Thermal performance study using parabolic collector and cavity receiver using nano-storage materials for solar drying of apples in Baghdad, Iraq

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Abstract
Drying serves as both a preservation method and a processing step for certain products. It is utilized in both rural and industrial settings,particularly within the food processing industry
Dryers that operate on fossil fuels consume significant amounts of energy.Given the rising costs of oil in recent years, which are likely to continue increasing, it is essential to develop drying systems that do not rely on traditional energy sources. Solar drying is one such method that harnesses solar radiation as a free and renewable energy source
Solar dryers are relatively easy to construct using locally available materials and tools, and they can function through natural or forced convection The drying process requires energy and heat, which depend on various factors, including the relative humidity of the air, the drying temperature, the characteristics of the product (such as thickness, surface area, and air resistance), and the moisture content of the item being dried.Consequently, the performance of the dryer is directly influenced by the level of solar irradiation and the relative humidity in the area where it is used.

Keywords: Thermal performance,parabolic collector,cavity receiver,nano-storage,solar drying , apples.

● Introduction

We call drying the operation aimed at partially or totally eliminating water from a humid body by ,evaporation of this water ,The wet body involved can be solid or liquid, but the final product is solid which distinguishes drying from the concentration of a liquid by evaporation, in which case the final .product is a concentrated liquid
During drying, the water contained in the material gradually disappears into the ambient air under the action of two phenomena: the evaporation of water and its diffusion inside the material ,These phenomena depend on the characteristics of the surrounding gas (air or superheated steam), namely
Its temperature✓
Its relative humidity✓
Its speed ✓
Its pressure ✓
Flow rate ✓
Water evaporation is a phenomenon that requires heat and is more intense the higher the temperature of the material

● Literature Review

Drying kinetics_1

The drying kinetics of different products are studied by curves representing the evolution of the drying speed as a function of time, or that giving the drying speed (-dX/dT) as a function of X. These curves are generally obtained for different experimental conditions (temperatures, speed of drying air, hygrometry, etc.). They characterize the overall behavior of the product to be dried over time. On the schematic curve presented in Figure (1), three phases can be distinguished:[1]

Warm-up period (Period 0)
The humidity of the product in this period varies but not significantly and the temperature of the product varies (increases or decreases) up to the wet bulb temperature corresponding to the drying environment (zone A-B). This period is short and only really appears if the products are large, or if the temperature difference between the air and the product is important

Constant speed period
During this period, the drying rate remains approximately constant for most products. Moisture moves to the surface in the liquid state mainly due to capillary forces, the balance between diffusion in the boundary layer (at the air-material interface) and internal moisture transfer mechanisms within the product to the surface is established, the temperature remains uniform in the product because the heat flux exchanged with the hot air is entirely used for the vaporization of water at the surface, this period ends when capillary forces can no longer support the vaporization of surface water, and generally covers a large part of the drying time .[2]

Slowdown period
During this phase, capillary forces are no longer sufficient to transport water to the surface of the product. The drying rate can no longer be maintained constant and it begins to decrease

Different drying methods _2
Mechanical drying
,It is the removal of liquid by purely mechanical forces (pressing, centrifugation, compression (decantation and filtration

Chemical drying
It is a process based on the use of dehydrating (osmotic) products (calcium chloride, etc.) to extract water

Thermal drying_3
This operation primarily involves mass transfer, necessitating the prior "activation" of water through a specific amount of energy supplied by heat transfer
The process can be divided into two distinct phases: external and internal
Internal heat transfer occurs from the heat source to the product's surface -
Internal heat transfer then takes place from the surface to the core of the product -
Internal mass transfer moves from the core to the surface of the product -
Finally, external mass transfer occurs from the product surface to the surrounding environment.[3] -

Drying air temperature
Solar dryers: the air temperature varies between 45°C and 55°C with maxima of 70°C (table 1). The highest temperatures are reached in regions with strong sunshine, and with dryers equipped with good insulation (case of the indirect cabinet) and a large collector surface

Factors	Air drying devices	Direct cabinet	Tight	Indirect cabinet
Energy	Direct solar exposure Surface variable	Direct solar exposure	Direct solar exposure	Indirect solar exposure
Dried products	C: corn, sorghum, millet, sesame T : manioc L: okra, chili	L: onion, cabbage, tomato, pepper, okra	L: onion, cabbage tomato, okra F: coconut	L: onion, cabbage, tomato, pepper F: coconut
Shape of Product presentation	seed, slice, piece	leaves, slice, piece	leaves, slice, piece	leaves, slice, piece
Duration of a drying cycle	A few days	1 to 3 days	1 to 3 days	2 to 3 days
Maximum drying air temperature (°C)	Room temperature (28 to 35)	50	50	55

Table 1: Operating data of the inventoried dryers

Different types of solar dryers_4

Natural dryers

They utilize sunlight and air directly by spreading the products on racks, mats, in cribs, or even on the ground. The principle behind open-air drying is straightforward: solar radiation strikes the surface of .the crop, with some of the energy being reflected back into the environment (see Figure 1)

These dryers are very cost-effective; however, they require regular human intervention. This includes protecting or gathering the products in case of rain, frequent mixing to prevent overheating of the upper .layer, and ensuring that the product is evenly homogenized to allow the lower layer to dry effectively

This type of drying method is commonly used in rural communities to address the challenges of temporarily preserving products while waiting for sale or consumption.[4]

Nevertheless, it has certain drawbacks, including losses of inadequately dried or spoiled products during handling, the destruction of vitamins A and C due to direct sunlight exposure, and degradation caused by adverse weather conditions and pests (such as insects, rodents, and dust)

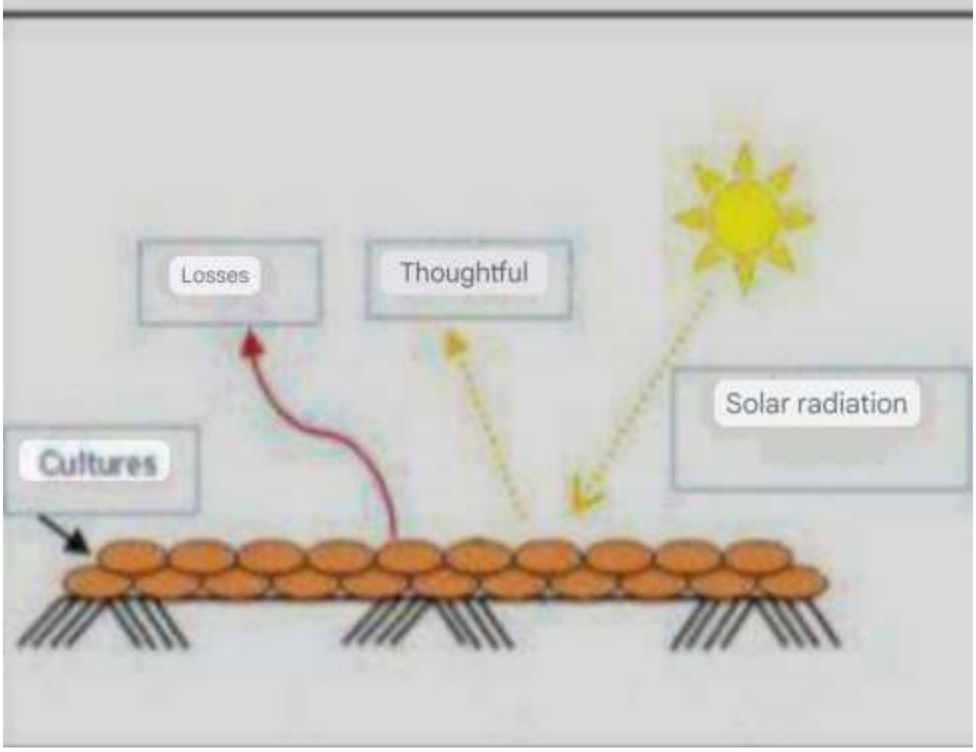


Figure 1 Principle of open air drying

Direct solar dryers

Direct solar dryers are easy to use and construct. They provide a variety of design options, ranging from a box dryer with trays suitable for small-scale production to a cabin dryer designed for processing larger quantities.[5]

Operating principle

The sun's rays directly strike the products in a direct solar dryer, which consists of a single chamber that functions as both a drying area and a solar collector. The floor of the drying chamber is painted black to enhance heat absorption. Typically, a transparent plastic or polyethylene sheet serves as the roof, although more expensive materials, such as glass or specialized plastics (like agricultural polyethylenes), can also be utilized

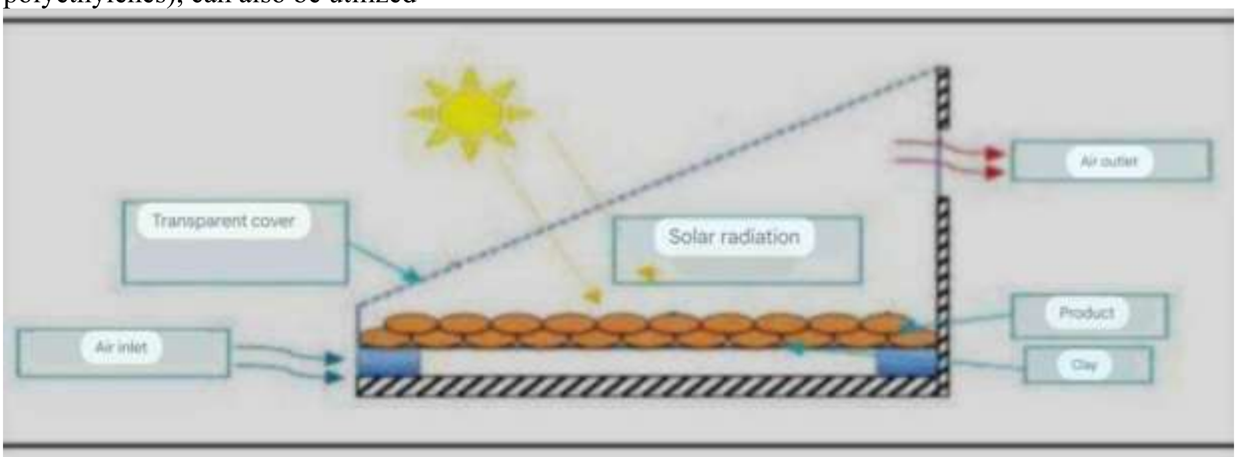


Figure 2. The principle of a direct solar collector

Advantages

Enhanced protection against dust, insects, animals, and rain compared to traditional drying methods

No requirement for skilled labor

.Wide range of design options available

Disadvantages
Quality degradation caused by direct sunlight exposure, leading to the destruction of vitamins A and C,as well as wilting and discoloration
The fragility of polyethylene materials necessitates regular replacement ,The relatively high temperatures within the dryer, exacerbated by sunlight exposure, can destroy nutrients
Inadequate air circulation limits drying speed and increases the risk of mold growth.[6]

Indirect solar dryers_5
These systems are more efficient than direct dryers and have the advantage of better preserving the .attributes of food, including its color, appearance, and nutritional value
.As a result, they are especially well-suited for drying food products

Operating principle
The indirect solar dryer is composed of several components: a collector that converts solar radiation into heat, a drying chamber that holds the product, and a chimney (see Figure3). Air flows into the collector, where it is heated, resulting in an increase in temperature. The hot air then rises naturally through convection to the drying chamber. The drying time can vary significantly depending on the climatic conditions.[7]

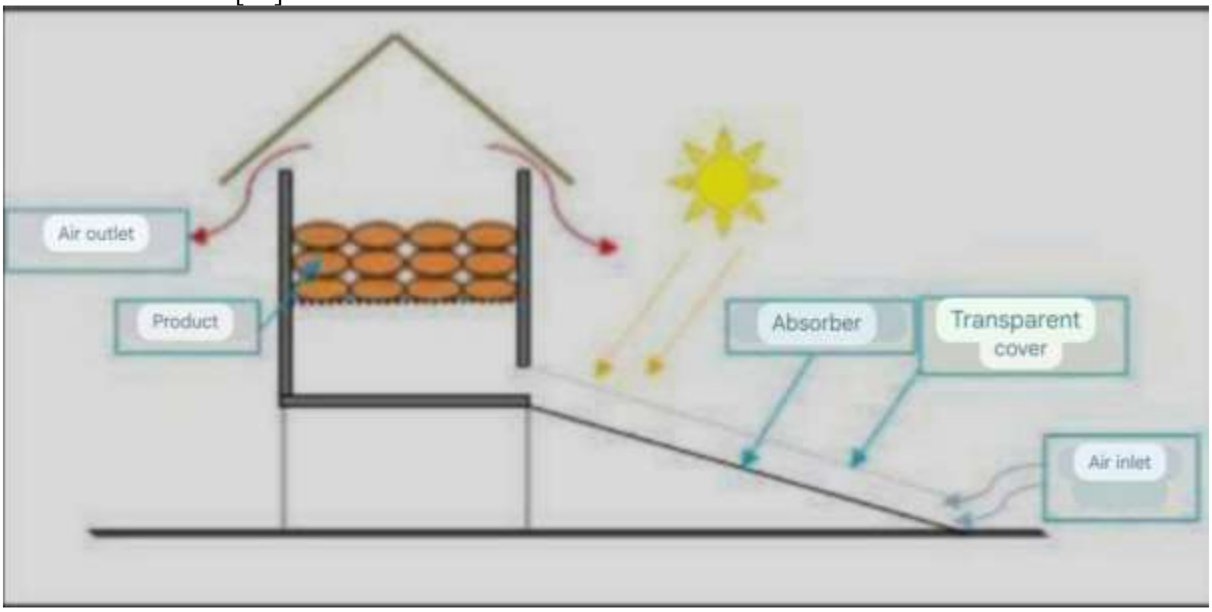


Figure 3 The principle of an indirect solar collector

Advantages
The product is not exposed to direct sunlight, allowing it to better retain its color and nutritional value,particularly vitamins A and C
There is also the option to construct this type of dryer locally at a lower cost
Furthermore, their operation does not rely on electrical energy or fossil fuels

Disadvantage
Drying speed varies greatly depending on climatic conditions and the design of the dryer
Fragility of polyethylene materials which must be changed regularly

Hybrid dryers
Research has concentrated on hybrid dryers that utilize supplementary energy sources such as fuel,electricity, wood, or gas. The additional energy can be distributed in two distinct ways within the dryer
To maintain a constant temperature inside the dryer using a gas burner, electric resistance, or wood .1 fire. In this scenario, solar energy plays a secondary role, primarily functioning to preheat the air.[8]

To enhance air circulation through the use of electric fans. In this case, solar energy serves as the .2 primary heat source, while the improved ventilation allows the dryer to achieve a higher evaporation capacity

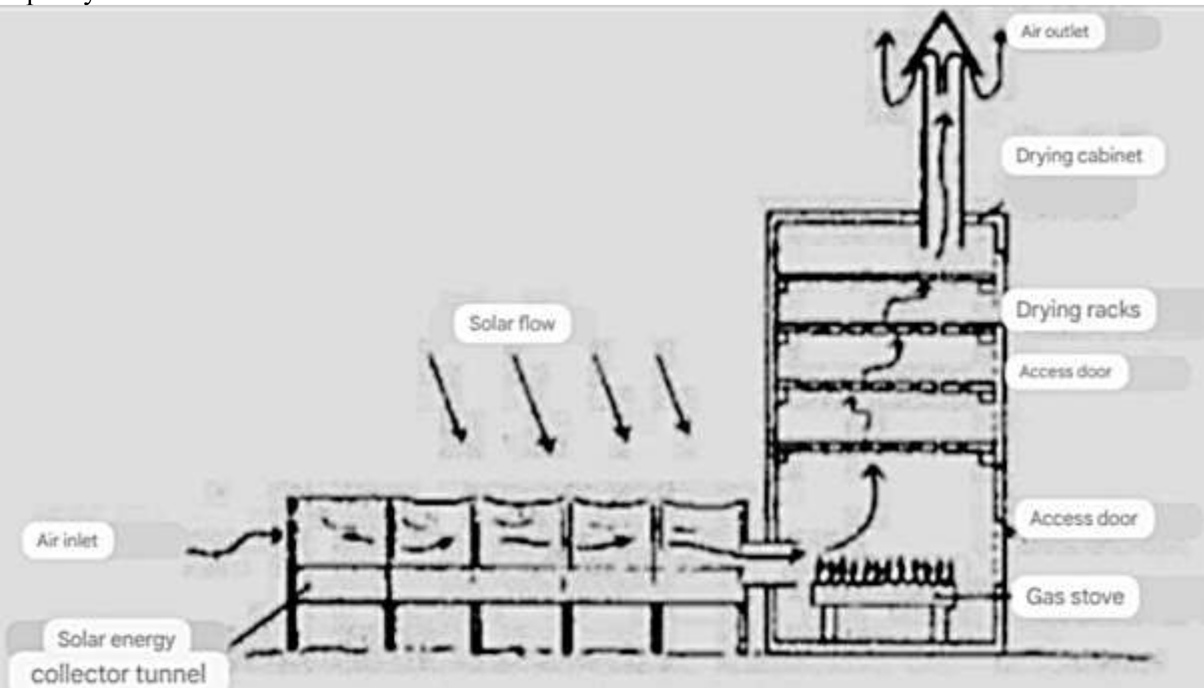


Figure 4 Hybrid solar dryer

Advantages
Postage in relation to climatic conditions
Better drying control
Significant increase in production compared to other types of dryers, as the device can operate at night or in the rainy season if necessary.[9]

Disadvantages
High production and investment cost
Need for local supply of fuel, electricity, spare parts
Qualified personnel for maintenance

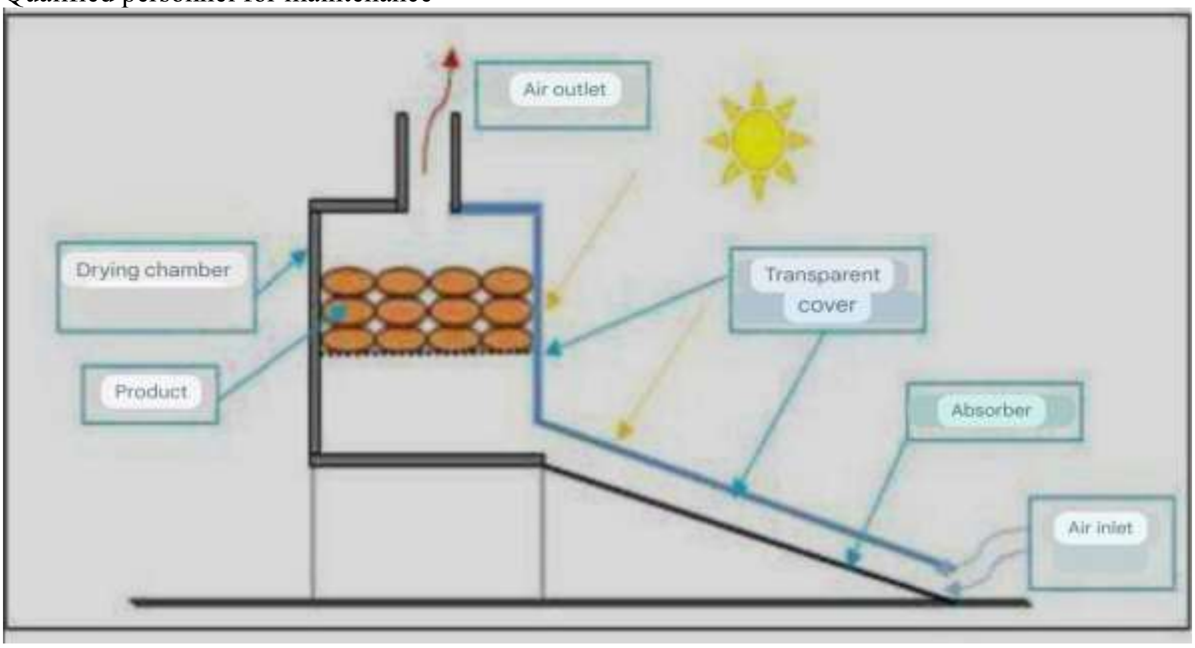


Figure 5 The principle of a mixed solar dryer
Mixed dryers_6

These dryers integrate the characteristics of both direct and indirect dryers. In this type of dryer, the simultaneous action of direct solar radiation on the drying product and the solar collector provides the heat required for the drying process. A mixed dryer with natural circulation (as shown in figure 5) shares the same structural elements as an indirect dryer, including a solar collector, drying chamber, and chimney. However, the walls are fitted with glass panels to allow direct exposure of the product to solar .radiation, similar to an integral dryer

The different types of solar dryer structure _7
To improve the efficiency of drying, some kind of structure must be used that captures solar radiation.Several types of solar dryers have been developed and are illustrated below .[10]

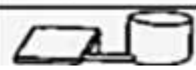
Solar desiccation	description of dryer types	
Direct cabinet	The drying chamber is enamelled and no separate solar collector is used.	
Indirect cabinet	The solar collector is separate from the drying chamber.	
Tunnel direct	Usually a structure with a hoop frame covered with plastic or two layers of film.	
Tunnel bas	Direct dryer similar to above but built close to the floor, typically can only hold one layer of product.	
Tent	Direct dryer with a straight rather than curved frame.	
[illegible]	Indirect dryer with forced air flow.	

Table 2: Structure of some solar dryers
Dried products
Table 3 showcases various dried products along with their characteristics, including initial water content, final water content on a dry basis, and the maximum temperatures at which these products can be dried. The products are categorized into cereals, tubers, vegetables, and fruits based on the classification used by the FAO. Notably, the cyanobacterium Spirulina is classified here as a vegetable due to its exceptionally high water content. The initial water content of the dried products ranges from for cereals (such as maize, millet, and rice) to 1900% for apples. The sugar content varies from %30 to 27% in bananas. The diverse components of these products result in different behaviors during %0 the drying process, leading to phenomena such as enzymatic or non-enzymatic browning, crusting, and discoloration, which can occur due to exposure to radiation (e.g., heat). The thicknesses indicated in Table 2 represent the average height of the product layer ,In our survey, we discovered that direct solar drying primarily processes products with low initial water content, such as cereals, legumes, and leafy vegetables. This characteristic can be attributed to the low surface water load. For other products, this can only be achieved by preparing them in very thin slices (non-traditional formats). The combination of a low surface water load with low concentrated solar energy allows for a relatively low water content after the first day of drying, thus minimizing degradation. Operators remain particularly sensitive to product loss, regardless of the type of dryer used.[10]

Dried products	Initial water content (%)	Final water content (%)	Sugar content (g/100g)	Maximum drying temperature (°C)
Cereals				
but	32 - 54%	14 - 18%	3.64	60
rice	32%	12%	0.13	50
sorgho, mil	27%	16%		60
Tubers				
yam	233 - 400%	11 – 16%	5.8-7.2	65
cassava	163 - 233%	11 – 20%	3.9	65
Fruits				
pineapple	400 - 567%	14 - 11%	6.4-14	65
banana	257 - 400%	14 - 18%	14,8 - 27	70
Vegetables				
cabbage	400%	5%	2.8-3	60-65
carrot	233%	5%	6.7	75
tomato	1900%	8%	2.8-3.5	50-60
chilli, bell pepper	245 - 567%	5-15%	2.2-4.7	70

Table 3 Characteristics of dried products

- **Methodology**

we present the electronic card developed is designed around an Arduino Nano microcontroller card and a set of three temperature and humidity sensors used for collecting information from the drying system.The developed card also contains an LCD display module for displaying the measurements taken, a data storage module on an SD memory card, a real-time clock module and a Bluetooth RF].communication module. Finally, we present the software part associated with this measurement card [11

Hardware Part_1

In this part, we present the hardware part of the electronic measurement card as well as the production of the printed circuit

Management and processing block: The measurement card developed for our drying system is based on an Arduino Nano microcontroller card. The latter constitutes the brain of our installation, it receives the signals from the temperature and humidity sensors and ensures management of the other blocks

The Arduino Nano Board

Presentation

The Arduino nano board is a small electronic board measuring 44 x 18 mm, it is equipped with a microcontroller. The latter allows, from the data and events detected by sensors, to manage and control actuators. The Arduino board illustrated in Figure 7 is therefore an electronic development platform which constitutes a programmable interface.[12]

Figure 7 The Arduino Nano board

Features of the Arduino Nano board

The following table summarizes the general characteristics of this development platform

Features	Values
Microcontroller	Atmel ATmega328
Operating voltage (logic level)	5V
Supply voltage (recommended)	7-12V
Supply voltage (min-maximum)	6-20V
Digital Inputs/Outputs	14 (6 of which can provide PWM output, marked with a white line)
Analog inputs	8
Current available per I/O pin	40mA
Flash memory (program memory)	32 KB (of which 2KB used by the bootloader)
SRAM memory	2 kB
EEPROM memory	1 kB
Clock speed	16 MHz
Dimensions	44 x 18 mm

Table 3 Characteristics of the Arduino Nano board

ATMega328 microcontroller

The ATMega328 microcontroller is an integrated circuit that brings together on a chip several complex elements in a small space. Today, by soldering a large number of bulky components such as transistors;resistors and capacitors everything can be housed in a small black plastic case with a certain number of pins that can be programmed in C language. Figure III.3 shows the appearance of an, ATMega328 microcontroller in a DIP package, which is found on some Arduino boards.[13]

Figure 8 ATMega328 microcontroller

The ATMega328 microcontroller is made up of a set of elements that each have a specific function. It is in fact made up of the same elements as on a computer motherboard. Overall, the internal architecture of this programmable component essentially contains:[14]
A Flash memory: which will contain the program to be executed. This memory is erasable and programmable, it can receive a program up to 32 KB in size (including the boot loader of 0.5 KB)
A RAM memory: this is the so-called "live" memory, it will contain the program variables. It is called volatile" because it loses its contents when the microcontroller is powered off, its capacity is 2 kb ,An" EEPROM memory is the hard disk of the microcontroller. It stores information that needs to survive over time, even if the card must be stopped. This memory is not erased when the microcontroller is turned off or when it is reprogrammed

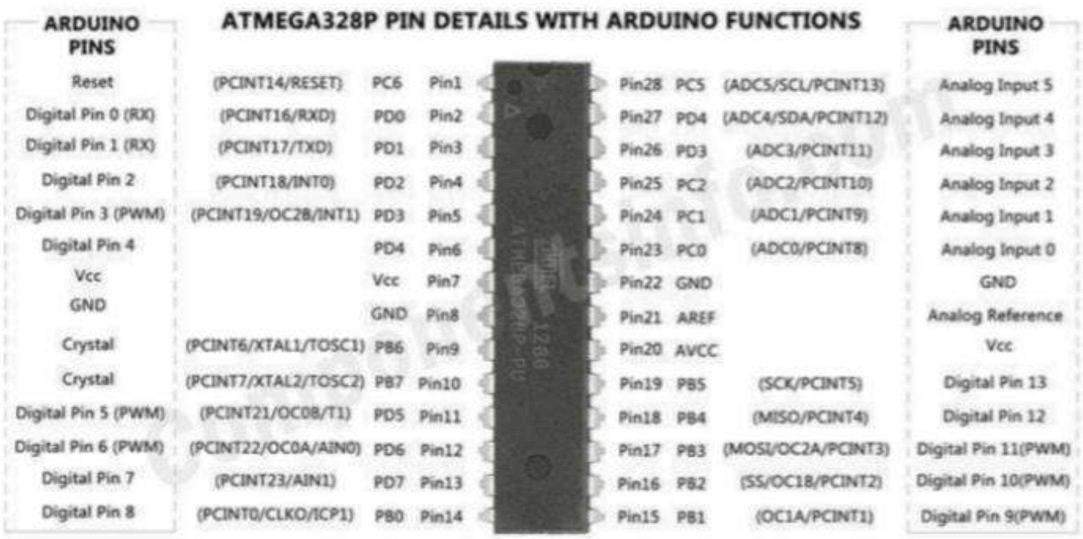


Figure 9 Pinout of the Atmega328 microcontroller

Inputs/outputs of the Arduino Nano board
Figure 10 shows the external appearance of the Arduino Nano board that we used for our measurement board

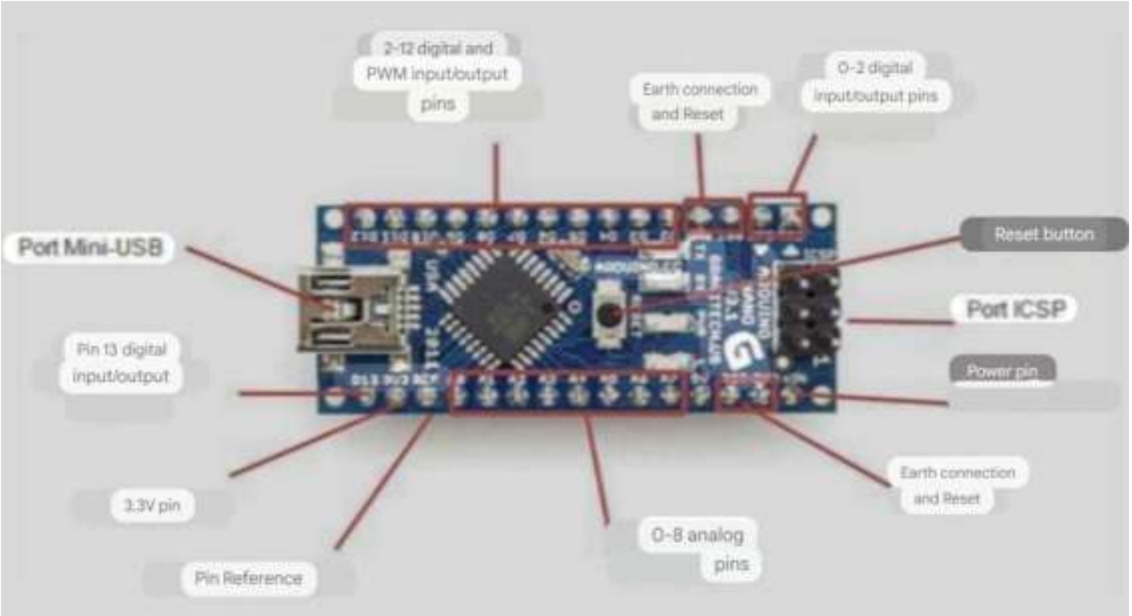


Figure 10 Description of the Inputs/Outputs of the Arduino Nano card

Each of the 14 digital pins on the Nano board can be used as an input or output, using the pinMode(),digitalWrite(), and digitalRead() functions. Each pin can source or receive a maximum of ,mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. Additionally 40 some pins have specialized functions.[15]

Figure 11 shows the detailed pinout of the Arduino Nano board

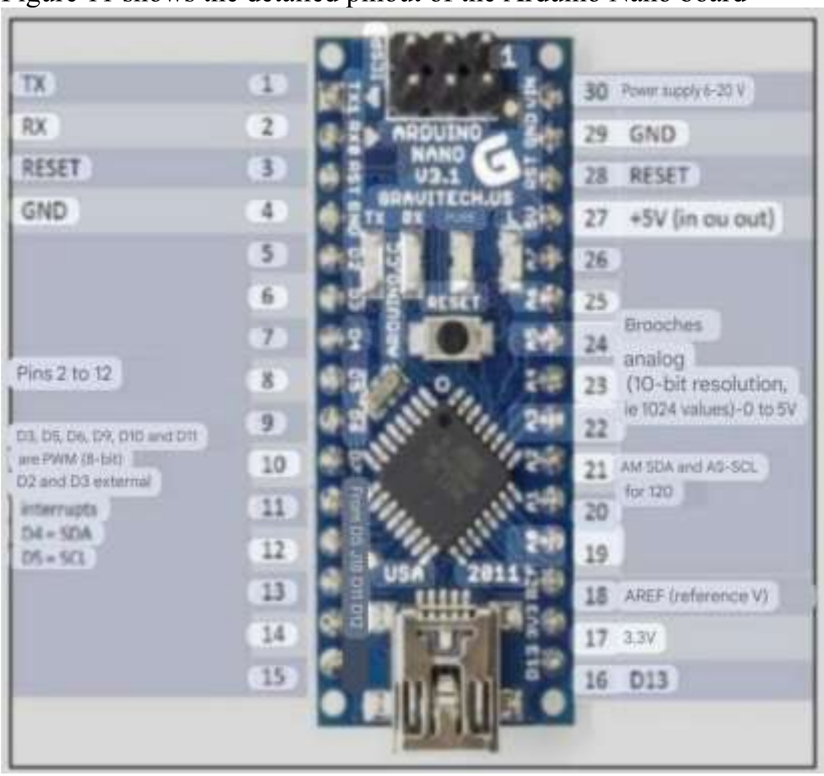


Figure 11 Pinout of the Arduino Nano

The following table summarizes the pin assignments of different pins on the Nano board

The Arduino Nano board has a built-in fuse that protects the computer's USB port from overload current (the USB port is typically limited to 500mA in current). While most computers have their own internal protection, the board's fuse provides an additional layer of protection. If more than 500mA is applied to the USB port, the board's fuse will automatically disconnect the connection until the short circuit or overload is stopped [16]

Power supply

To operate the electronic measurement card, a power supply is required. Since the microcontroller operates at 5V, the card can be powered at 5V via the Mini-USB port or by an external power supply that is between 7 and 12V. This voltage must be continuous and can for example be provided by a 9V battery. A regulator is then responsible for reducing the voltage to 5V for the proper functioning of the card's elements. There is no risk of burning out the Nano card and its associated modules provided that the input supply voltage range is respected, which must be between 7 and 15V. The power supply pins :are distributed as follows

VIN: The input voltage to the Arduino board when using an external power source (as opposed to 5V from the USB connection or other regulated power source).[17]

5V: The pin outputs regulated 5V from the Nano board's regulator. The board can be supplied with power from the DC power jack (7 to 12 V), the USB connector (5 V), or the board's VIN pin (7 to 12 V). Supplying voltage through 5 or 3.3 V pins bypasses the regulator and may damage the board

3V3: A 3.3V supply generated by the FTDI chip's built-in regulator, the maximum current flow is 50mA

GND: This is the ground pin

Display block

This block is essentially made up of a 4 x 16 character LCD (Liquid Crystal Display) screen (4 lines of characters each) associated with an interface module of the type I2C to reduce connectivity to a 16 minimum

The LCD (Liquid Crystal Display) display

This module was used to display temperature and humidity, this information is mostly needed by a skilled person, who can check the measurements from the various sensors without needing to connect a PC to the Arduino board and use specialized software.[18]

LCDs or liquid crystal displays are becoming more and more common in our environment, whether to display useful information or to serve as a command selector. There are displays of all types ranging from simple character displays to giant color displays. The most commonly used displays in Arduino applications are alphanumeric character displays (Figure 12)

Pin	Function
Series	0 (RX) and 1 (TX). Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins on the FTDI USB-TTL serial chip.
External interrupts	2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a value change.
PWM	3, 5, 6, 9, 10 and 11. 8-bit PWM output with analogWrite() function.
SPI	10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK). These pins support SPI communication.
LED 13	There is an onboard LED connected to digital pin 13.
Reset	set this line to LOW to reboot the microcontroller. usually used to add a function or a reset button directly on the shields/modules.
AREF	Reference voltage for analog inputs. Used with analogReference
Analog inputs	The card has 8 inputs for this, labeled A0 to A7, which can accept any analog voltage between 0 and 5 V.

Table 4 Pinout of the Arduino board

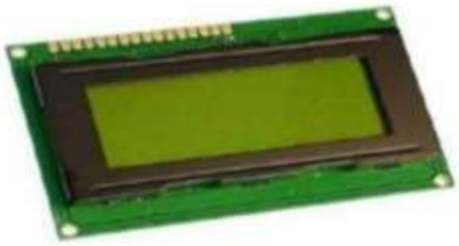


Figure 12 Alphanumeric LCD displays with parallel interface

Definition of the 12C interface

12C (Inter-Integrated Circuits) is a technology that allows the operation of a set of elements or devices using the least number of electronic connections as efficiently as possible ,This technology allows the operation and exchange of data in serial mode with all devices through only two wires or more precisely through two lines. A serial data line and a serial clock line. Each element has a predefined address during manufacturing (such as the Internet IP address or the MAC address of wireless networks). The ATMEGA328 microcontroller then communicates with each device according to its own address and operates from the clock. All devices are connected in a row, each component can be manipulated independently.[19]

The I2C interface (or bus) is sometimes called TWI (Two Wire Interface) or TWSI (Two Wire Serial Interface) by some manufacturers

Purpose of installing the 16x4 LCD display with I2C interface

There are also small modules (Figure 13) that allow you to interface an LCD screen with an I2C bus.This solution can be interesting if you are desperately short of pins on the ATMEGA328 microcontroller as in our project since instead of monopolizing 6 to 7 pins, the screen will only use 2

GND , UCC , SDA , RSC

Figure 14. Mounting the 12C Module with the LCD display , **Figure 13 Interface 12C d'un module .LCD**

However, the most commonly encountered module is built around the chip NXP's PCF8574P, a circuit for increasing the number of digital inputs and outputs via the I2C bus Figure 14 illustrates the assembly of the 12C interface module with the conventional LCD display.[20]

Real-time clock block

In this block, we used a DS 3231 type real time clock to measure time in hours, minutes and seconds in the indirect solar drying system ,The DS3231 (Figure 15) is a very accurate low-cost module that can keep hours, minutes and seconds, as well as information about the day, month and year. In addition, it offers automatic compensation for leap years and months with less than 31 days. What makes it stand out is its operation with its own external battery, which allows it to maintain time calculation even when the power is cut off from the Arduino board. The connection of the module to our measurement board is made via the I2C communication bus that is supported by the module The question that may arise at this point is why we really need an RTC for our measurement board, when the Arduino itself contains a built-in stopwatch? The problem is that the RTC module runs on battery power and can keep track of the time even if we reprogram the microcontroller or disconnect the main power supply.[21]

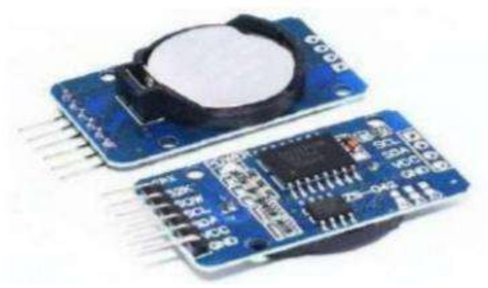


Figure 15. DS3231 real-time clock module

Data storage block

For this block, we used an electronic module to record indirect solar drying data (temperature and humidity) from the sensors on an SD type memory

In the following we will describe how to use an SD card data storage module with an Arduino board to ,read and write data files ,The SD card module is especially useful for projects that require data logging the Arduino can create a file on an SD card to write and save data using the SD library,There are different models offered by different vendors, but they all work in a similar way, using the SPI communication protocol (bus). The module (Micro SD card adapter) is a module that provides reading and writing of data in the form of files from the SD card via the SPI interface ,The SD card adapter module used in our design supports the following memory card models: Micro SD card (capacity < 2 GB), Micro SDHC card (high-speed memory card with capacity <= 32 GB). The adapter module we used ensures the conversion of voltage levels from 5 to 3.3 V necessary for accessing the SD memory through a voltage regulator integrated into the module ,The module management interface is as follows: A total of six pins (GND, Vcc, MISO, MOSI, SCK, CS), GND and ground line, Vec is the power line, MISO, MOSI, SCK are the communication lines between the module and the Arduino Nano board, CS line is the adapter module selection line among the electronic modules connected on the SPI bus.[22]

Figure 16 SD Card Adapter Module

Command block

In this block, we used a rotary encoder, having a wheel that will allow us to scroll through the options of any display menu on the LCD module, know how to navigate the menus, select submenus and also modify setting values in these menus. In addition to an integrated switch that allows us to validate the choices made, The rotary encoder is a rotation sensor without a stop, from which the direction of rotation and the angle can be known. Similar in appearance to the potentiometer, the encoder has no limit travel and instead of returning a resistance value, like the potentiometer it returns two digital signals in the form of pulse trains which allow the angle of rotation to be calculated and the direction of rotation to be determined , With a suitable algorithm, it is possible to recover the state of the two contactors and find its position. The rotary encoder is sometimes coupled to a push button (switch) which is practical for validating commands.[23]

Figure 17 The rotary encoder

Temperature and humidity sensor

In our project we have chosen to use a single sensor that provides both temperature and humidity measurement. The DHT sensor family contains two sensor models (DHT 11 and DHT 22) that are well known, have acceptable accuracy and are inexpensive. Thus this type of component combines both a temperature probe and a humidity sensor. The DHT22 version is more accurate and has a wider measurement range than the DHT 11 version. Figure 18 illustrates the external appearance of the DHT [24].22

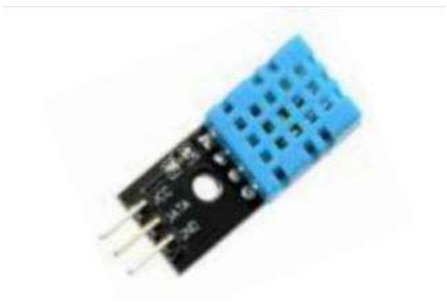


Figure 18 The DHT 22 probe

Figure 19: The DHT11 probe

Figure 19 presents the DHT 11 version

The following table shows a general comparison of the characteristics of the two sensor models

Features	DHT 11	DHT 22
Supply voltage	0 – 5 V	0 – 5 V
Humidity range	20 to 80%	0 to 100%
Temperature range	0 to +50 °C	-40 to +80°C
Humidity measurement accuracy	± 5 %	± 2 %
Temperature measurement accuracy	± 2 °C	± 0.5 °C

Table 5. Comparison between DHT11 and DHT22 sensor

In our realization we have opted for the DHT22 which gives us the temperature and humidity with great precision. It is reliable and can even measure negative temperatures. We have used three DHT22 sensors, the first sensor is for measurements outside the drying chamber, the second sensor is located inside the drying chamber (between the calais) and the third sensor is placed at the entrance of the chamber. The DHT 22 sensor is composed of 04 pins, in reality, only 03 are usable:[25]

VCC: power pin -1
Data: data pin -2
NC: pin not used -3
GND: ground pin -4

Presentation of the electrical diagram of the measurement card
Figure 20 shows the overall electrical diagram of our measurement card

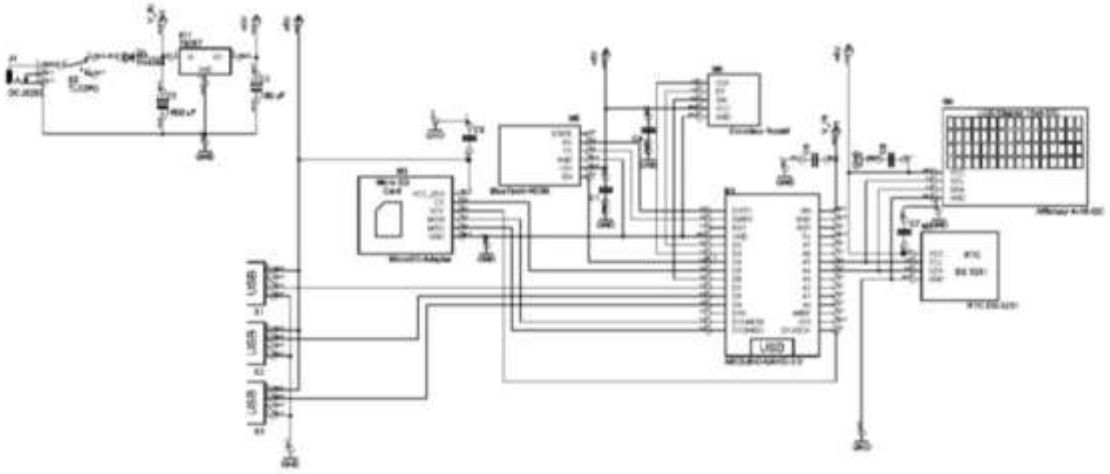


Figure 20. Electrical diagram

- **Results & Discussion**

we will present the experimental results of indirect solar drying. This chapter includes two experiments.The first experiment included the results of solar drying of apples slices of 1 cm thickness and the same for the second experiment of 2 cm thickness. The results were presented in the form of curves and discussed

Preparation of Samples
The apples chosen are of good quality (neither too ripe nor too raw). They are sorted to have the same dimensions. Then they are washed with fresh water, then weighed and cut using a sharp-bladed cutter

Experiment No. 1
The first experiment was carried out during the day of 05/21/2020 and 05/21/2021. This experiment concerns the drying of apples slices of thickness equal to 1 cm, with a total weight equal to 1000g, With a uniform distribution (500 g per rack), the drying procedure is carried out from 9:00 to 19:00. We monitor the temperature and humidity during this period

Variation of the temperature of different elements of the dryer
Figures 21 and 22 show the evolution of temperatures in different locations of the dryer over time during the days of May 21 and 22, 2021

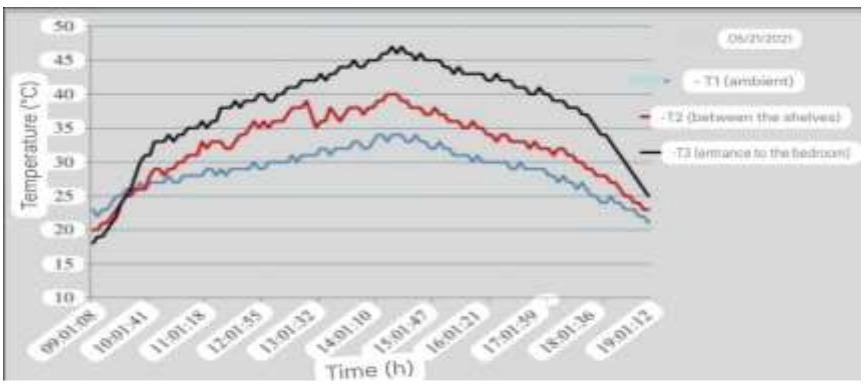


Figure 21. Evolution of experimental temperatures for the day of 05/21/2021

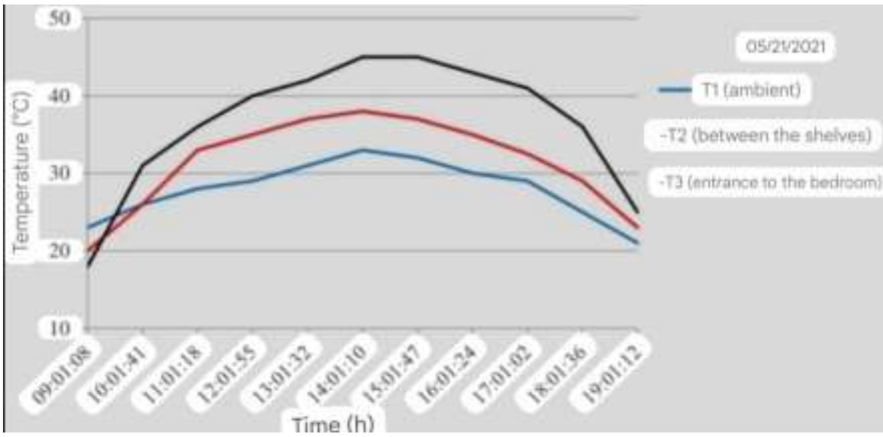


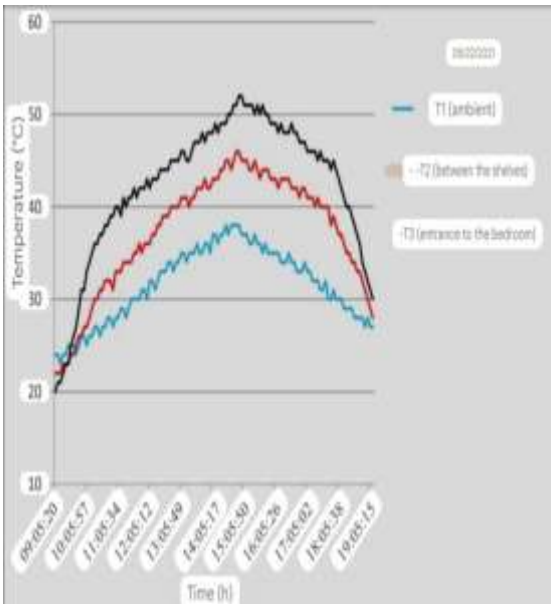
Figure 22. Evolution of average temperatures for the day of 05/21/2021

The black curve represents the evolution of the inlet temperature of the drying chamber, the red curve the evolution of the temperature in front of the racks and the blue curve characterizes the temporal variation of the ambient temperature. For the day of May 21, 2021, from 09:01 to 14:40, we observe an increase in temperatures (ambient and in the drying chamber) while from 14:40 to 19:00, we observe a decrease in these temperatures

Figure 23. Evolution of experimental temperatures for the day of 05/22/2021

The same observations are also valid for the day of May 22, 2021, from 09:05 to 02:30, and from 02:30 to 19:30. We also observe a difference between the ambient temperature (sensor inlet), the temperature at the entrance to the drying chamber and the temperature at the racks

This difference is due to the heating of the absorber in the solar collector. In fact, under the effect of solar radiation, the temperature of the ambient air increases at the outlet of the collector



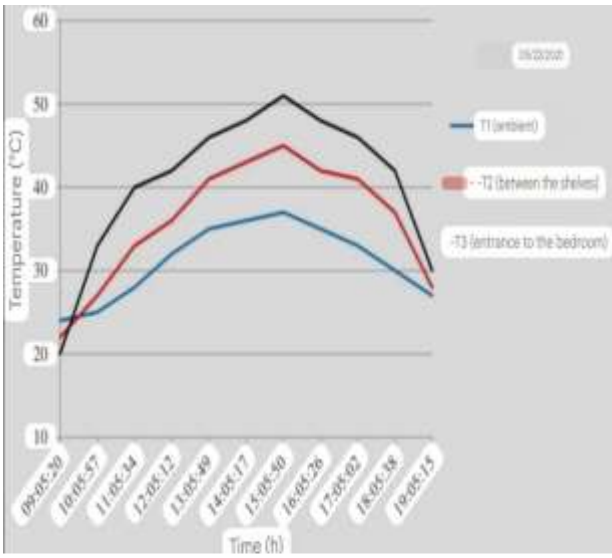


Figure 24. Evolution of average temperatures for the day of 05/22/2021

Variation of the relative humidity of different elements of the dryer

Figures 25 and 26 represent the evolution of relative humidity at different locations in the dryer as a function of time during the days 21/05/2021 and 22/05/2021

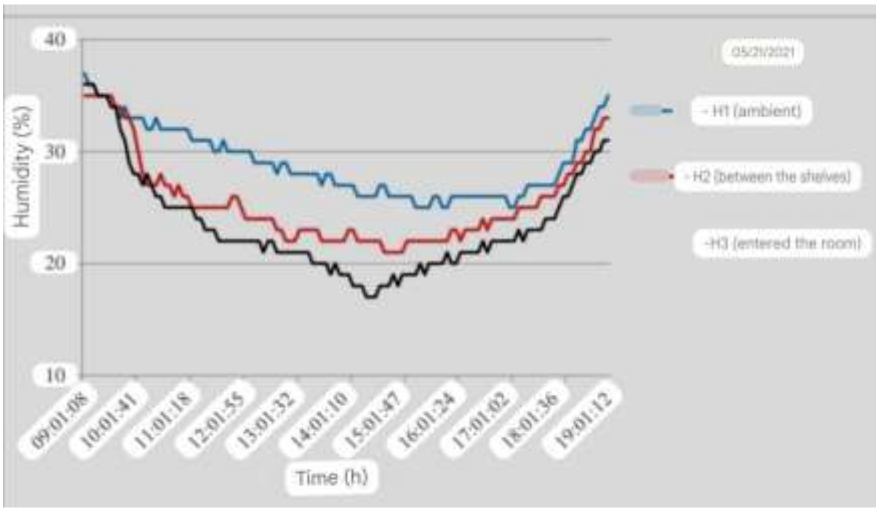
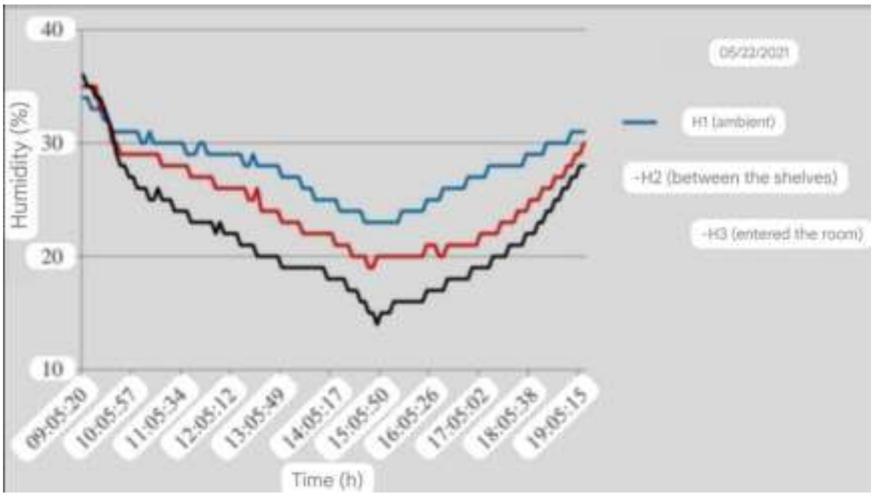


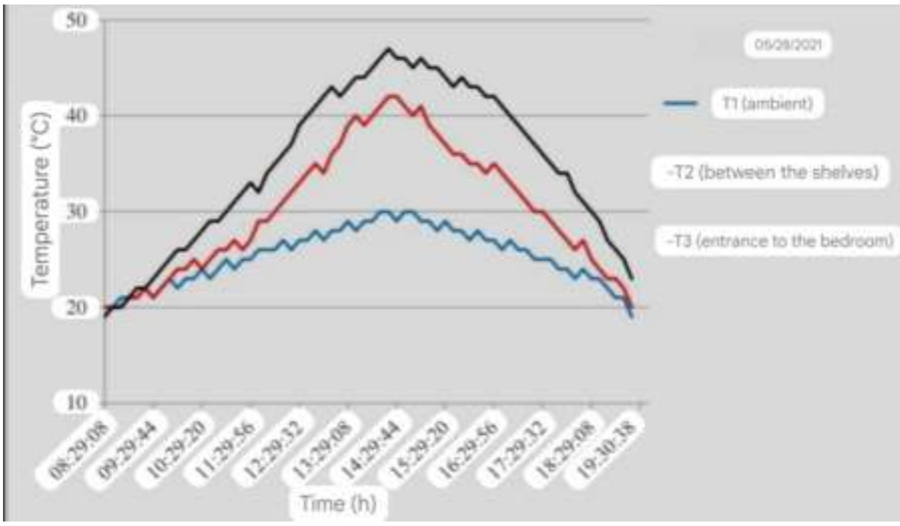
Figure 25. Evolution of relative humidity for the day of 05/21/2021

The black curve represents the evolution of the relative humidity at the entrance to the chamber, and the red curve represents the evolution of the relative humidity in front of the racks. The blue curve represents the relative humidity outside the drying chamber. On May 21, 2021, from 09:01 to there was a decrease in humidity (ambient (25%), the entrance to the chamber (17%) and between,02:30 the racks (21%)) while from 02:30 to 19:00, there was an increase in this relative humidity

Figure 26. Evolution of relative humidity for the day of 05/22/2021

The same observations are also valid for May 22, 2021, from 9:05 to 14:45 a decrease in humidity and from 14:45 to 19:30 an increase in this relative humidity. There is also a difference between the relative humidity outside the room (23%) and the humidity at the entrance to the room (19%) and between the racks (14%) ,This difference is due to the higher temperature at each position of the dryer





Experiment No. 2: A second experiment was carried out during the day of 05/28/2020, 05/29/2021 and with a thickness of 1cm, in which we followed the same steps with the same weights in 2021/30/05 racks

Variation of the temperature of different elements of the dryer
Figures 27, 29 and 31 show the variation of temperatures in different locations of the dryer as a function of time during the days of May 28, 29 and 30, 2021

Figure 27. Evolution of experimental temperatures for the day of 05/28/2021

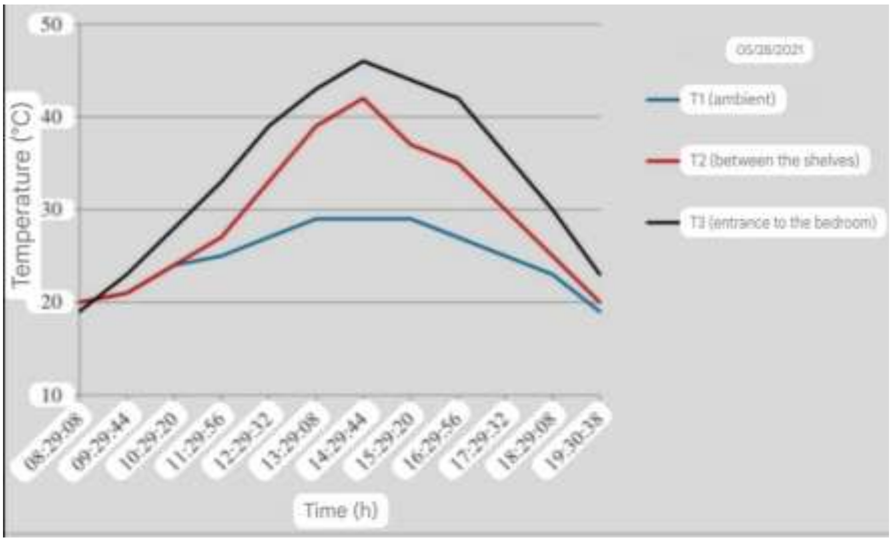


Figure 28. Evolution of average temperatures for the day of 05/28/2021
A relative increase is observed in the three temperatures, where the temperature at the entrance of the drying chamber reaches 47 degrees at 14:30 and then gradually decreases until reaching 23 degrees at (black curve), while the temperatures between the racks reach a maximum of 42 degrees at 2:30 19:30 and then gradually decrease to 20 degrees at 19:30 (the red curve), when the ambient temperature varies from 20 degrees to 30 degrees

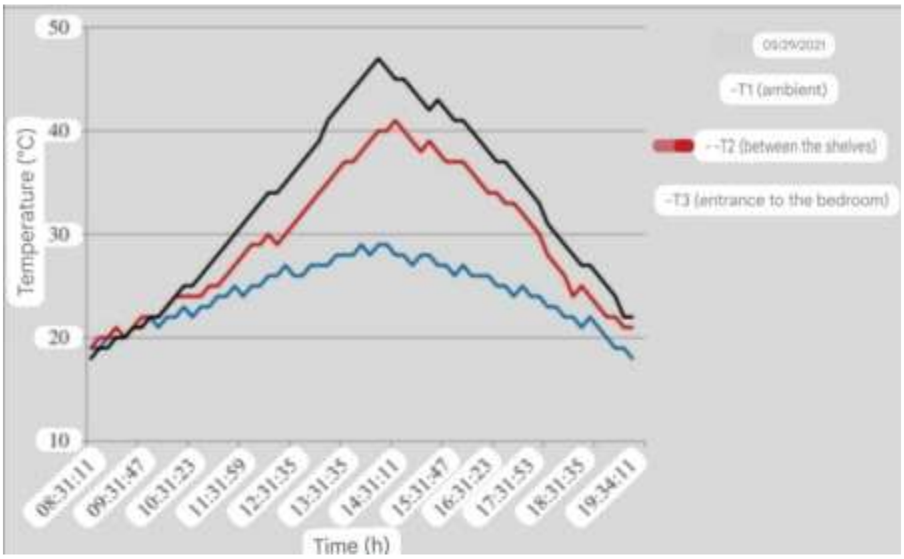


Figure 29. Evolution of experimental temperatures for the day of 05/29/2021

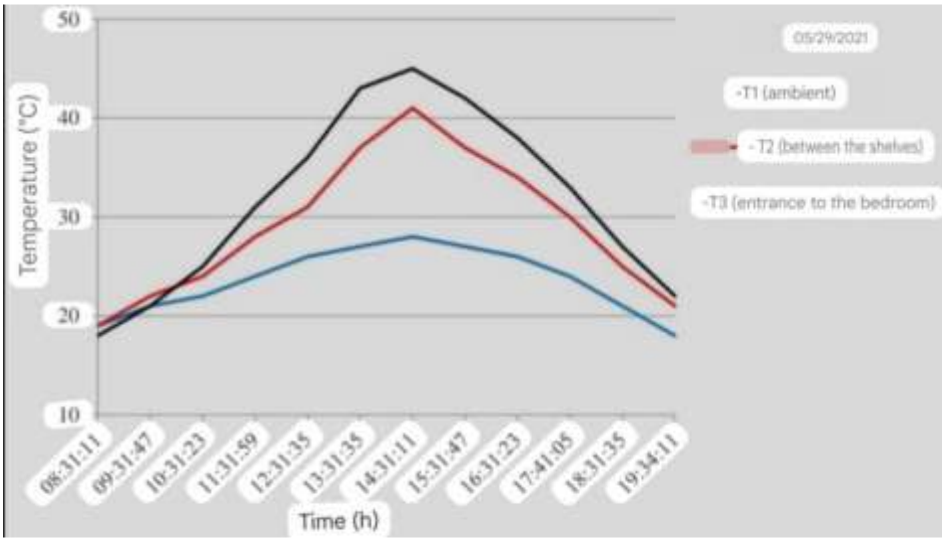
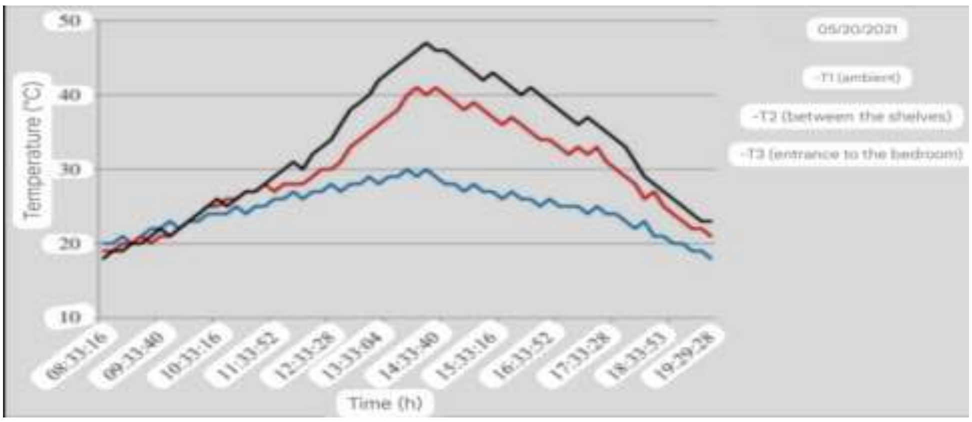


Figure 30. Evolution of average temperatures for the day of 05/29/2021

On the second day, there was an increase in temperatures at all three locations, reaching a maximum at the entrance to the chamber of 47 degrees Celsius (the black curve) and between the racks reaching 41 degrees Celsius (the red curve), and this at 2:30 p.m. and then gradually decreasing to reach 22 and 21 degrees Celsius, respectively, while the ambient temperature varied between 19 and 30 degrees Celsius

Figure 31. Evolution of experimental temperatures for the day of 05/30/2021



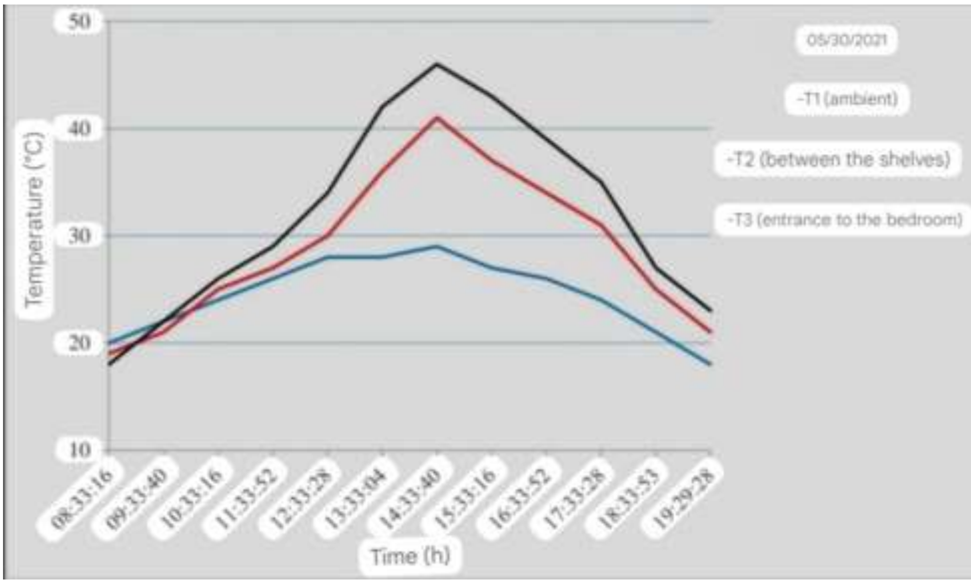


Figure 32. Evolution of average temperatures for the day of 05/30/2021

The same observations occurred on the last day of drying. While temperatures increased in the same way, but to different degrees, reaching 47 °C at the entrance of the chamber, and 41 °C between the racks at 14:30, so that the temperatures converged again at 19:00, while the ambient temperature varied .between 20 °C and 30 °C

We note that the cloudy passage during this day has an influence on the temperatures recorded (around (.a.m. to 11:00 a.m 9:00

Variation of the relative humidity of different elements of the dryer

Figures 33, 34 and 35 represent the evolution of relative humidity at different locations in the dryer as a function of time during the days 05/28/2021, 05/29/2021 and 05/30/2021

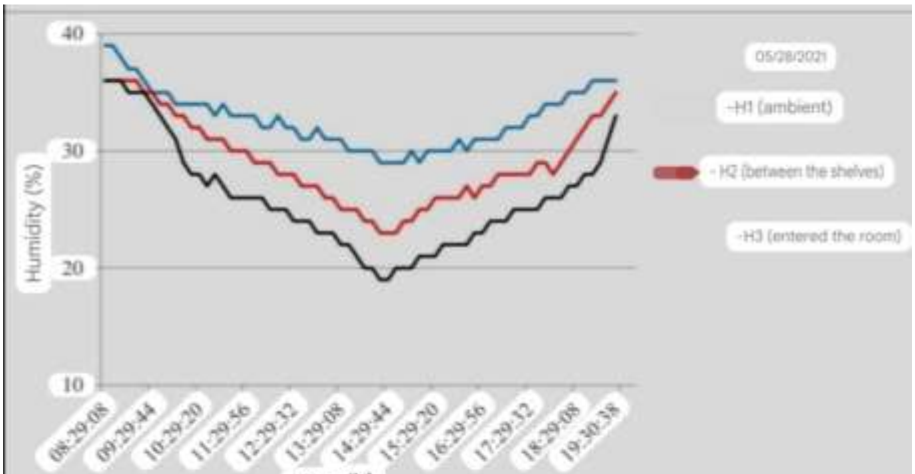
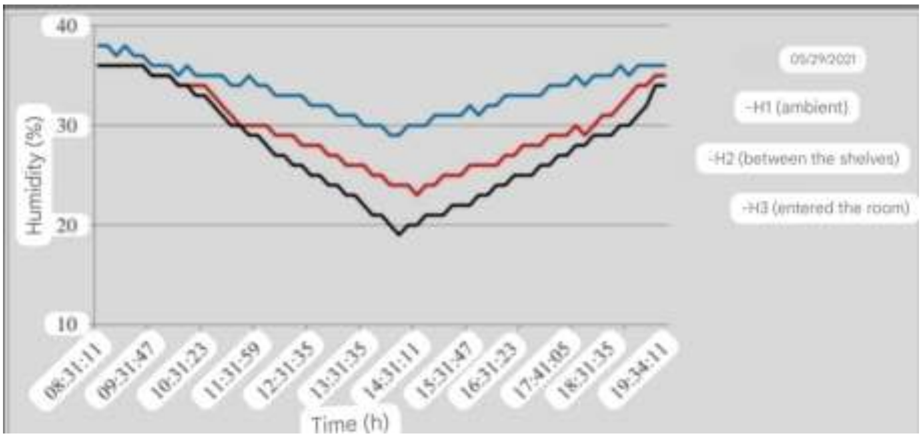


Figure 33. Evolution of relative humidity for the day of 05/28/2021

The relative humidity at the entrance of the dryer reached a minimum (19%) and between the racks a minimum (23%), while outside the chamber it was 29% from 2:30 p.m. local time, the time when the temperature reached its highest value which corresponds to maximum solar flux

Figure 34. Evolution of relative humidity for the day of 05/29/2021



On the second day, the relative humidity at the beginning of 8:30 am at the entrance of the chamber was (the black curve), then it decreased to 19% at 2:20 pm, then it rose again to reach 34% at 7:30 %36 pm.Between the racks, the relative humidity at 8:30 am was 36% (the red curve), then it decreased to at 2:20 pm, then it rose again to reach 35% at 7:30 pm. While the ambient relative humidity was %24 varied between 29% and 36%, during the drying period (the blue curve). This difference is due to the temperature variation at each location

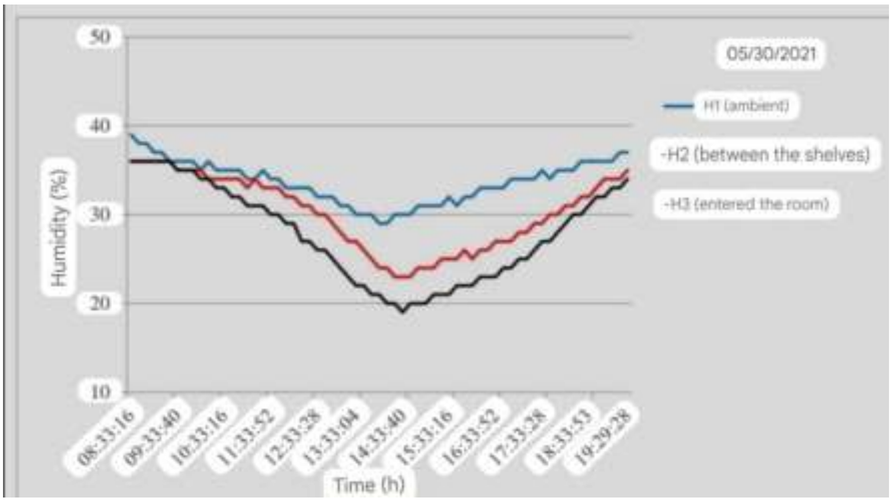


Figure 35. Evolution of relative humidity for the day of 05/30/2021

The same observations are valid for the last day. At the entrance of the chamber at the beginning of drying at 8:30, the humidity was 40%, then decreased to 19% at 2:30, until 19:00 reached 34%. Between the racks was 36%, it decreased to 19% at 2:30, is increased to 35% at 19:00. The ambient relative humidity varied from 38% to 29% ,The evolution of the relative humidity of the air varies in a way opposite to the evolution of the air temperature inside the dryer. Indeed, the increase in the air temperature causes a decrease in its relative humidity During all the drying days, a difference of about C is noted compared to the ambient (outside) temperature, which implies a good performance of°18-14 the dryer. Despite the cloudy passage (The last day of the second experiment.) And winds at intervals (the first and second days of the first experiment)

Influence of product size on the quality of the dried product

It should be noted that for both cases studied, for the thickness 1 cm, the washers are deformed so they have become a dark color ,They are fragile (breakable) because of the large amount of water extracted.The washers of thickness 2 cm. are less deformed and less dark They also have a soft appearance

- **Conclusion**

In this work, we presented the results of the analysis of temperature and humidity of apples drying in an indirect solar dryer operating in natural convection and discontinuously (only during the day)
The results obtained seem to us to be satisfactory.In this present work, we are interested in indirect solar drying of hot air which is ensured by an energy production unit towards the drying chamber and more particularly for experimental study of the drying of certain agro-food products (apples) ,Our report concerns the Design and Implementation of an indirect solar drying system based on an Arduino electronic card using programmable electronic components managed by a microcontroller (Arduino) This final year project was a valuable opportunity for us to do multidisciplinary work, combining, electronics, mechanics The most relevant result of this project is that through humidity and temperature measurements inside and outside the drying system and translating them into graphic curves in order to facilitate the reading and analysis of the results obtained

For this, the system that we were able to realize proved to be capable of controlling the drying, operating ,at approximately 100% or with some defects , Despite the problems encountered during the realization among which we cite
Mechanical equipment -
Lack of electronic parts -
,Recommendations for future projects are very diverse, namely: Increasing the level of drying control Subject to the provision of professional sensors and an effective monitoring mechanism, the owner will be informed about all the conditions surrounding his drying system and therefore will be able to react quickly in real time. the use of high-tech sensors, the connection of the system via the Internet given the reference instructions.

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