1):** Advantages and limitations of different solar dryers [7].

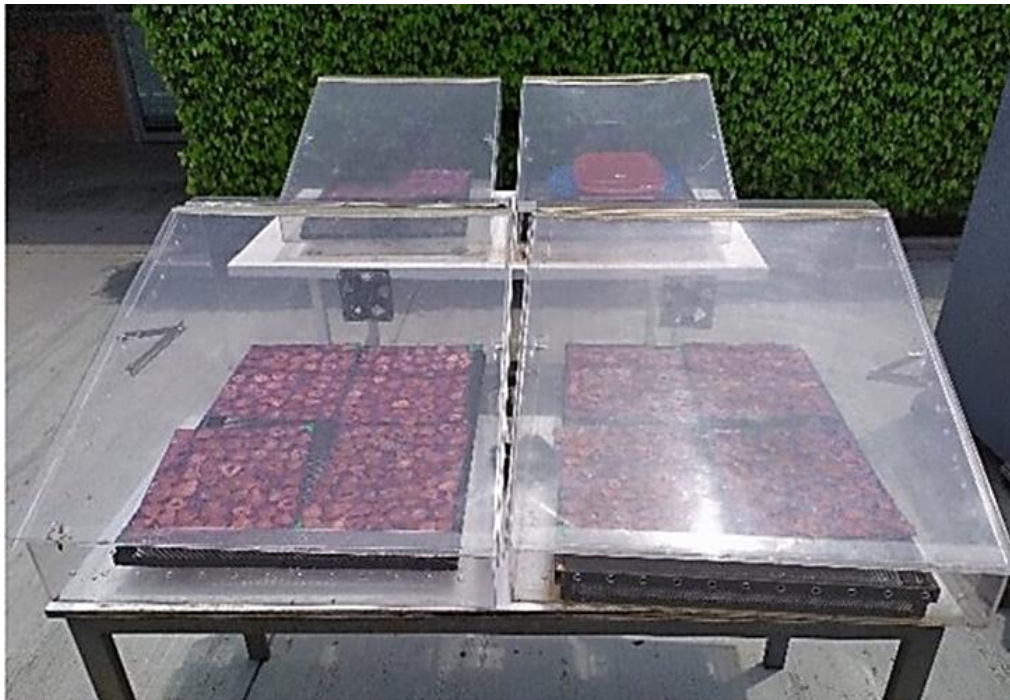
<b>Configuration</b>	<b>Advantages</b>	<b>Limitations</b>
<b>Direct</b>	Simple construction Lower investment cost Little maintenance	Products overheat Low thermal efficiency Degraded product quality
<b>Indirect</b>	Controlled drying Superior product quality Easier implementation of TESS	Higher capital cost Higher operating cost Elaborate components
<b>Mixed</b>	Faster drying Easier implementation of TESS	Higher costs Elaborate components Products overheat
<b>Additional energy source</b>	Improved thermal efficiency Works under adverse weather Allows active systems to stand-alone	Dependent on external fuel Elaborate components Higher costs
<b>Storage System</b>	Lengthens the drying capacity Easier implementation Lower investment and operating costs	Harder to work under natural convection Might need elaborate components Does not guarantee continuous drying

## II.2.2 Mode of Air Movement

Another way to classify solar dryers is by their air movement mechanism. They are divided as follow: passive dryers which depend on natural convection; active dryers which use an electric fan to generate airflow.

### II.2.2.1 Passive solar dryers systems :

Passive solar dryers are also called natural convection systems. They are typically of an appropriate size for on-farm use. Natural circulation solar dryers rely entirely on solar thermal energy for their process. In such systems, air heated by the sunlight circulates through the product due to buoyancy forces [8].



**Figure (0-5):** passive solar dryer for drying strawberry [9].

### II.2.2.2 Active solar dryers systems

Active solar dryers are also referred to as forced convection or hybrid solar dryers. An optimal airflow can be maintained in the dryer throughout the drying process to control temperature and humidity across wide ranges, regardless of weather conditions. Additionally, the apparent depth is less restricted, and the airflow rate can be regulated. Thus, the capacity and reliability of these dryers are significantly increased compared to natural convection dryers.

It is generally accepted that well-designed forced convection solar dryers are more efficient and controllable than natural circulation types.

The utilize of forced convection can reduce drying time by threefold and decrease the required collector area by 50%. Therefore, a dryer using fan can achieve the same throughput as a natural convection dryer with a collector six times larger. The fans can be powered by electricity if available or by a photovoltaic solar panel. Nearly all types of natural convection dryers can also work with forced convection [8].

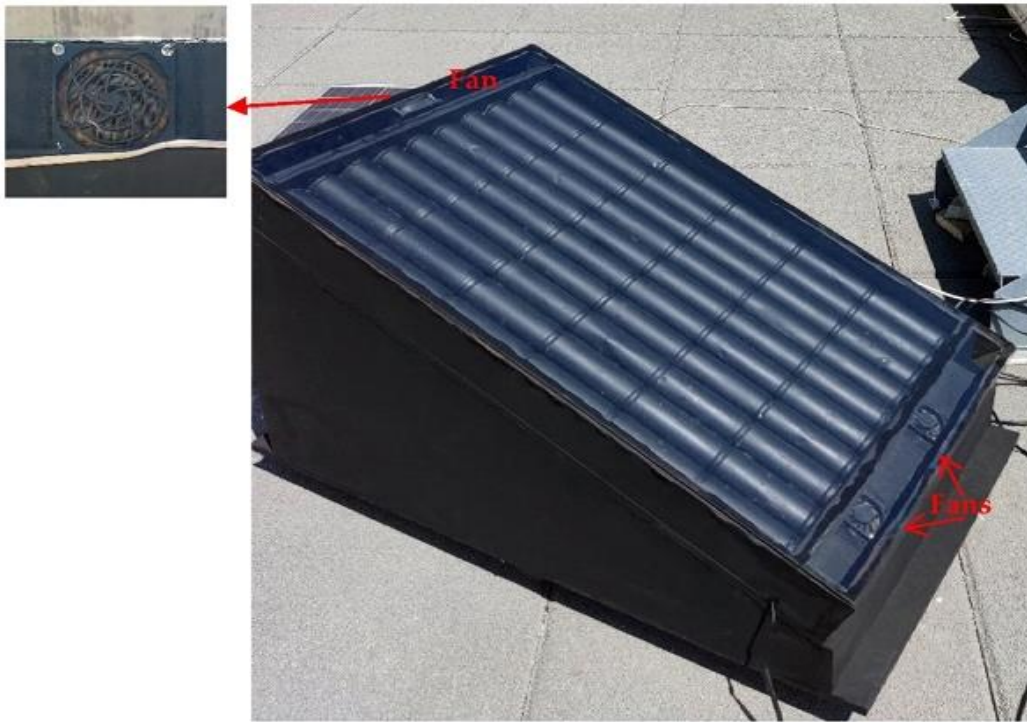


Figure ( 0-6): An Active solar dryer [10] .

### ❖ Advantages and Limitations of active and passive Solar Dryers

Both active and passive solar dryers have advantages and limitations are illustrated in the next Table :

Table ( 0-2): Advantages and Limitations of active and passive Solar Dryers [7].

Configuration	Advantages	Limitations
<b>Natural convection</b>	Simple construction Lower investment cost Independent of external fuel	Inadequate airflow Less efficient during low sunshine Harder to implement TESS
<b>Forced convection</b>	Controlled airflow Better performance on low sunshine	Dependent on external fuel Higher operating costs

## II.2.3 Type of drying chamber:

Two main types of drying chambers are documented: the greenhouse solar dryer and the cabinet-type dryer. The greenhouse dryer integrates a solar collector with a greenhouse structure, typically constructed from transparent materials with a blackened surface to improve solar absorption. The cabinet-type dryer, on the other hand, is a large enclosure built from basic materials, where products are dried on trays inside the cabinet. This type can function as either a direct or indirect dryer [3].

## II.3 Various components of solar drying systems

### II.3.1 Solar collectors:

Solar dryers rely primarily on thermal air collectors to function effectively, as these devices capture sunlight and convert it into usable heat for drying food products. Two main types exist: non-concentrating collectors (like flat-plate and evacuated tube models) that absorb sunlight directly for moderate heat (20-100°C) and concentrating collectors (including parabolic troughs and Fresnel systems) that focus sunlight to achieve higher temperatures for power generation [6].

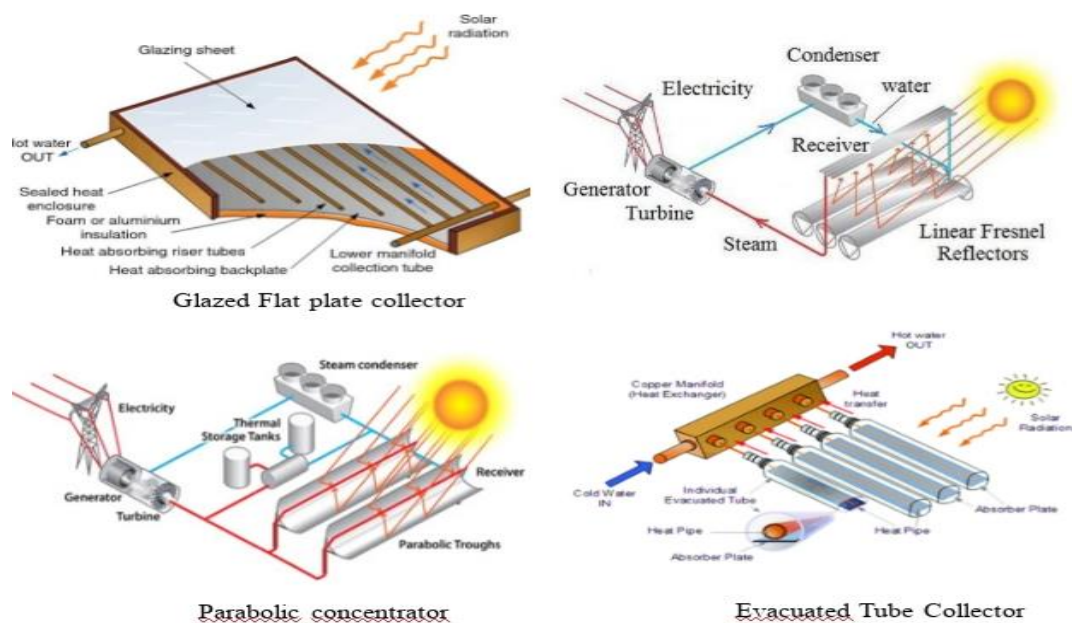


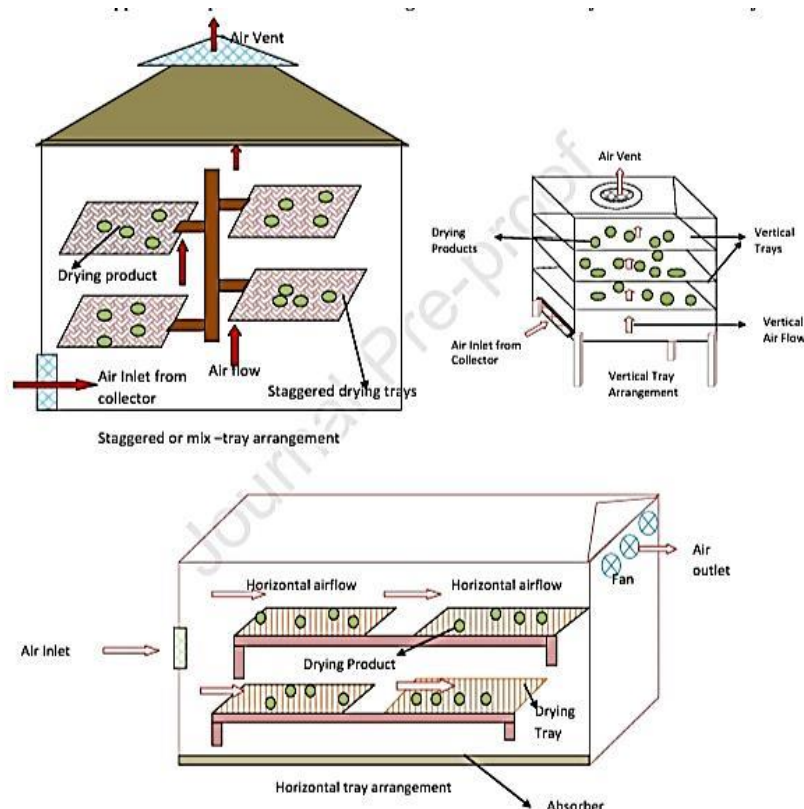
Figure ( 0-7): Different forms of solar collectors [11,12,13]

### II.3.2 Absorbers :

Solar absorbers are materials designed to capture and retain solar heat, making them beneficial for dryers by sustaining heat even without direct sunlight. [2]

### II.3.3 Drying chamber:

The drying chamber is a critical element in solar dryers, functioning as the main space where products are dehydrated to their target moisture content. Effective chamber design must ensure consistent airflow, temperature, and humidity levels to avoid uneven drying and the formation of hotspots. Additionally, the chamber should allow for easy loading and unloading of materials. Its size and shape depend on the product type and volume bulkier items demand a more spacious chamber, while smaller quantities require a reduced footprint. The choice of construction material is also essential, as it must be durable, weather-resistant and permit proper ventilation; common options include wood, metal or plastic [6].



**Figure ( 0-8):** Different tray arrangements in solar drying chamber [14]

### II.3.4 Ventilation:

Ventilation the air flow rate is important to the overall system performance. Higher air flow rate consumes more power and lower air flow rate causes poor thermal performance. In general [15]:

- The higher the mass flow rates, the higher the efficiency of the collector .
- The electrical energy of the fan increases with the mass flow rate of air .
- The effect of leakages increases with the air flow rate

## II.4 A Comprehensive Review of Design and Technology for Various Types of Solar Dryers

### II.4.1 Solar Tracking Systems:

A solar tracking system is a device used for aligning a solar photovoltaic panel toward the sun beam direction, the main aim of the system is to find the maximum solar power output. Figure (II- 9) represents an actual solar tracker [16]

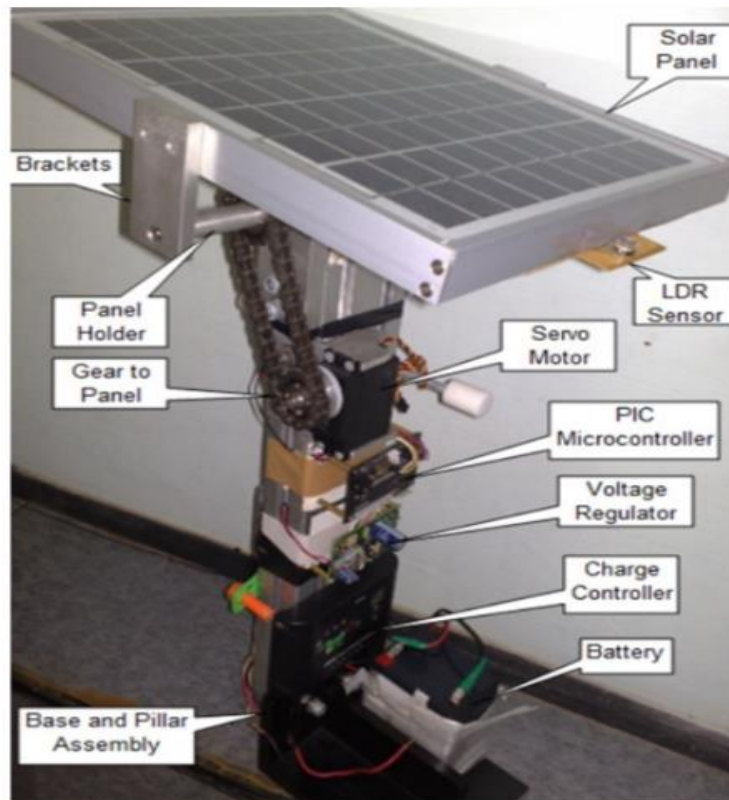


Figure (0-1):An actual solar tracking system

By the mode of their motion, solar trackers can be classified as :

### A. Single Axis Tracker

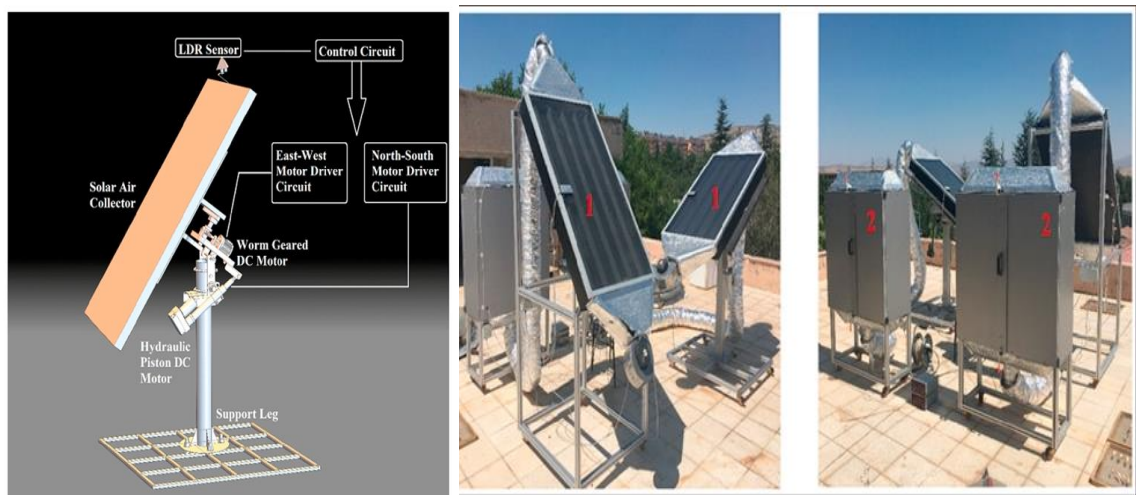
Simply, single axis trackers have only one degree of freedom that is they can either move north to South or East to West.

### B. Dual-Axis Solar Trackers

Dual Axis Tracking System: These systems can move in two different directions. The main rotation axis stays fixed to the ground while the second axis moves relative to the first one [17].

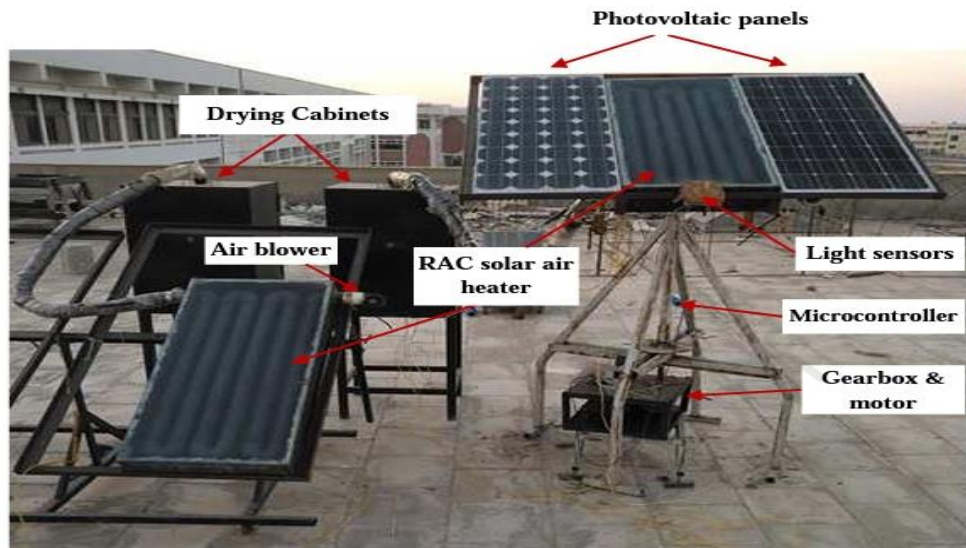
The integration of solar tracking systems in solar drying technologies has been extensively studied to enhance thermal efficiency and drying performance.

- Mehmet Daş and Ebru Kavak Akpınar [18] examined the performance of a solar dryer equipped with a two direction tracking system using a programmable logic control system. Their study compared a moving solar air collector dryer (SACD) with a fixed SACD of the same dimensions. The results showed that the moving SACD achieved a thermal efficiency of 75.7%, significantly higher than the 51.7% efficiency of the fixed SACD.



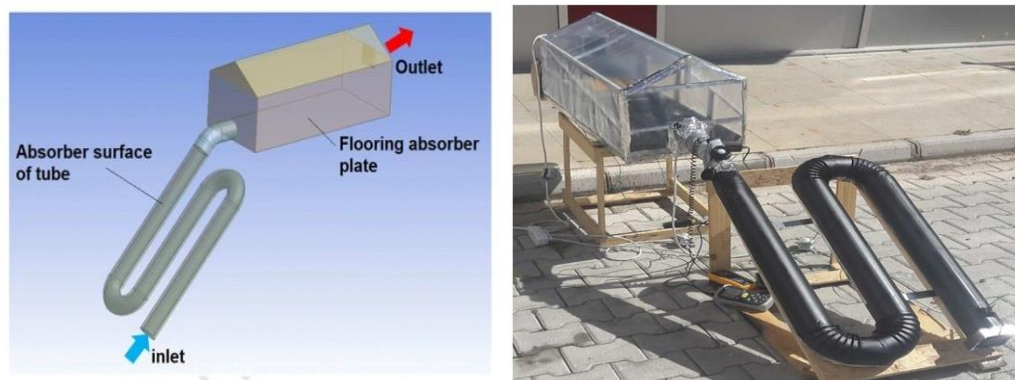
**Figure (0-3):** Experimental set-up (1)-Solar air collector, (2)-Drying chamber and schematic illustration of PLC [17]

- El Gamal et al. [19] developed an incorporated tracking mechanism made from recyclable aluminum cans (RAC) for drying apple slices. Their results demonstrated that the thermal efficiency of the solar collector with a tracking unit enhanced by approximately 45% compared to traditional fixed dryers. The highest thermal efficiency of 87.1% was achieved at an air flow rate of 44 m<sup>3</sup>/h.



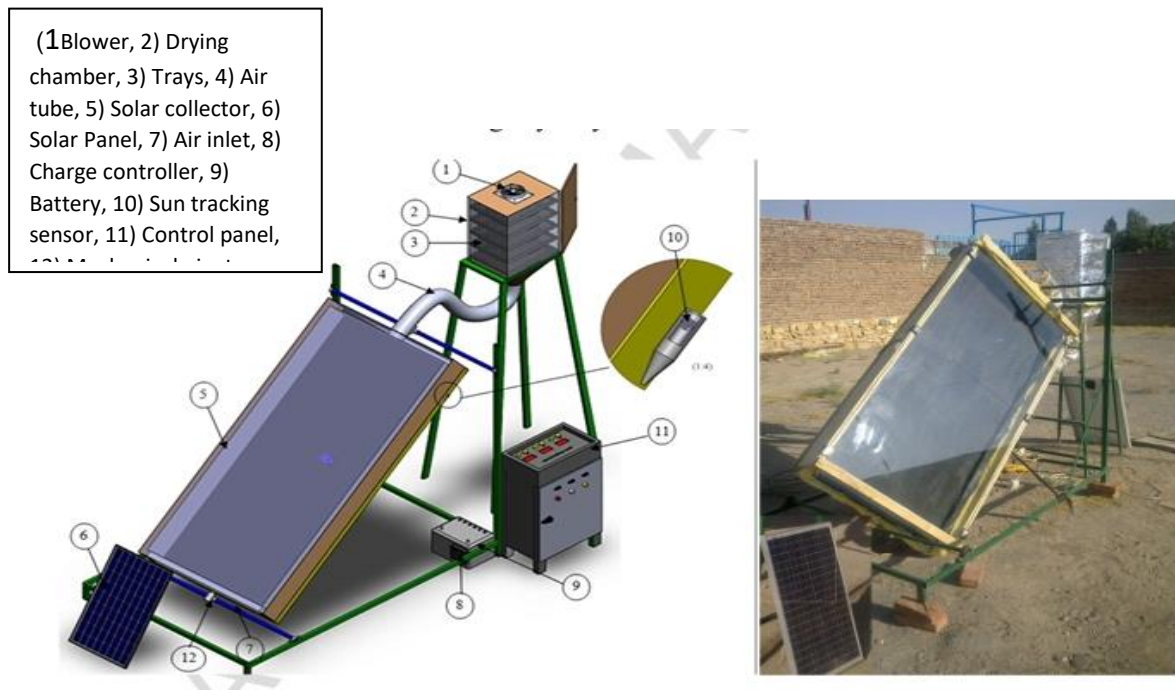
**Figure (0-4):** A photograph of solar air heaters integrated with drying cabinets [19].

- Khanlari et al. [20] concentrated on improving the performance of a greenhouse dryer (GD) by integrating a cost-effective tube-type solar air heater (T-SAH). Their study involved both numerical analysis and experimental validation. The T-SAH-assisted GD significantly reduced drying time for apricot samples with the average efficiency of the T-SAH ranging from 45.6% to 56.8%. This integration demonstrated the potential of simple and environmentally friendly solar air heating systems to enhance drying efficiency in greenhouse applications.



**Figure (0-5):** A greenhouse dryer with tube -type solar air heater [20]

- Hadi Samimi-Akhijahani and Akbar Arabhosseini [21] examined the influence of a sun tracking mechanism on the solar drying kinetics of tomato slices using a lab-scale PV-assisted solar drying system. Their experiments tested different air speeds and product thicknesses with and without the sun tracking mechanism. The results showed that the tracking mechanism reduced drying time by 16.6% to 36.6% and augmented effective moisture diffusivity by 9.1% to 64.6%.



**Figure 0-6:** PV integrated solar dryer using sun tracking system [21]

Many studies were conducted aimed at improving solar drying techniques for agricultural crops in El-OUED city (Algeria), using inverted solar dryers based on renewable energy for solving the problem of surplus agricultural production.

- Khadidja et al. [22] tested the feasibility of using a simple solar dryer to dry mint and potatoes under the climatic conditions of Wadi Souf. The dryer successfully removed 74.73% of mint moisture in 3 hours. Removed 72.31% of potato moisture in 8 hours
- Samah and Hala .[23] Added heat storage materials and drying chamber insulation. The potatoes were completely dried within 5 to 6 hours and approximately 81.71% of the moisture content was removed from them.
- Abd Elaali and Mouhamed Ali [24] Added heat storage materials (black gravel and activated carbon) and the dryer was placed on the tracking system receiving the maximum solar radiation. The average efficiency of

the inverted absorber solar dryer was 18 to 35% in the first half of the drying test, and the efficiency of the carbon-assisted dryer was higher than that of the black gravel-assisted dryer.

- Aoun and Nasr [25] added a solar tracking system to increase the conversion efficiency of the dryer and the study of the behaviour of the dryer for drying tomato slices, comparing it with the performance of a fixed dryer and conventional solar drying, also incorporating copper tubes (fins) in the drying chamber and comparing their performance with the chamber without fins. The ISD with a tracking system was found to have better thermal efficiency than a static dryer and conventional solar drying and a dryer with copper tubing had greater efficiency compared to ISD without them.

Based on the previous studies the aim of our work was to add a glass cover (GC) to maximize the conversion efficiency for ISD through the greenhouse effect.



**Figure (0-7):** Reversed absorber type solar dryers

(b)



**Figure (0-8:** (a) and (b) the previous design of ISD.

The following section will systematically examine the fundamental design components constituting this specific type of ISD.

#### **II.4.2 Design of the previous ISD:**

As outlined in the study's objectives, increasing demand for clean and sustainable technologies has driven the advancement of solar thermal drying systems for Oranges in the Eastern Algerian Sahara. Accordingly, the design of the proposed dryer prioritized cost-effectiveness and material accessibility, while accounting for regional climatic conditions.

The novel configuration was developed and fabricated using simple, low-cost tools in El Oued, Algeria. The system comprises two primary elements: (1) an Inverted Solar Collector (ISC) equipped with an eco-friendly powered fan, and (2) a drying chamber featuring a ventilation chimney, where in oranges is arranged on trays for drying. The finalized design specifications are detailed below [26].

### II.4.2.1 Design of the ISC:

The solar collector assembly comprises an inverted absorber integrated with a 3 mm thick glass cover, which is directly connected to the drying chamber. The inverted solar collector (ISC) features a curved base beneath the drying chamber, positioned at an optimal tilt angle to maximize solar energy absorption. Constructed from a 2 mm thick iron plate, the ISC has a top surface area of 0.5 m<sup>2</sup> and a curvature radius of 1 m at its base to facilitate effective air heating for the drying chamber. The entire system is supported by an iron frame with 0.5 m wide stabilizing legs. The glass cover permits solar radiation transmission while being securely sealed with adhesive tape to ensure operational efficiency, as depicted in Figure (III-16) [26].



**Figure (0-9):** Photograph of the inverted solar collector [26].

### II.4.2.2 Design of the Drying Chamber

The drying chamber consists of a cylindrical enclosure measuring 50 cm in diameter and 30 cm in height. The base of the solar dryer chamber is perforated with 101 uniformly distributed holes, each with a diameter of 0.22 cm, to facilitate the even dispersion of heated air from the inverted collector into the drying space. Inside the chamber, two shelves are installed to hold agricultural produce during the drying process. A centrally located chimney, with a diameter of 7 cm and a length of 18 cm, is integrated into the upper base of the chamber to enhance airflow, as depicted in Figure (III-17) [26].



**Figure (0-10):** Photograph of the drying chamber [26].

## II.5 The Fundamental equations of drying:

Through rigorous experimental methodology, the collected empirical data are systematically analyzed to conduct a comprehensive performance evaluation of the ISD developed specifically for orange drying, incorporating the energy efficiency and thermodynamic analyses to quantify the following parameters performance indicators:

- The useful energy rate during the drying process is the energy gained ( $\dot{E}_G$ ) in solar dryer system, which can be determined using the following equation [26]:

$$\dot{E}_G = \dot{m}_a \times C_{pa} (T_{Out} - T_{In}) \quad (1)$$

Where  $\dot{m}_a$  is the mass air flow (kg/s) and  $C_{pa}$  is the heat capacity of air  $\dot{m}_a$  and  $C_{pa}$  are determined by the following equations[26]:

$$\dot{m}_a = \rho_a \times A_{SC} \times V_a \quad (2)$$

$$C_{pa} = 1009.26 - 0.004003 \times T + 0.00061759 \times T^2 - 0.000000409 \times T^3 \quad (3)$$

- Drying efficiency of the ISD ( $\dot{\eta}_d$ ) is generally defined as the ratio of energy gained to evaporate the moisture at any time period to the energy supplied to the dryer. This efficiency can be computed using the following equation [27]:

$$\dot{\eta}_d = \frac{\dot{E}_G}{G + P_{fw}} \quad (4)$$

Where  $P_{fw}$  is the fan power and  $G$  is gained energy.

- Moisture content in the orange ( $M_C$ ) is generally given based on weight of water and dry matter present in the orange. This parameter can be quantified on a percentage basis through Equation (5)[26].

$$M_C = \frac{\dot{m}_i - \dot{m}_f}{\dot{m}_f} \quad (5)$$

Where  $\dot{m}_i$  is initial mass of the orange before drying,  $\dot{m}_f$  is mass of the dried orange.

- Drying rate  $\dot{D}_r$  was calculated as the difference in mass of water removed from the wet orange per kg of dried solid per unit time, as defined by the following equation[26]:

$$\dot{D}_r = \frac{\dot{m}_{t+\Delta t} - \dot{m}_t}{\Delta t} \quad (6)$$

## II.6 Conclusion

In this chapter, we have examined various types of solar dryers, their working principles, elements. Besides, their applications in different fields. In the next chapter, we divided the work into two experiments. In the first experiment, we explained the role of the glass cover (GC) surrounding the drying chamber for a pre-designed solar dryer, the details of whose design were mentioned previously. In the second experiment, we added a tracking mechanism for the dryers.

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# **Chapter III:**

## **Results and Discussion**



## III.1 Introduction

Drying is a widely utilized process in Algeria, primarily due to the abundant solar thermal energy available for exploitation in the Sahara region. This method plays a crucial role in preserving agricultural products, ensuring their availability for consumption at any time. In the 2024-2025 periods, Algeria produced approximately 1.6 million quintals of Oranges. Therefore, the main aim of this study is to evaluate the performance of an inverted solar dryer (ISD) for drying Oranges and to develop this system as an eco-friendly alternative to conventional electric drying methods. This chapter provides an overview of the experimental setup, including the location and equipment employed in the study. Additionally, selected samples are presented to illustrate the outcomes of the drying process.

## III.2 Experiments location and zone climate

### III.2.1 Experiments location

The experiments were conducted in the research unit of Renewable Energies Development in Arid Zones (REDAZ) at the University of Chahid Hamma Lakhdar, located in southeastern Algeria. The site lies between longitudes  $6^{\circ}$ - $8^{\circ}$  E and latitudes  $31^{\circ}$ - $34^{\circ}$  N.



Figure (III-1): A photograph of UDERZA.

## III.2.2 Experiments zone climate

EL-OURD region is characterized by a hot, dry desert climate in summer and cold conditions in winter. The average summer temperature reaches 34°C and can sometimes exceed 50°C, while in winter, the average temperature drops to 10°C. Most days of the year are sunny, making the area rich in solar thermal energy. The region has an average annual solar radiation of 4.85 kWh/m<sup>2</sup>, with a total sunshine duration of 3,900 hours per year [26].

## III.3 Results and discussions

In this section, the important outcomes of the experimental analysis of an ISD are illustrated as follows:

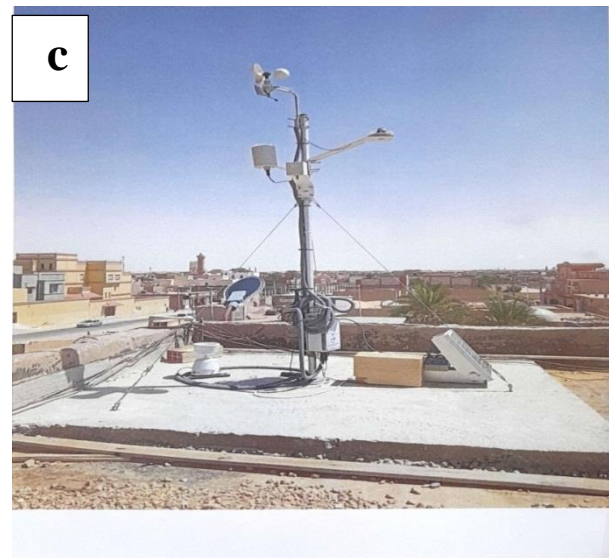
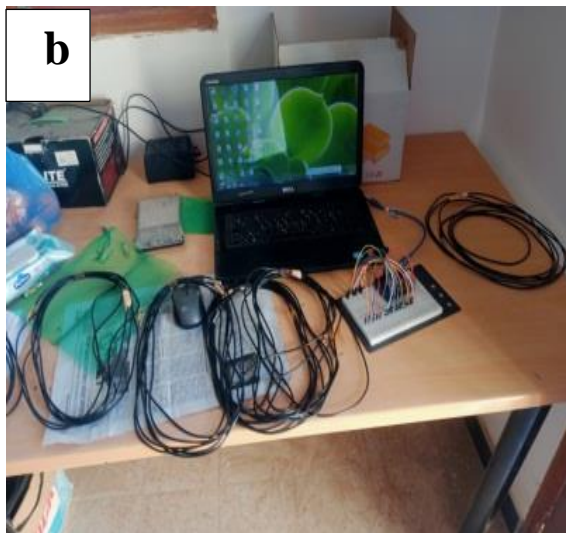
### III.3.1 Influence of GC in ISD performance

In this experimental investigation we are going to present the influence of the glass cover (GC) (ISD with and without GC) in the ISD performance such as air temperature, useful energy, drying efficiency, and mass of dried orange.

#### III.3.1.1 Experimental set up

As illustration in Figure (III-2), the ISD was experimentally tested in the UDERZA (EL-OUED City) during April 17, 2025. The experiments were divided into two cases: the ISD with GC and the ISD without GC. The experimental run is conducted for drying Orange under two chambers and the open sun drying. Before each experiment, fresh Orange was washed by running water and some fruits were peeled before being sliced. In experiments, the weight of dried Orange was measured in 1h periods with a digital weight meter (see Figure (III-4)). The experiments continued until the weight of the Orange slices changed. In the study, Orange slices were cut in an unequal semi-sphere shape to 2-3 mm thickness before drying. The cut Orange slices were then placed horizontally on the perforated metal drying tray. The two dryer's chambers and Orange slices before drying are shown in Figure (III-4). The daytime of the drying starts from about 7.30 a.m. and finish at 5.00 p.m. A data acquirer (Arduino Uno), laptop, local weather station, thermocouples and are used for data acquisition during the experiment as depicted in Figure (III-2) and Figure (III-3). The predicted and experimentally measured outlet temperature, also the weather conditions in that day are presented in Figure (III-5). It was observed that the ambient temperature varies between 21.64 and 9.53 °C. A

maximum outlet temperature of 31 °C was reached at 13 p.m. corresponding to the maximum solar radiation (937 W/m<sup>2</sup>).



**Figure (III-2):** (a) A photograph of ISD components, (b) Arduino Uno, (c) and Weather station in the UDERZA.

```
sketch_apr9a
#include <OneWire.h>
#include <DallasTemperature.h>

// Data wire is connected to digital pin 2
#define ONE_WIRE_BUS 7

// Setup a oneWire instance to communicate with any OneWire devices
OneWire oneWire(ONE_WIRE_BUS);

// Pass oneWire reference to DallasTemperature library
DallasTemperature sensors(&oneWire);

void setup() {
  Serial.begin(9600);
  Serial.println("DS18B20 Temperature Sensor Example");

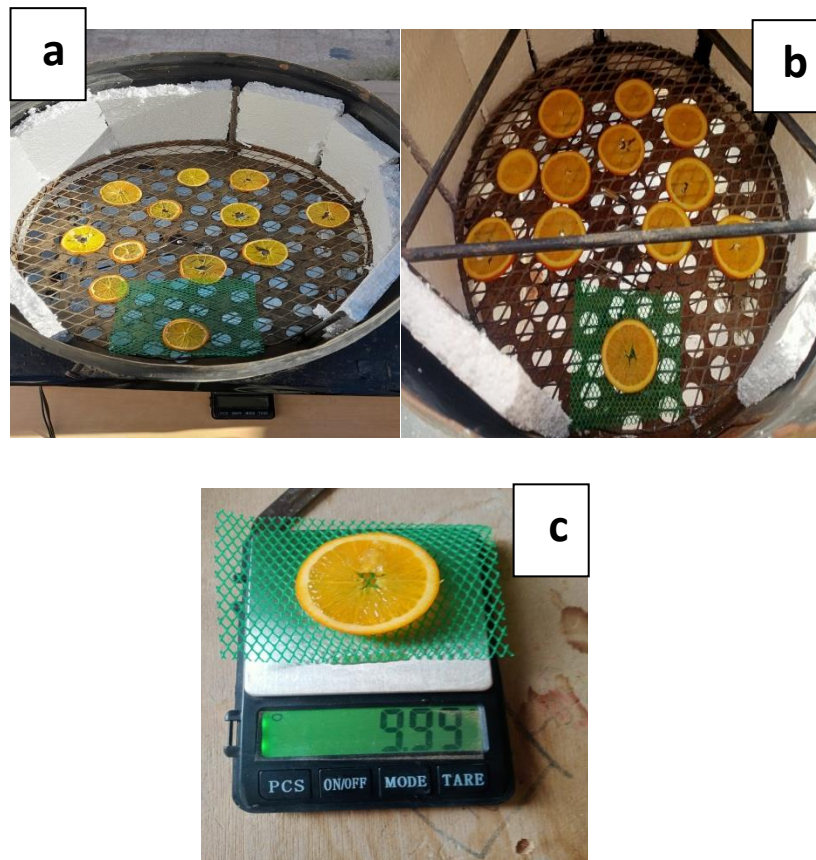
  // Start up the sensor
  sensors.begin();
}

void loop() {
  Serial.print("Requesting temperatures...");
  sensors.requestTemperatures(); // Send the command to get temperatures
  Serial.println("DONE");

  float temperatureC = sensors.getTempCByIndex(0);
  float temperatureF = sensors.getTempFByIndex(0);

  Serial.print("Temperature (C): ");
  Serial.print(temperatureC);
}
```

**Figure (III-3):** A visual representation of an arduino program designed to measure temperature inside a dryer.



**Figure (III-4):** A photographs of Orange slices (a) in chamber with GC (b) in chamber without GC (c) on digital weight meter

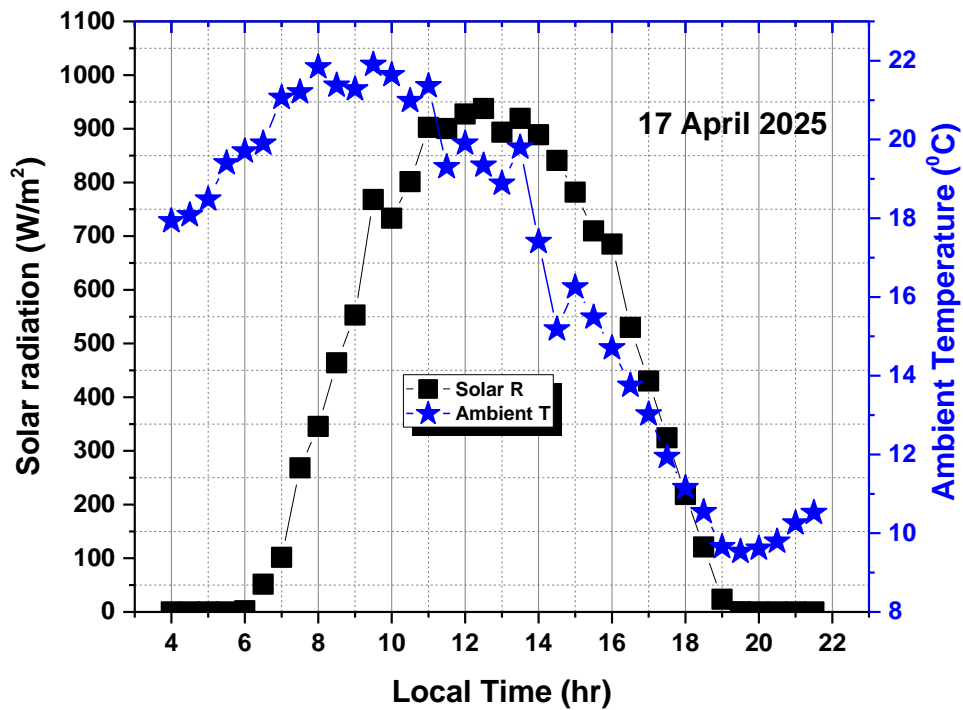
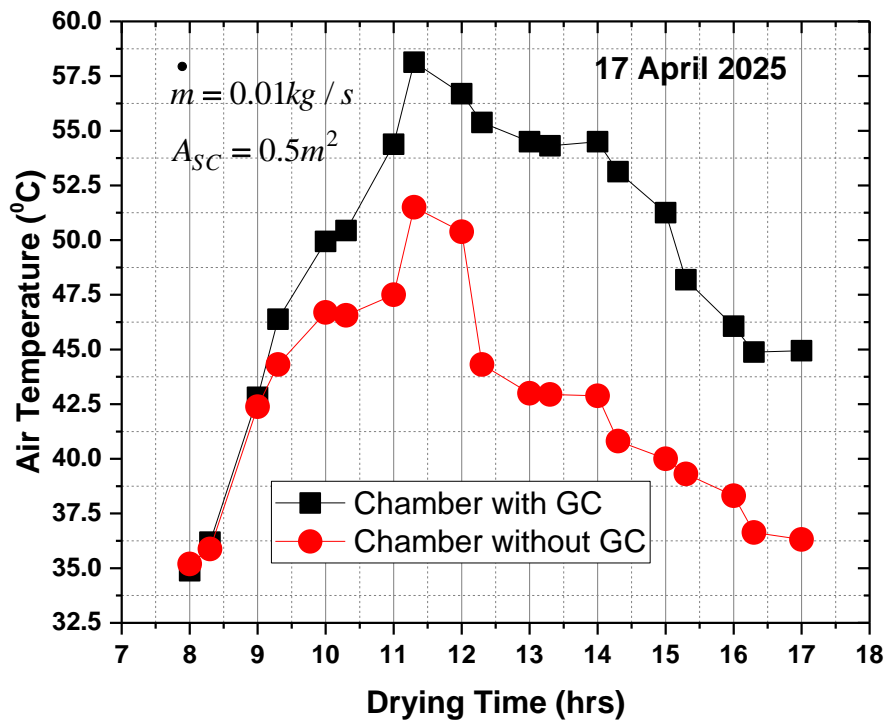


Figure (III-5): Environmental data throughout day in April at El Oued city.

### III.3.1.2 Experimental results compared

The air temperature in the two chambers of the ISD is also important when designing drying purposes and application. The changes in average air temperature at drying chamber with and without GC during the drying process are displayed in Figure (III-6). Based on the above results, the average useful energy of the two ISD systems at different times is given in Figure (III-7).

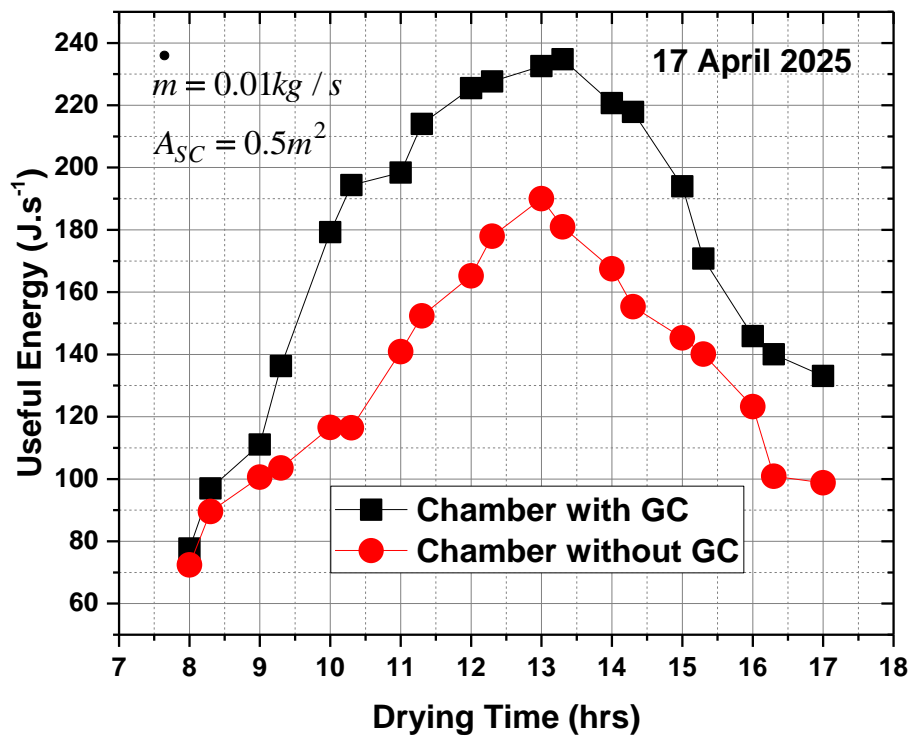


**Figure (III-6):** Variation of air temperature during the drying time in ISD with and without GC.

It is quite clear that the ISD equipped with a GC unit heats up the air to temperatures higher than that in the ISD without GC at all tested. This implies that the greenhouse system maximized the benefits from the solar irradiation incident on the drying chamber resulting in higher temperatures during the full drying period. Similarly, as revealed in Figure (III-6), the results showed that the useful energy of the ISD is affected by irradiation and ambient temperature variation.

Performance study of the ISD system provides a means of evaluating just how well a system operates under real climate conditions. Based on chapter 2 (section II.6) and climatic conditions, the variation in drying efficiency and orange mass of the ISD with and without GC during experimentations are showed in Figure (III-7 and 8), respectively.

As expected, higher efficiency values were obtained in ISD with GC compared to the ISD without GC and open sun drying. As displayed in Figure (III-8), dryer's efficiency is high in the first of the drying process; this is due to the presence of moisture near of the oranges. Afternoon, the efficiency reduces continuously until the end of the drying process because of the diminution in moisture content.



**Figure (III-7):** Useful energy of ISD with and without GC during the drying process.

On the other hand, orange samples were weighed using an electronic balance, and their mass was recorded. The variations in Orange mass during the drying process using open sun drying and ISD with and without GC is shown in Figure (III-9) and Table 1. As drying progresses, the mass of Orange decreases exponentially, indicating the removal of moisture through different drying methods. Open sun drying requires a longer drying time compared to the ISD method. This demonstrates that the ISD with GC effectively green housing internal air temperature in the chamber, enabling hot air at optimal temperatures for the product.

Experiments were conducted to dry Orange using the methods detailed in Table 2. Different drying techniques were employed to evaluate the thermal and performance parameters of the ISD.

Performance of the setup was notably enhanced when employing an ISD with GC compared to drying without GC and open sun drying. This improvement was attributed to the inclusion of GC in the ISD, which maintained a consistently optimal temperature for vaporizing moisture from the Orange. The addition of GC increased the thermal transfer area inside the chamber, while GC effect on decreasing drying time of the orange slices.

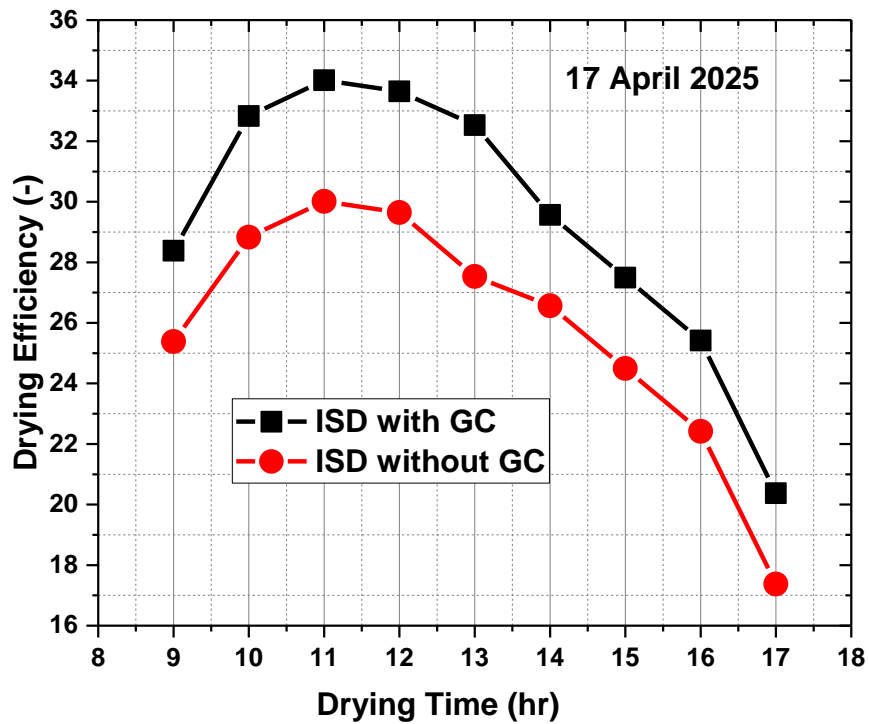


Figure (III-8): Efficiency of the ISD with and without GC during the drying process.

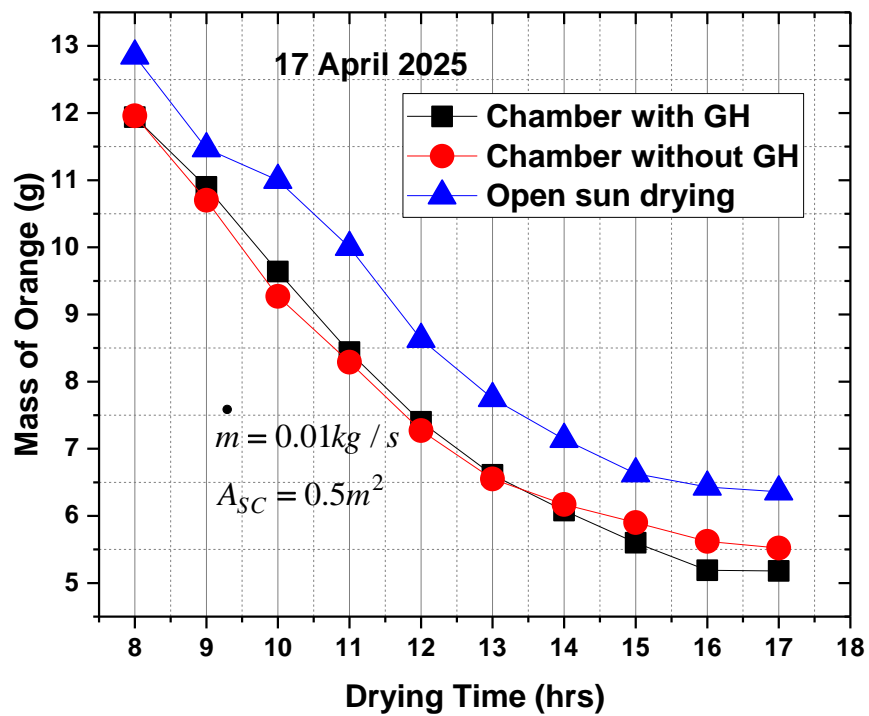








Figure (III-9): Variation of mass Orange in three drying methods.

**Table 1.** Evaluation of drying Orange using various methods

Drying methods	Before drying	After drying
<b>Open Sun drying</b>		
<b>ISD With GC</b>		
<b>ISD without GC</b>		

Consequently, the ISD with GC took 7 hours to desiccate Orange to a minimum level, compared to 7.43 hours with ISD without GC and over 8.5 hours with open sun drying.

**Table II 2.** Performance of the ISD systems by applying various methods

Thermal parameters	Orange drying methods		
	ISD with GC	ISD Without GC	Open Sun
Max Temperature in the chamber (°C)	58.13	51.5	-
Maximum ISD efficiency (%)	34.01502	30.01502	-
Drying time (hr)	7	7.43	More than 8.5

### III.3.2 Influence of GC and tracking system in ISD performance

In this experimental investigation we are going to present the influence of the greenhouse (ISD with and without GC) and tracking mechanism in solar drying kinetics of orange slices

#### III.3.2.1 Design of the solar dryers

As illustration in Figure (III-10), the ISD equipped with a solar tracking mechanism was designed and developed for drying experiments. The experimental setup consisted of two solar dryers with and without GC, solar PV-panel, two fan, sun mechanical pivot, support leg, tracking controlling unit, photocell sensor, battery, and charge controller.

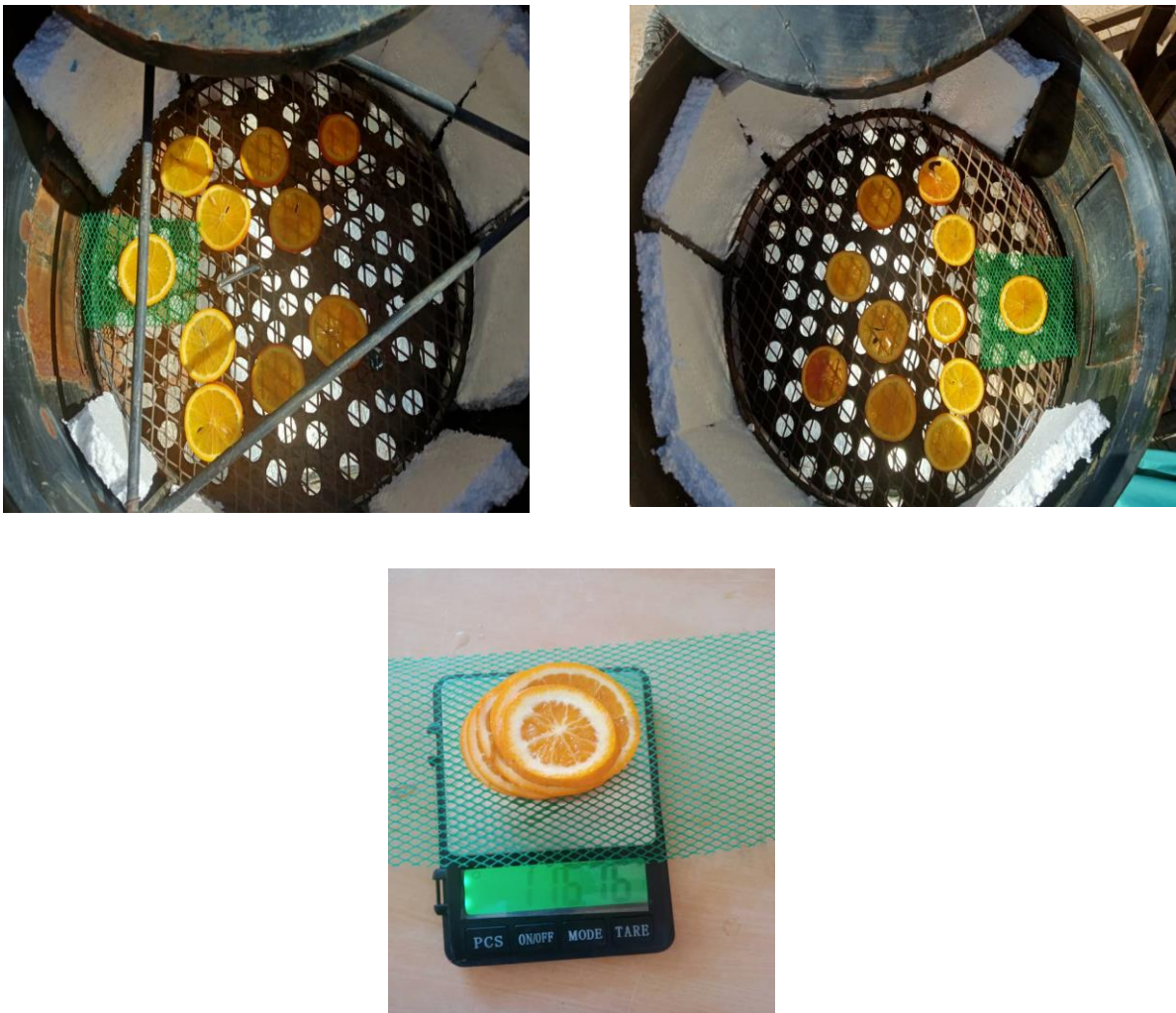


**Figure (III-10):** A photograph of ISD components in tracking system.

#### III.3.2.2 Experimental set up

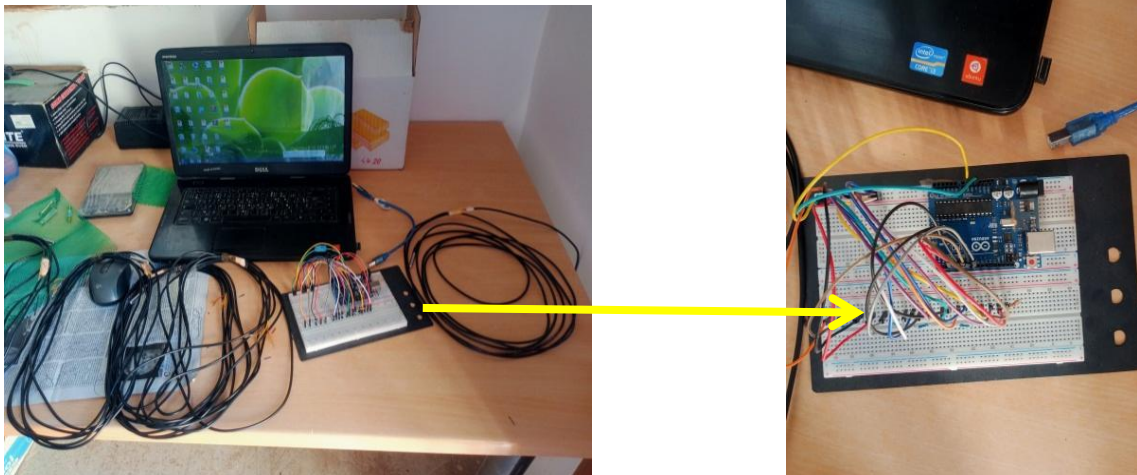
The ISD equipped with a solar tracking mechanism was experimentally tested under clear weather conditions in the UDERZA (EL-OUED City) during May 17, 2025. The developed experimental setup consist of two drying chambers with and without GC, an inverted solar collector fixed according to  $33^\circ$ , a ISD with a mechanical pivot that can track the sun in all directions. In addition, both drying systems have a circulation fan.

The experimental run is conducted for drying Orange under two chambers with and without GC, and the open sun drying. Before each experiment, fresh Orange was washed by running water and some fruits were peeled before being sliced. The test started at 07:00 and continued until 16:30. In experiments, a detailed preparation Orange slices and Specimens can be found in a previous section. The weight of dried Orange was measured in 1h periods with a digital weight meter. The experiments continued until the weight of the Orange slices changed. The two drying chambers and Orange slices before drying are shown in Figure (III-11).



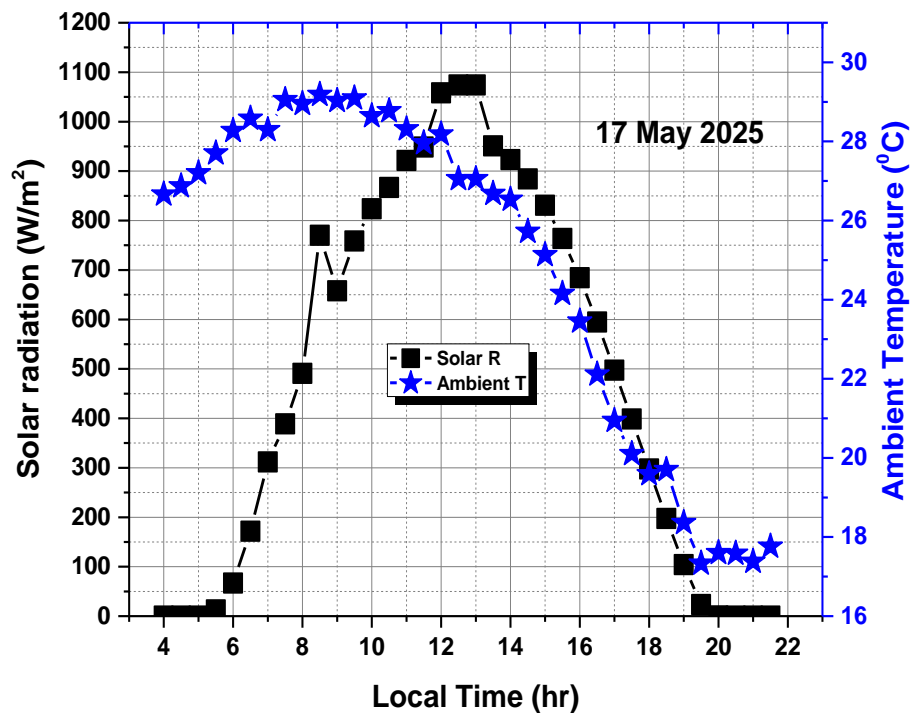
**Figure (III-11):** A photographs of Orange slices (a) in chamber with GC (b) in chamber without GC (c) on digital weight meter.

The temperatures of the drying air were continuously recorded during the experiments using a data logger connected with a computer supported (Arduino Uno) with instantaneous data acquisition software (see Figure (III-12 and 3)). Weather conditions such as Wind speed, solar intensity were recorded by a meteorological station installed in the experimental location at UDERZA.



**Figure (III-12):** A photographs of data acquisition software (Arduino Uno)

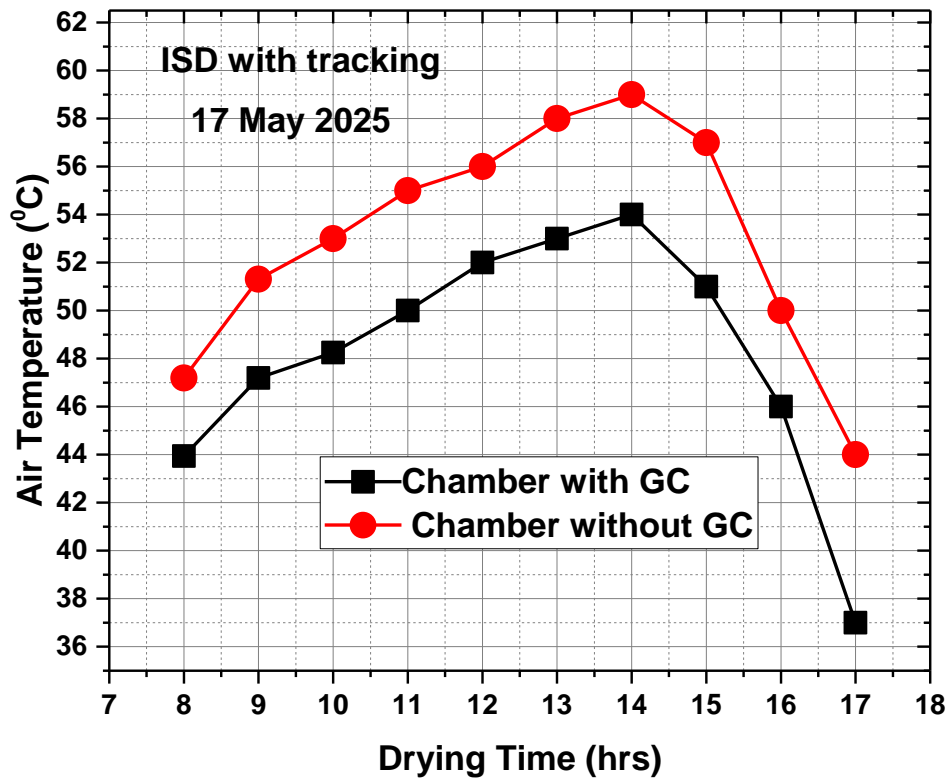
The predicted and experimentally measured outlet temperature, also the weather conditions in that day are presented in Figure (III-13). It was observed that the ambient temperature varies between 17.33 and 29.18 °C. The solar irradiation during the drying period where the minimum recorded was observed at the beginning and at the end of the drying time (9 am and 4 pm) with a minimum value of 171.82 W / m<sup>2</sup>. While, the maximum values of the solar irradiation were recorded at noon (10-2 pm) with a minimum value of 1074.15 W / m<sup>2</sup>.



**Figure (III-13):** Environmental data throughout day in May at El Oued city.

### III.3.2.3 Experimental results compared

The air temperature in the two chambers of the ISD is also important when designing drying purposes and application. The changes in average air temperature at drying chamber with and without GC during the drying process are displayed in Figure (III-14)



**Figure (III-14):** Variation of air temperature during the drying time in two chamber with tracking

As shown in Figure (III-14) the tracking ISD has benefited from solar intensity effectively as it has solar tracking mechanism. Due to the tracking mechanism, the intensity value on the inverted collector was about  $1075.15 \text{ W/m}^2 \text{ K}$ .

The variations in moisture content and drying rate during the drying process using open sun drying and ISC dryer with and without GC are depicted in [figure \(III- 15 and 16\)](#).

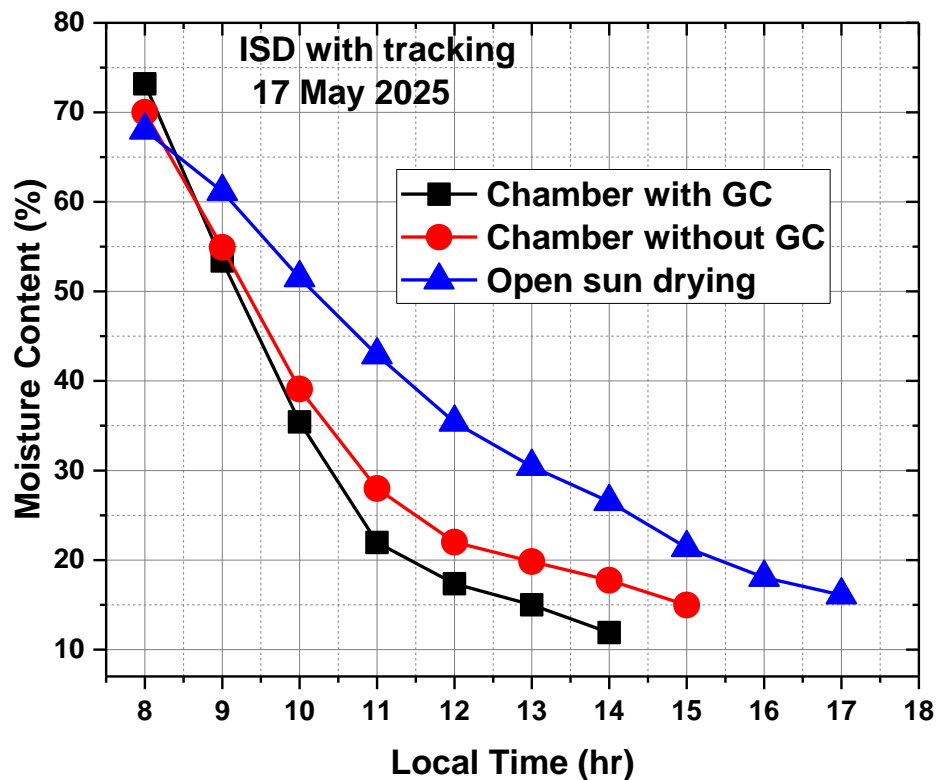
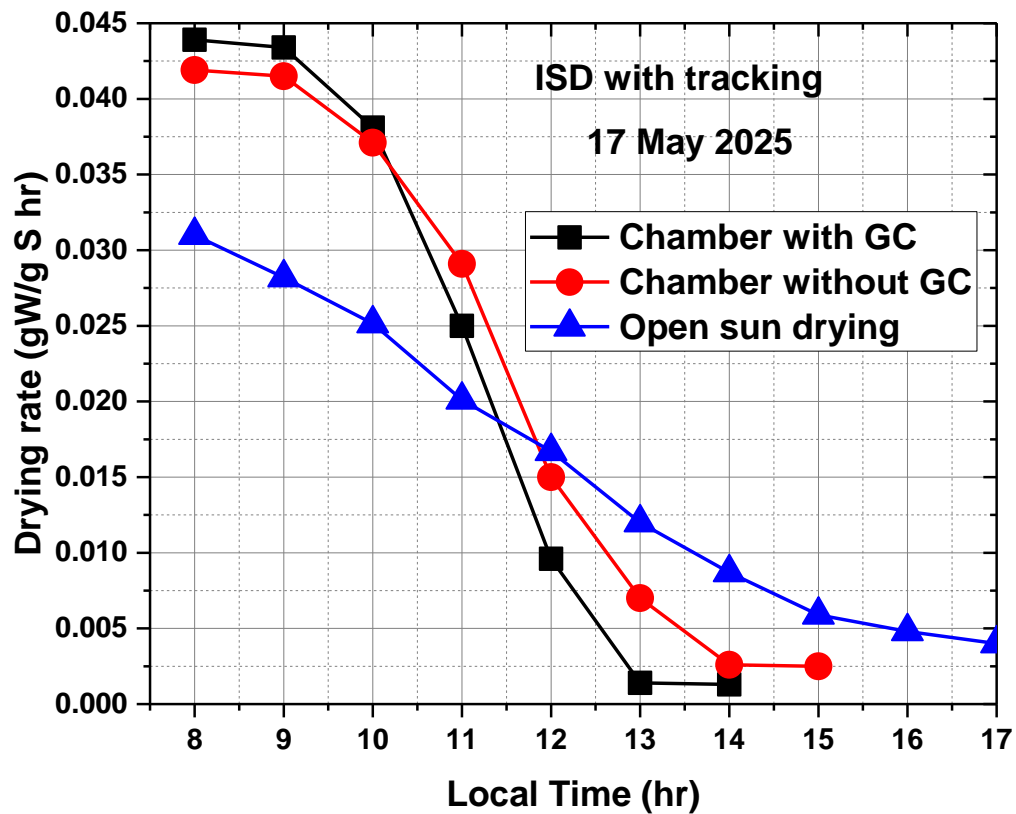


Figure (III-15): Variation of moisture content with operating hours

As drying progresses, the moisture content decreases exponentially, indicating the removal of moisture through different drying methods. Open sun drying requires a longer drying time compared to the two chambers drying. Figure (III-15) shows that the chamber incorporating GC reduced moisture content from almost 73% to 11% in less time than the dryer without GC. This demonstrates that the chamber with GC effectively stores internal air temperature, enabling hot air at optimal temperatures for the product by storing excess heat.

As depicted in Figure (III-16), during the experiment, there was an initial slight decrease in drying rate across all methods in the first few hours of operation, followed by a gradual slowdown as the interior moisture migrated to the outer surface. Notably, both chamber with and without GC initially exhibited faster moisture evaporation rates compared to open sun drying, with the ISC dryer incorporating GC showing the highest overall drying rate. This advantage stemmed from the utilization of GC, which significantly elevated recorded air temperatures, facilitating quicker moisture evaporation.



**Figure (III-16):** Variation of drying rate with operating hours

In conclusion, this study found that using a Chamber incorporating GC reduced Orange drying time by 1h compared to using a chamber without GC and up to 2h compared to open sun drying.

# *General Conclusion*



## **General Conclusion**

Solar energy is a renewable and free energy. We can take advantage of such characteristics to produce dried products through solar drying especially in an area like the city of El-OUED, Algerian Sahara, where the sun is abundant. One of the essential purposes of the solar dryer is to reduce the non-solar energy sources, such as electricity or fossil fuels burning resulting also in a reduction of CO<sub>2</sub> emissions. In this study we have tested inverted solar dryer (ISD) for drying Orange Slices and develop this type to introduce an alternative heating system to the electrical system and be environmentally friendly.

Thence, the main aim of this study was to develop an incorporated glass cover (GC) and tracking mechanism to maximize the solar radiation of the dryer chamber by continually adjusting its direction to the optimum angle towards the sun during daytime hours. In addition, the designed ISD was combined with a GC to compare the performance of the ISD without GC such as drying time orange slices and efficiency under real weather conditions in El Oued city. This experiment was performed on April and May 2025.

- The first experiment was performed to evaluate the influence of the GC on the ISD performance. The results showed that the maximum temperatures in the drying chamber with and without GC are reached 58.13°C, and 51.5°C respectively. Correspondingly, the maximum ISD efficiency with and without GC was 34.01502% and 30.01502% respectively. In addition the ISD with GC took 7 h to desiccate Orange to a minimum level, compared to 7.43 h with ISD without GC and over 8.5 h with open sun drying.
- The second experiment explored the influence of tracking mechanism on drying kinetics of Orange slices in chamber with and without GC. The results showed that utilizing a chamber incorporating GC reduced Orange drying time by 1h compared to utilizing a chamber without GC and up to 2hrs compared to open sun drying. This experiment improved the results of the first one by reducing the drying time.

Further research is needed to assess the impact of various influencing parameters for large-scale industrial applications in agricultural drying

# *Abstract*



## Abstract

This study aims to enhance the performance of an indirect solar dryer (ISD) by integrating a glass cover (GC) and a tracking mechanism to maximize solar radiation absorption within the drying chamber. Two main experiments were conducted under real weather conditions in El Oued city, located in the Algerian Sahara during April and May 2025. The results revealed that the first experiment investigated the effect of the GC on the ISD's thermal performance.

The maximum temperature at the high levels of drying was obtained in the dryer with GC and a tracking mechanism. The values for the drying efficiency of the drying process were 34.01502% and 30.01502% for the processes with and without GC, respectively. The results indicate that ISD with GC showed shorter drying time than ISD without GC or open sun drying.

The future challenges and recommendations on the selection, implementation and testing of the glass over and tracking mechanism for different solar dryers are also reported.

**Keywords:** Indirect solar dryer, Glass Cover, tracking mechanism, Efficiency, Performance

## ملخص

تهدف هذه الدراسة إلى تحسين أداء مجفف شمسي ذو الماص المقلوب (ISD) من خلال دمج غطاء زجاجي (GC) وآلية تتبع لتعظيم امتصاص الإشعاع الشمسي داخل حجرة التجفيف. أجريت تجربتان رئيسيتان في ظل ظروف جوية حقيقية في مدينة الوادي الواقعة في الصحراء الجزائرية خلال شهري أبريل ومايو 2025. كشفت النتائج أن التجربة الأولى بحثت في تأثير الغطاء الزجاجي (GC) على الأداء الحراري لمجفف (ISD). تم الحصول على أقصى درجة حرارة عند مستويات التجفيف العالية في المجفف باستخدام GC وآلية تتبع. كانت قيم كفاءة التجفيف لعملية التجفيف 34.01502% و 30.01502% للعمليات مع GC وبدونها على التوالي. تشير النتائج إلى أن ISD مع GC أظهر وقت تجفيف أقصر من ISD بدون GC أو التجفيف الشمسي المفتوح.

كما تم الإبلاغ عن التحديات المستقبلية والتوصيات بشأن اختيار وتنفيذ واختبار الغطاء الزجاجي وآلية التتبع لمختلف المجففات الشمسية.

**الكلمات المفتاحية:** مجفف شمسي غير مباشر، غطاء زجاجي، آلية تتبع، كفاءة، أداء

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ