DOI:https://doi.org/10.61841/vmdthb60 **Publication URL:**https://nnpub.org/index.php/FAES/article/view/2604

LOW-COST PROTOTYPES WITH SOLAR THERMAL UTILIZATION

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How To Cite This Article:
Díaz, A. E., Di Lalla, N. ., & Hernández, A. L. (2025). LOW-COST PROTOTYPES WITH SOLAR THERMAL UTILIZATION. Journal of Advance Research in Food, Agriculture and Environmental Science (ISSN 2208-2417), 10(3), 12-20. https://doi.org/10.61841/vmdthb60

ABSTRACT

This paper presents the construction of five solar thermal utilization devices: two food dryers, a solar water heater, a solar water distiller, and a solar food cooker. These devices were built under the direction and supervision of the authors of the article by students enrolled in the semester course "Materials and Construction of Solar Equipment" in the final year of the "Technical Degree in Solar Energy" at the National University of Salta. The devices were made with the premise of using recycled materials and low-cost techniques. While the prototypes developed are demonstrative and of medium scale, they are fully operational and functional. The results were satisfactory, as the reductions in the initial masses of the products dried by the prototypes were around 90%, the solar cooker reached 80ºC on days with low solar radiation, the outlet water temperature of the solar water heater reached 58ºC, and the solar distiller produced 500 ml daily with a conductivity of 68 µS/cm.

KEYWORDS: Solar Thermal Prototypes, Solar Cooker, Solar Water Heater, Solar Distiller, Solar Dryer, Low-Cost Construction.

INTRODUCTION

Within the framework of the course "Materials and Construction of Solar Equipment" in the final year of the "Technical Degree in Solar Energy" at the National University of Salta, students who attended the second semester of the years 2023 and 2024 designed, built, and characterized four prototypes for solar energy utilization: a water heater, a distiller, two dryers, and a cooker (UNSa, 2025). According to the highly technical profile of the subject, one objective is to achieve a practical application synthesis of the knowledge acquired during the course; the use of basic physical concepts, and especially the emphasis on properly selecting materials based on their mechanical, chemical, thermal, and optical properties. Another significant aspect of this subject is providing students with the opportunity to strengthen their knowledge related to various measurement techniques and handling instruments (temperature sensors and recorders, solarimeters, flowmeters, conductivity meters, etc.) in a real experimental situation.

Water is a vital liquid of great importance for the development of a community, as it is indispensable for the health of its inhabitants. However, not all water is suitable for human consumption; specific percentages of salts make it potable. There are various processes to obtain fresh water from water with higher percentages of salts necessary for consumption, all of which involve the use of energy sources to achieve the separation of excess salts. These include thermal, electrical, and pressure processes (Díaz, 2016). Distillation is a process in which the components or substances of a liquid mixture, in this case, water, are separated by selective boiling and condensation. For this, an energy source is necessary, and what better inexhaustible energy source than the sun. The advantage of solar distillers is that they operate at low temperatures, so evaporation is slow, minimizing the possibility of contamination of the product to be obtained. Basin-type solar distillers are remarkably interesting due to their ease of construction. However, they have low productivity as they are sensitive to changes in radiation, making their nighttime production almost zero (Díaz, 2018). This article presents the construction of a basin-type solar distiller prototype and proposes alternatives for its optimization.

Argentina is one of the countries rich in energy resources, particularly excelling in the exploitation of its oil resources, which form the basis to produce electricity and gas. Despite this, the energy problem has not yet been resolved in many areas of the country, meaning they still lack electricity or access to a gas network. Gas undoubtedly provides a better service for water heating and food cooking compared to electricity; it is more economical and better utilized, but more expensive to install and has associated risks. Currently, the price of gas is low due to subsidies, but it is not a resource that reaches all rural communities (Cadena, 2017). The purpose of this article is to present an alternative to this problem by exploring box-type solar cookers. This solar equipment originated in the 17th century and has been improved and developed into new types of cookers throughout history. Additionally, we will analyze the different materials chosen for this prototype and conduct tests of its functionality.

The energy consumption dedicated to heating sanitary water is the second most important consumption after heating and cooling. There are different types of equipment for sanitary hot water (SHW); 95% of these sales run on gas or electricity. In Argentina, natural gas constitutes 50% of the energy matrix, with 10% of this dedicated to SHW. Hence, it is important to highlight that these devices generate an increase in greenhouse gases, making it a crucial issue to address. Over time, society has adopted solar technology for electricity production, cooking, or sanitary use. Particularly, this technology is environmentally friendly, and solar resources are unlimited. Solar collectors are devices that utilize solar radiation to raise the temperature of a fluid. They are divided into two groups: low-temperature collectors (heating, SHW, and pool heating) and high-temperature collectors. This article will develop a scale prototype of a solar water collector; there are also air collectors, which operate similarly: collecting, absorbing, and transferring solar energy to a fluid (Di Lalla, 2023).

Solar drying is the oldest known method of food preservation. Its simplest form is known as open-air or sun drying, where fresh produce is spread on the ground and directly exposed to solar radiation. While this method has advantages, such as zero technological cost and low associated labor costs, it also presents various disadvantages related to the final product quality and the required drying time. The thermal use of solar energy for food drying is a scientific topic in continuous development by research groups worldwide. Most of these contributions are dedicated to small-scale production equipment, known as domestic dryers. The use of solar dryers allows the exploitation of solar radiation to extract the moisture contained in food, thereby concentrating its nutritional value, and preventing crop losses during periods of abundance. In addition to extending the consumption period throughout the year, it also favors storage and transportation. Thus, solar drying is used to reduce the water activity of food and thereby prevent the proliferation of microorganisms. Most fruits and vegetables dehydrated in solar dryers require a temperature range of 50°C to 70°C to be safely dehydrated (El-Sebaii and Shalaby, 2012). Low technological complexity solar drying systems, with overall efficiencies in the range of 20% to 40% (Babu et al., 2018), present a very favorable cost-benefit ratio compared to conventional dryers that consume gas or electricity, both in terms of acquisition and operation. This economic aspect encourages local producers to use solar drying to solve conservation and storage problems for agricultural products (Prakash and Kumar, 2015; El Hage et al., 2018). This paper presents the design and preliminary testing of a low-budget solar dryer for drying apples; it is estimated that the construction time is 2 days for one person. The prototype is of the direct type with natural convection air circulation.

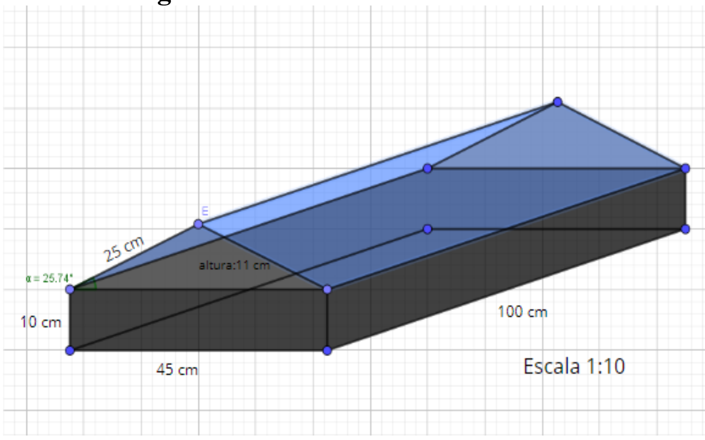
MATERIALS AND METHODS

The designs of the equipment presented here were carried out with the premise that they should be simple to construct and economical in terms of the materials used. Accordingly, simple techniques and easily accessible materials were utilized. Although all prototypes were made on a small to medium scale, they were intended to be fully functional and very low-cost. The development and characterization of the equipment were performed at the Experimental Campus of INENCO. The instruments for measurements and characterization of the equipment were provided by the "Energy Efficiency in Buildings Group," also from INENCO. Thermal measurements were carried out using K-type thermocouples, and solar radiation was measured using a photovoltaic solarimeter.

THE SOLAR DISTILLER

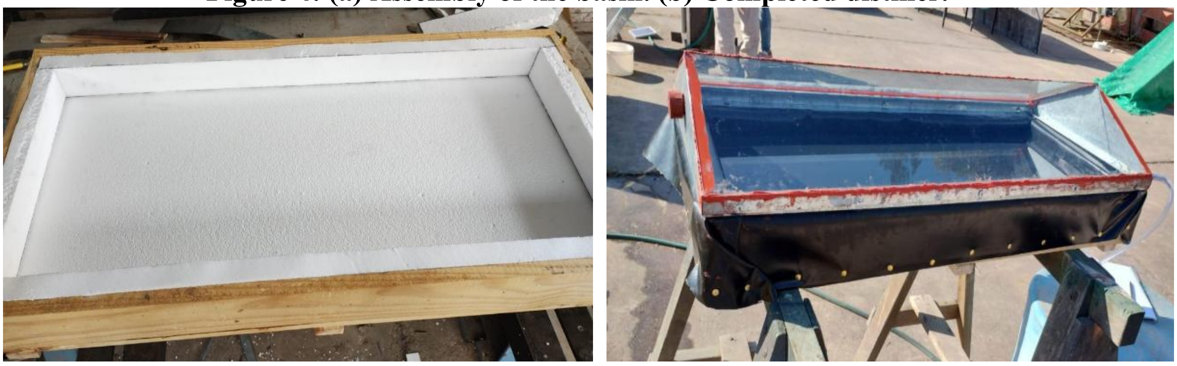
The distiller is a single-stage basin type with a double-sloped condensing surface (Díaz, 2018). Figure 1 shows the most important external measurements.

Figure 1: Dimensions of the Distiller



The condensing surface was made of 4 mm thick glass, sealed with silicone-based adhesive, and arranged at an inclination angle of 25°. Gutter channels were placed on both sides to collect the dripping condensed water. The basin structure was made from ½” thick pine boards, which were internally insulated using 3 cm thick low-density expanded polystyrene sheets. These were further covered with black PVC tarpaulin. Thus, the effective dimensions of the basin were 0.30m x 0.9m x 0.04m. Figure 2(a) shows part of the basin assembly, and Figure 2(b) shows the completed distiller.

Figure 4: (a) Assembly of the basin. (b) Completed distiller.



(a) (b)

THE SOLAR COOKER

Due to its simplicity, a box-type solar cooker was chosen (Cadena, 2017). The structure of the box was made with 16 mm thick pine boards, resulting in a parallelepiped of 0.48m x 0.48m x 0.40m. The internal insulation of the box was made with polyurethane foam, and over it, a single-sided aluminum-coated polyethylene foam membrane was placed. The absorber surface was made of galvanized iron sheet painted with high-temperature-resistant matte black paint. A simple 4 mm thick common glass cover was fixed on the top surface, as shown in Figure 3. The top cover was coated with a mirror to help reflect radiation into the box, which is adjustable thanks to a sliding mechanism. A side-opening door was placed on the front face, with the details shown in Figure 4.

Figure 3: Diagram of the Completed Box-Type Solar Cooker.

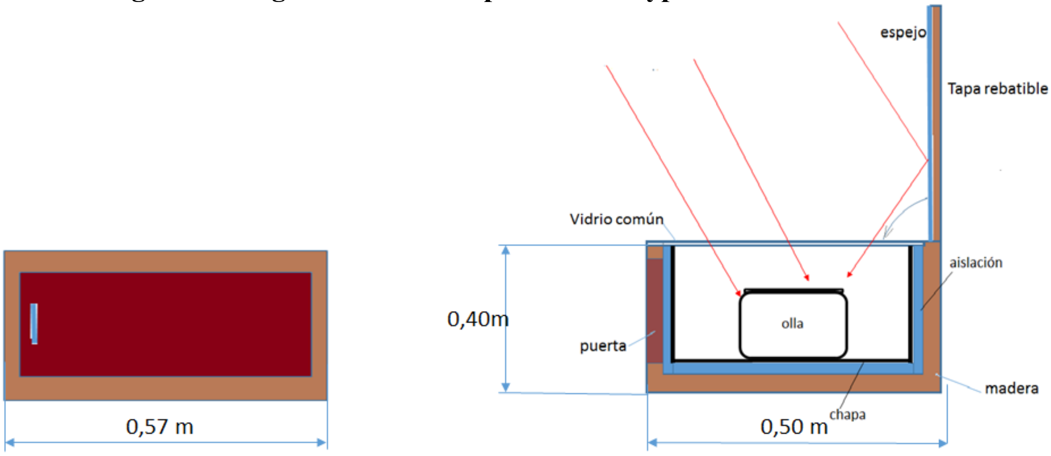


Figure 4: Completed and Operational Solar Cooker.

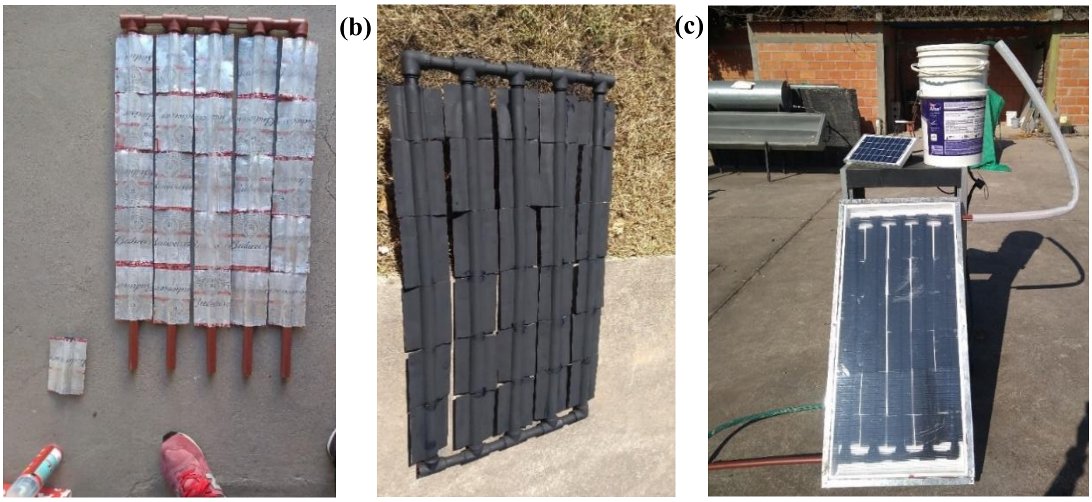
THE SOLAR WATER HEATER

A flat-plate solar water heater with a capture area of 1m x 0.5m was chosen. The absorber, of the grill type, was made with ½" thermofusion pipes (Martínez et al., 2012). To increase the capture area, fins made from recycled aluminum cans were incorporated, as shown in Figure 5(a). The entire assembly was coated with a high-temperature-resistant matte black paint. The external structure of the absorber was made with 30-gauge galvanized sheet metal, and the insulation was made with 3 cm thick low-density expanded polystyrene. Alveolar polycarbonate of 4 mm was used for the cover. Figure 5(b) details the interior part of the absorber. Figure 5(c) shows the completed water heater.

The hot water storage tank was made from two recycled plastic containers, one internal with a capacity of 20 liters and another external that acts as insulation. To circulate the water between the tank and the collector (5 liters), a small 2-watt water pump was adapted, which works in conjunction with a 3-watt mini photovoltaic panel (Di Lalla et al, 2016).

Figure 5: (a) Assembly of the grill-type absorber. (b) Absorber. (c) Completed water heater.

(a) (b) (c)



SOLAR DRYERS

The first solar dryer built is of the indirect type (Gutiérrez et al, 2012). Figure 7 shows a schematic with its shape and measurements. It consists of a collector and a drying chamber. The collector is a 0.48 m x 1m x 0.11 box made from 15 mm thick particleboard pine. The interior was covered with 3 cm thick low-density expanded polystyrene sheets, which were further covered with a 5 mm thick double-sided aluminum-coated polyethylene foam sheet. Air inlet and outlet windows of 0.25m x 0.05 m were left on both sides of the collector (bottom and top). The drying chamber was also made from 15 mm thick particleboard, with the interior simply covered with a 5 mm thick double-sided aluminum-coated polyethylene foam sheet. The chamber has a foldable door for easy access and a hot air outlet of 0.35 m x 0.04m. The absorber was made from 25-gauge corrugated galvanized sheet metal, coated with high-temperature-resistant matte black paint, and placed in the middle distance between the insulation and the cover in the collector, as shown in Figure 6. Alveolar polycarbonate of 4 mm was used for the cover. As a result, this dryer has a ratio between the collection area and the drying chamber volume of approximately 0.44 m2/m3.

Figure 6: Position of the Absorber in the Collector.

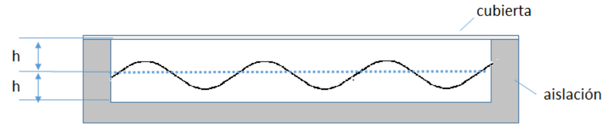
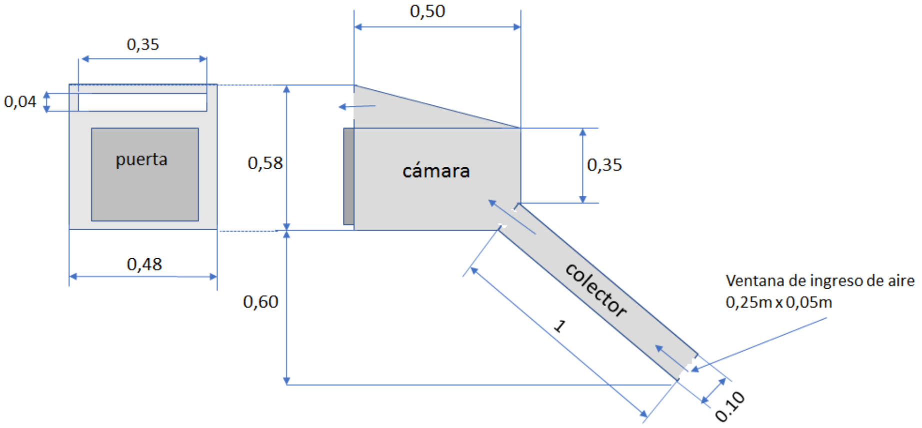


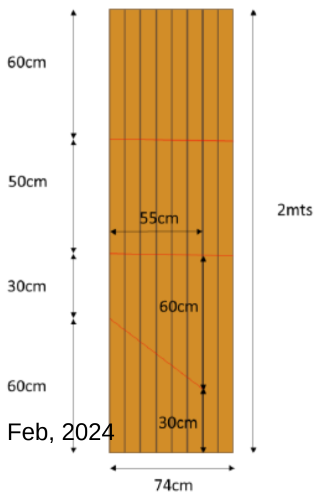
Figure 7: Most Important Measurements of the Solar Dryer in Meters.



The second dryer consists of five sides: a front and a back, where the height of the back is twice that of the front; two sides that connect them, and a base. The five sides are made of wood, and the interior is insulated with expanded polystyrene. The top is closed with an alveolar polycarbonate plate. This cover allows solar radiation to enter and increases the enthalpy of the circulating air, which favors the drying process of the product. At the base, above the insulation, a galvanized sheet painted black is placed, which functions as an absorber. Ambient air enters the dryer through an opening in the front side and is heated by convection upon contact with the absorber plate, decreasing its density and producing the natural upward movement of the air, which exits through two openings at the top of the rear side. This dries the product, which has been pre-treated and placed on a tray positioned on internal supports halfway up the front side. Loading and unloading the dryer is simple, done by removing part of the front side. To optimize radiation gain, the dryer is manually oriented to follow the sun's trajectory.

The external construction was done with nine half-inches by two-meter tongue-and-groove boards. They were cut as shown in Figure 1, where the base, rear side, and two sides can be seen; eight boards were used for this, and the remaining one was used for the front side. Each side is assembled with wooden rods and nails, making two openings in the rear side. Once the wooden box was assembled, as shown in Figure 8, expanded polystyrene was placed in each part, and it was left until the next day. On the second day, openings were made in the expanded polystyrene, and the absorber plate, previously painted, was placed. Then the front side was added, with insulation and an opening made, and inside the cubicle, a mosquito net screen was placed for the product. Finally, the box was closed with the alveolar polycarbonate on the top, sealed with silicone, and reinforced on the sides with wooden handrails, as shown in Figure 8.

Figure 8: Cuts in Tongue-and-Groove Boards, Assembly of Insulation, and Front View of the Prototype.

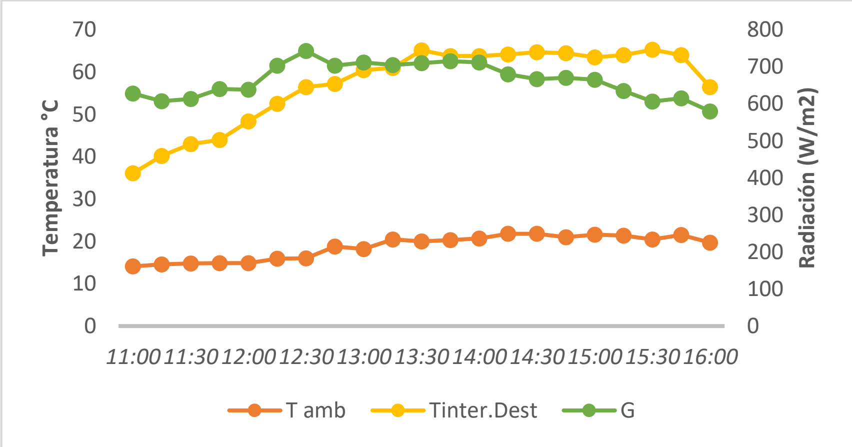


RESULTS

Solar Distiller Results

The graph in Figure 9 shows the temperature changes inside the distiller and the external environment, as well as the irradiance values on the horizontal plane, from 11 a.m. to 4 p.m.

Figure 9: Temperature Evolutions Inside the Distiller and the External Environment.

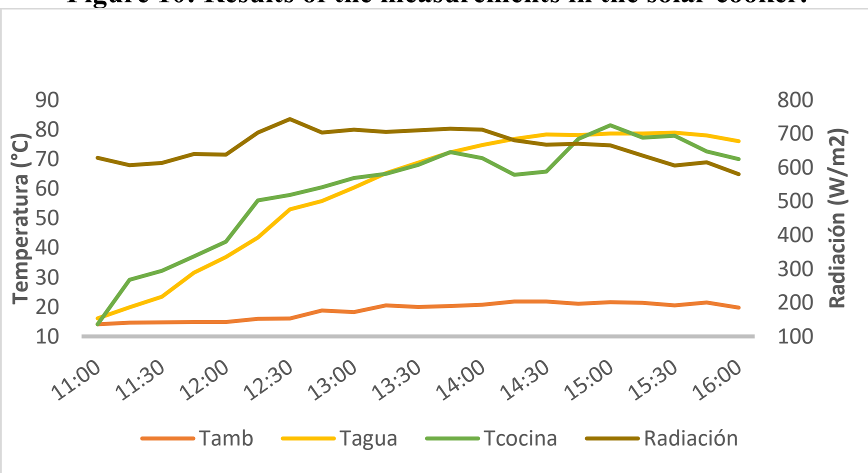


During the measurement, 500 ml of high-quality distilled water was obtained, as the electrical conductivity was approximately 68 µs/cm.

Solar Cooker Results

The temperature changes of one liter of water inside the pot, the air inside the cooker, and the external environment were measured. The experiment started at 11 a.m., with the entire system at an initial temperature of 15°C (radiation was measured on the horizontal plane). The results are shown in the graph in Figure 10. We can see that the water in the pot reached 80°C at 3:15 p.m.

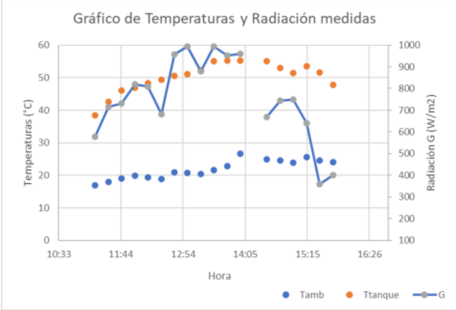
Figure 10: Results of the measurements in the solar cooker.



Results of the Solar Water Heater

With the collector positioned at a 45° angle, the evolution of the water temperature in the tank was measured during the time frame close to midday, as well as the solar irradiance “G” on the collector plane. Figure 11 shows the graph of the obtained values. The maximum temperature reached in the tank water was 58°C.

Figure 11: Evolution of the tank water temperature.



Results of the First Dryer

Figure 12 shows the evolution of the temperature in the chamber on a sunny day with good insolation.

Figure 12: Evolution of the temperature in the drying chamber.

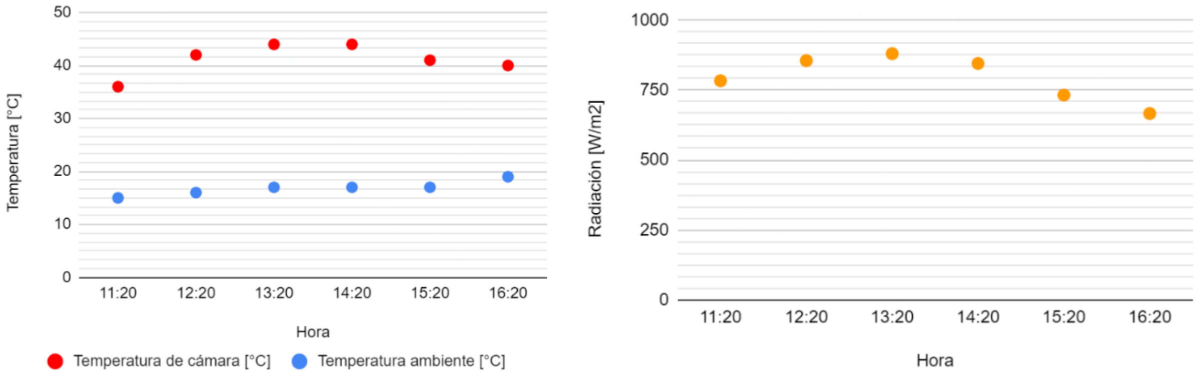


Figure 13 shows, as an example, the drying curve of banana slices on two different trays

Figure 13: Drying curve of banana slices.

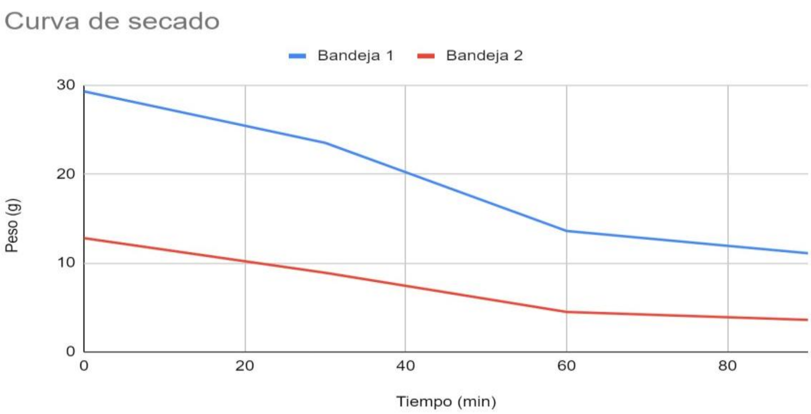
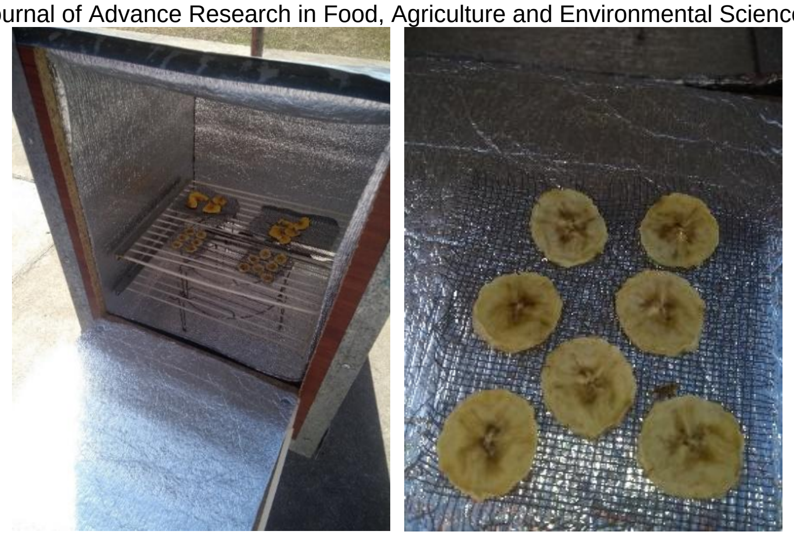


Table 1 shows the comparison of the initial and final masses of two types of fruits after being dehydrated for 5 hours in the prototype. The percentage of reduction is also given. Figure 14 shows photos of the dried fruits.

Table 1: Percentage of mass reduction of two types of fruits placed in the dryer for 5 hours.

Fruit	Initial mass (gr)	Final mass (gr)	Mass reduction (%)
Apple	11.5	2.4	80
Banana	9.4	3.6	61

Figure 14: Photos of the fruits dried for 5 hours.

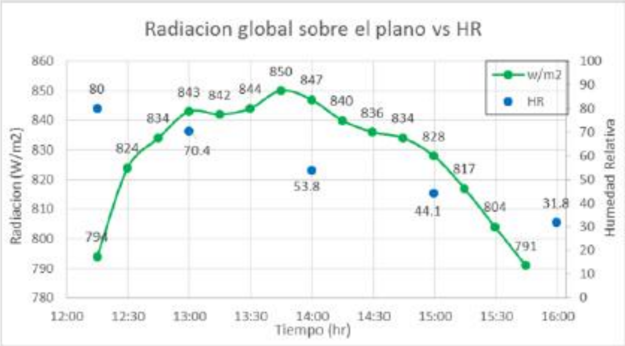


Results of the Second Dryer

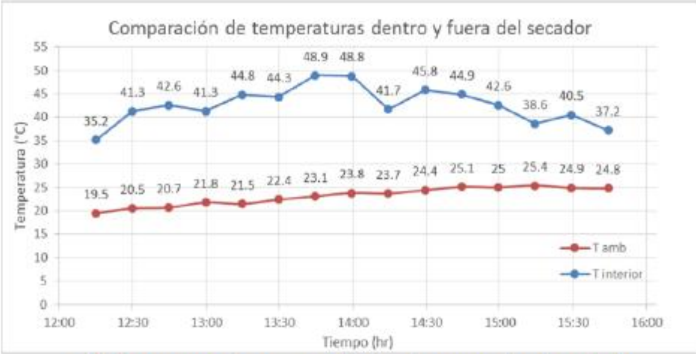
The dryer was tested during the first days of July. The instruments used included: a Fluke 52 II manual thermometer with type K thermocouples to measure the air temperature inside and outside the drying chamber; an Ohaus Scout Pro scale to monitor the weight evolution of test products; and a CEM solarimeter to measure global solar radiation on the inclined plane. The prototype was tilted northwards and rotated to follow the sun's position. The chosen fruit was apple, which contains 86% water and 14% carbohydrates. The apples were cut into slices of 1-2 mm for drying, ensuring no seeds were left and adding orange juice to prevent oxidation, then distributed across the entire tray.

The test was conducted from 12:15 PM to 3:45 PM, with data taken every 15 minutes. The initial mass of the selected sample was 59.4 grams. After just under 4 hours, it reduced to 8.7 grams, implying a reduction to 13.78% of the initial mass. Maximum temperatures inside the dryer reached 48°C around 2 PM. It was generally observed that the solar dryer could reach temperatures about 15°C higher than the outside temperature. Wind speeds varied between 0.15 and 0.35 m/s. Figures 15(a-c) show the results of ambient and interior dryer temperatures, solar radiation on the collector plane, and sample weight. As it was the first trial, the product was exposed to the sun for only a few hours, not enough to displace the maximum possible water content. At the end of drying, the apples had a "rubbery" texture and retained their yellowish color.
The tests showed that the drying process curve was present in the sample. The first phase, the constant drying rate phase, showed the most significant reduction in moisture content, behaving like a wet surface. The transition phase, where part of the surface is wet and part dry, saw a reduction in the drying rate. Lastly, the falling drying rate phase, where the product's surface becomes increasingly dry and moisture migrates from the interior, mainly through diffusion processes, making the drying process almost constant.

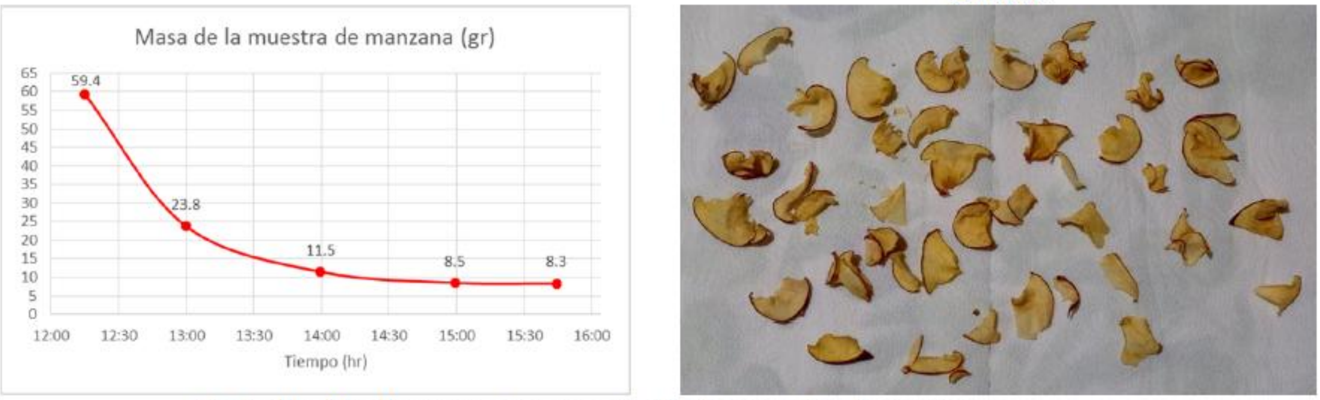
Figure 15: Results of the measurements of the second solar dryer.



(a) radiación solar y humedad relativa.



(b) temperatura en el interior y exterior del secador.



(c) reducción de su masa y apreciación de muestra de manzana .

CONCLUSIONS

The fundamental objectives of the course "Materials and Construction of Solar Equipment" were met, aiming to prepare students for their professional future. The course aimed to deepen knowledge in various forms of utilizing renewable energies through practical experience, always focusing on sustainability and energy efficiency. Students learned to design, construct, and characterize thermal conversion equipment, select, and apply various construction materials according to their physical properties, and master conventional measuring instruments through hands-on practice in real experimental situations. Additionally, students gained skills in writing and preparing technical reports, including using calculation software and graphing tools.

All prototypes, though made with the fundamental premise of using recycled materials and low-cost techniques, were operational and functional. The respective characterizations of the prototypes showed that they satisfactorily fulfilled their functions, and further modifications or additions can be made for better energy utilization.

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