Solar Dehydrator*

An EPS@ISEP 2019 Project

ABSTRACT

This paper is a general review of the development of a solar dehydrator, a project which took place during the European Project Semester at the Instituto Superior de Engenharia do Porto in the 2019 Spring. This project was conducted by a team of six Erasmus students coming from six different countries. The main objective of the European Project Semester is to develop teamwork, communication and problem-solving skills while working together. The project itself had for purpose to make a sustainable solution to dehydrate and preserve food, while also making sure to respect some requirements such as a budget, the use of reusable materials and components and European Union directives. For this project, the team had to realize different analyses in technological, ethical and deontological, economic and environmental fields. This paper describes, after a short introduction, the research on the state of the art, the analyses, the development and the testing the students made, as well as what they obtained from this experience.

CCS CONCEPTS

• Social and professional topics -> Professional topics -> Computing industry -> Sustainability • Applied computing -> Education -> Collaborative learning

KEYWORDS

Designing Sustainable Projects, Pedagogical Advances in SD, European Project Semester, Collaborative learning, Project based learning, Education

ACM Reference format:

FirstName Surname, FirstName Surname and FirstName Surname. 2018. Insert Your Title Here: Insert Subtitle Here. In *Proceedings of ACM Woodstock conference (WOODSTOCK'18). ACM, New York, NY, USA, 2 pages.* https://doi.org/10.1145/1234567890

1 Introduction

The European Project Semester (EPS) is an international exchange of students, of usually engineering background, between universities from 18 countries throughout Europe. The aim of this one semester is developing teamwork, project management and design, communication between different cultures, and linguistic capacities by making students work, in teams of three to six students, on a project based on a modern-day problematic [1].

The Instituto Superior de Engenharia do Porto (ISEP) has been a partner of EPS since the academic year 2010-2011. It receives, every year, students from all over Europe and proposes, during the EPS, six disciplines: Project Management, Marketing, Communication, Eco-efficiency and Sustainability, Ethics and Deontology and Portuguese. These disciplines are taught by teachers who are available throughout the semester to coach the students. The school also offers the students access to a workshop and some laboratories if they need [2].

Sustainable development is one of the most important subjects nowadays. With all the issues and problematic linked to this topic, more and more people are interested in making a change in the world by using renewable energies to power all kind of products. It is in this mindset that Team 2, of the EPS at ISEP of 2019 Spring, chose to build a completely solar powered dehydrator. The Solar Dehydrator is a way to preserve food that doesn't require the use of electricity and additional costs like a fridge would.

This paper describes the steps taken by Team 2 in order to achieve this project: the analyses of the State of the Art, Marketing, Sustainability, Ethics and Deontology, the Design and Development chosen, the Tests and Results obtained and finally, the Conclusions drawn.

2 Background

2.1 State of the Art

Dehydrating food is an old practice very used in the world to preserve food economically while keeping all its nutrients. There are 2 different types of dehydrators: electrical and solar dehydrators. While electrical dehydrators all use the same method, solar dehydrators can be divided in 4 types: direct, indirect, mixed and hybrid.

The direct type, seen in Figure 1, is the simplest, the sunlight dries the food directly through a glass. This method is cheap but the ultra violet radiation risks damaging the food [3].

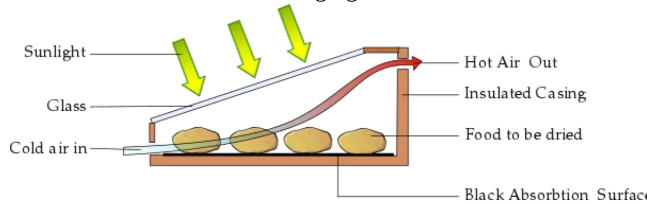

Figure 1: Direct dehydrator [4]

The indirect type, see Figure 2, uses a solar collector to heat up the air. This air will then rise because it is warmer and enter the cabinet where the food is stored. This method eliminates any risk of food damaging due to the radiation but is usually bigger, more expensive and harder to make [5].

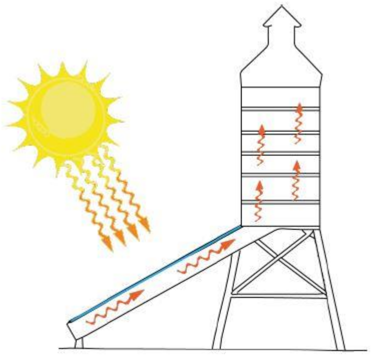

Figure 2: Indirect dehydrator [6]

The mixed type, in Figure 3, combines direct solar radiation and the use of a solar collector. It dries food faster than the indirect and direct types but exposes the food to the danger of the solar radiation.

Figure 3: Mixed dehydrator [7]

Finally, the hybrid type, Figure 4, is a more modern type of indirect dehydrator that uses other technologies to dry food faster. A common example is adding fans powered by a solar panel. This combination provides the advantage of continuous drying even during nights or cloudy days. The cost is higher but the quality and efficiency as well.

Figure 4: Hybrid dehydrator [8]

The type of dehydrator built in this project by the team is a hybrid dehydrator. This choice was based on the study the team made and it was judged to be the most efficient way to make the product.

2.2 Marketing

The team decided to start by analyzing the market of dehydrators using the SWOT Analysis to see the Strengths, Weaknesses, Opportunities and Threats, it could exploit.

The internal diagnostic helps in analyzing the strengths and weaknesses of the company/product itself while the external diagnostic helps in analyzing the opportunities and threats of the outside environment. The SWOT Analysis is done from the macro-environment and the micro-environment analyses. With these two analyses, the following SWOT Matrix was created (Table 1).

Table 1: **SWOT Matrix**

	STRENGTHS	**WEAKNESSES**
INTERNAL DIAGNOSTIC	Focusing on renewable energy (solar). Can influence two markets: the more "closed" market of solar dehydrators and the broader one of the dehydrators in general. Use of quite advanced technology for sensors and mechanisms that other solar dehydrators don't usually have.	Despite influencing two markets, the product is at a disadvantage for the dehydrators in general
	OPPORTUNITIES	**THREATS**
EXTERNAL DIAGNOSTIC	Growing demand for products using renewable energy and having low power consumption. Ecological, making it emotionally touching for people. Unaffected by laws and politics that punish polluting and non-renewable energy	Quite a strong and growing competition. "Better" technology exists for drying in terms of efficiency

This table shows that the strengths are mainly the use of renewable energy, the use of sensors and the fact that the product can influence two markets. The weakness linked to that is that even if the product influence two markets it is clearly at a disadvantage against electrical dehydrators for people who only want efficiency.

This analysis lead to a mapping of the product on the current market followed by a segmentation of the clients. After that, according to all the previous analyses the team formed the marketing mix.

The team chose, based on this marketing plan, to focus their attention on customers who want to eat good and natural food while making an action for the environment by using a product that uses only solar energy. Figure 5 shows the product logo the team made.

Figure 5: Product Logo

By focusing on these particular customers, the product is able to stand on an equal footing even with the more efficient electrical dehydrators. The team's first aim would be to sell 15 units of Dryfoo in a 2-year period.

For the brand, the team chose the name "BeSol". It is supposed to remind and encourage the possible clients to be more sustainable by making use of the Sun.

2.3 Sustainability

Sustainability is one of the main concerns of today's society and one of the most crucial points of this project. It is important to keep in mind every aspect of the production to make sure that none of them goes against the environment and to do so, the team realized an analysis on the sustainability of the future product.

In order to prevent pollution and to keep carbon emissions low, Dryfoo focuses in using renewable resources in its favor, such as solar and wind. The radiation of the sun is being used to create heat inside the cabinet and to power up the electrical components, generating electricity by a solar panel. The wind will help the hot air in the collector zone to move up into the drying chamber, where the food will be. In case of the sun not shining, a small battery will supply energy so that the dehydration process can continue.

Most of the elements used to make the proof of concept were reused materials and components and can be recycled. Local suppliers were chosen to provide the remaining parts according with the life cycle analysis.

Dryfoo is around 70% made of wood. It is a good insulator, easy to clean, easy to work with machinery or hand tools, and it's also a natural and recyclable material. In order to increase this efficiency, some very specific parts were covered with an eco-friendly black paint (A+). There are three bendable parts on the prototype, all build out of PVC, only the transparent part was not a re-used material. The trays to hold the food were made of a metal sheet that existed in an old ventilation system on a computer from ISEP. Before assembly and cutting, each part was marked in advance on the respective material in order to optimize the space used and avoid waste.

2.4 Ethics and Deontology

Ethics is a broad topic which is divided into four subsections: engineering, environment, marketing and liability. The environment aspect has a significant role and solution because of the re-used materials as seen in the sustainability topic above. The liability aspect roughly translates to keeping the guidelines and directives to ensure the safety factor, which the team made sure was respected. In the engineering ethics, the team will insure fair conditions and a professional work environment, during the development and the assembly phase. Just like the engineering part of ethics, the marketing part also has a key role in the distribution of the product later. It is all about the fair, equal, and ethically neutral advertisement and distribution. The team made sure that there will be no controversy or any bad reputation out of the marketing issues. Last but not least, based on consumer policies, BeSol will make every product that it distributes, safe and fair to the end user. He or she will be assured to use the best quality of components and materials that the products are made of. To keep this promise, BeSol pledges to give a 2-year warranty of every product that has been sold. Furthermore, free repairs within the warranty are guaranteed, and if the end user is done or has bought a newer product, BeSol will freely take back the product to either, refurbish or recycle every material as sustainably as possible. This way the consumer has the full confidence that BeSol is indeed an ethically good company.

3 Design and Development

3.1 Structure and Functionalities

As seen in the State-of-the-Art chapter, the team decided to build a hybrid dehydrator, using both solar collector and electronics to make the drying process more efficient while still being completely environment friendly.

As seen in Figure 6, the dehydrator's operation is the same as usual dehydrators. The air enters through the small gaps at the bottom and heats up because of the collector and its color (the black part). This collector is made of black rubber to ensure a good radiation absorptivity. The now warm air rises and enters the cabinet, where the food is stored, through small holes. The food, which is placed on four wooden trays, can now dry. The air circulation is facilitated by a fan placed above the food, see Figure 7. The air keeps going up and goes out by the chimney. This dehydrator's electronics, like the fan and the humidity and temperature sensors, are powered by a solar panel located on top of the dehydrator, see Figure 7.

Figure 6: Exterior and interior views of Dryfoo

Figure 7: View of the solar panel and fan

3.2 Cabinet control

To make sure the temperature and humidity are at the desired level, Dryfoo is equipped with adequate sensors. When the temperature and/or humidity are not at the right level, the fan will turn on or off. The user can also directly interact with the cabinet by using the interface at the back of the dehydrator.

Architecture

The black box diagram, in Figure 8, is used to visualize all inputs and outputs of a system without paying too much attention to the internal working.

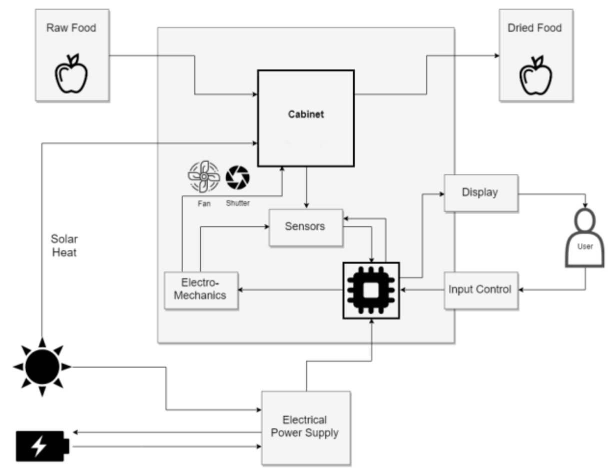

Figure 8: Black box Diagram

This diagram shows that there are two power supplies. One is the sun which heats the cabinet and the other is a battery which powers the electromechanics and microprocessor. The battery is itself powered by a solar panel, making the sun the only source of energy in the system. The most important input here is the raw food which then becomes dried food after it passes in the cabinet for a set amount of time. Finally, there is the action of the user on the product through the display. He or she can control the dehydrator from here. Figure 9 shows the basic electronics schematic.

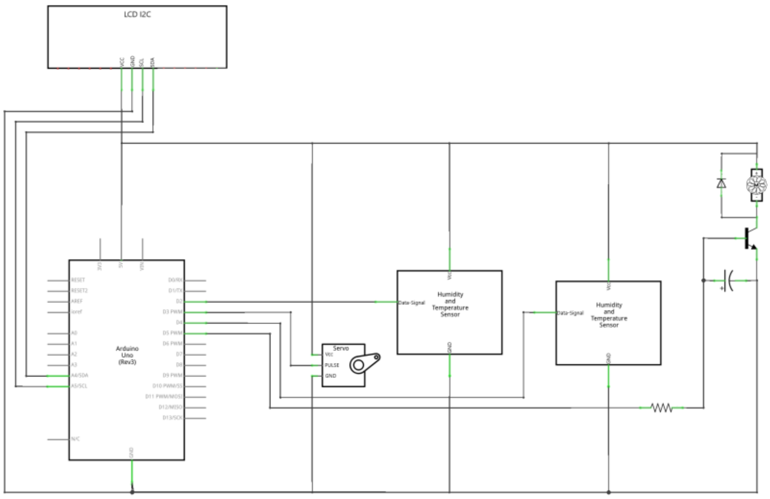

Figure 9: Basic Electronics Schematics

The schematics show that the Arduino Uno is the main control unit of the device. It consumes the power of the two main sources (the solar panel and the battery) and supplies the temperature/humidity sensors, the fan, the servomotor and the LCD display which occupies most of the pins. For that last reason, the LCD and a set of four navigation buttons are mounted on a premanufactured PCB which acts as a shield sitting on top of the Arduino. The buttons are connected to a single analog pin and programmatically evaluated later. The servo motor and fan are known to consume a high amount of power. This is the reason why both fan and servo are each switched on and off by a dedicated transistor in order to save energy. The DHT22 temperature and humidity sensors act as monitoring components for the cabinet. One is placed relatively at the upper part and the other relatively at the lower part of the cabinet. The PCB layout is represented in Figure 10, and its 3D Model in Figure 11.

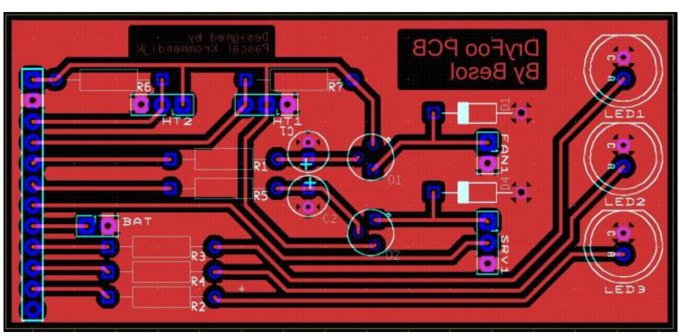

Figure 10: PCB Layout

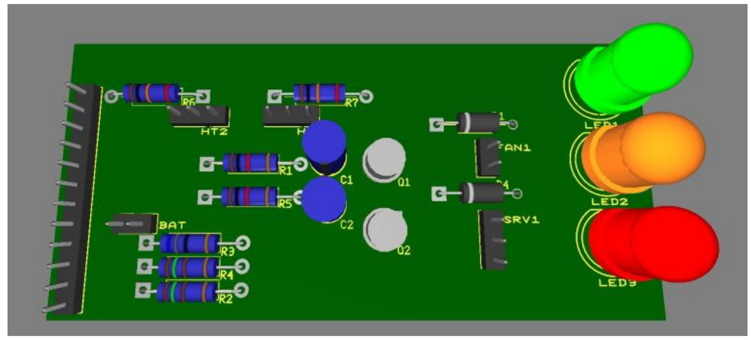

Figure 11: PCB 3D Model

For easier maintenance, the PCB has been designed to keep the external components such as capacitors, LEDs, resistors and transistors on one location. Standard sized headers are used to ease up assembly and disassembly work when doing maintenance. The long header row on the left of the PCB forms the input and the other smaller headers form the connecting part towards the components. Table 2 shows the power budget for each component.

Table 2: Power Budget

Component	**Voltage (V)**	**Current (mA)**	**Power (W)**	**Amount**	**Total Power (W)**
Arduino Uno	5.00	-20.0	-0.10	1	-0.10
Solar Panel	5.50	600 (max)	+3.30	1	+3.30
Battery	3.70	5200 (max)	+19.24 (max)	1	+19.24 **(max)**
Battery Charger	5.00	-0.15	-0.75 (mW)	1	-0.75 (mW)
Voltage Booster	5.00	-0.60	-3.00 (mW)	1	-0.75 (mW)
Fan	5.00	-74	-0.37	1	-0.37
Servo Motor	5.00	-3 [2] & -45 [3]	-0.015 & -0.225	1.	-0.015 & -**0.225**
LCD Keypad Shield	5.00	-130	-0.65	1	-0.65
DHT22 Sensor	5.00	1.10/2.10	-0.01	2	-0.20
LED	5	2.5	-0.01	5	-0.05
Diode	1.1	21.0	-0.02	1	-0.02
Consumption					**-1.63**
Production (max)					**22.54**

Functionalities

In this part, the software layout and functionalities of Dryfoo will be explained.

First of all, how does the food get dried when Dryfoo is operating?

It is a simple process that is best explained by the airflow schematic of Figure 12. To explain, the example of an apple will be used. An apple has a certain quantity of water molecules in it, just like every type of fruit or vegetable. When these water molecules get exposed to a certain rate of energy, in form of heat, the water transforms from a liquid state to an evaporated state. This transformation lets the molecules drift in an upward direction and leave the slice of apple, speeding up the overall drying process. This is only possible when the volume of air still has some space left in which the molecule can move through. The lack of free space for a molecule to get into is called relative humidity. If many evaporated water molecules are present, the humidity goes up and the overall drying process will slow down. Therefore, in order for the apple to get dried in the most efficient way, Dryfoo is designed in a way to increase the heat in the cabinet and decrease the humidity. This is done by heating up the cool air coming in from the bottom and then let it pass through the apple and pull out the water molecules. After that, a fan on top of the cabinet pulls out the hot humid air in a vortex flow.

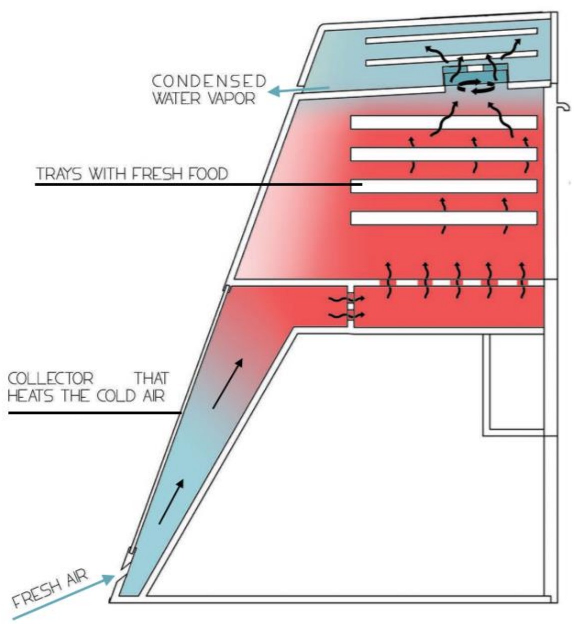

Figure 12: Airflow schematic

Table 3 shows how the operating user interface of Dryfoo looks like. After it booted up, the first menu is displayed on the screen after the Dryfoo and BeSol names and the loading progress bar. It is a list-based layout which is chosen because of the overview and the usage of a 16x2 LCD & 4 Buttons.

Basic controls: To "confirm" an action, the user must press the Right button. To go "back", the Left button is the option, and finally, to scroll the "Up" and "Down" buttons.

Table 3: Menu list

Menu List	
Start Drying	Item 1
Process Status	Item 2
Conditions	Item 3
Diagnostics	Item 4
Standby	Item 5
Stop Process	Item 6
About	Item 7

In the main menu the left button is redundant and does not need to be pressed. Every item will be explained below.

Item 1: Start Drying

Fruits and vegetables are grouped in different categories depending on the length of the drying and the maximum temperature that can be allowed for each. Because the maximum temperature of the different types of food is close to each other, the device has a fixed internal maximum temperature. Therefore, the user does only have to concern about the length of the drying process. Table 4 shows an example of the menu displayed when that item is chosen.

Table 4: Start Drying display

From	Sub Menu List
Start Drying	↑ +1h Time: 24h ↓ -1h

After pressing the "confirm" button, Dryfoo will start the process by starting a timer of the set time (eg. 24 h) and continuously checking the conditions in the cabinet to ensure that the food dries in the correct environment.

Item 2: Process Status

This item shows the status of the process, only if a process is currently going. Table 5 shows an example of the menu displayed when that item is chosen.

Table 5: Process Status display

From	Sub Menu List
Process Status	Chosen time: 24h 22 h 35 min left

Item 3: Conditions

This item shows the conditions in the cabinet. This is even possible if no process is chosen. The conditions are declared as the temperature and humidity. The conditions can be shown either coming from the top of the cabinet or from the bottom of the cabinet by pressing the "up" or "down" button. The chosen condition is indicated by an arrow facing up or down. Table 6 shows an example of the menu displayed when that item is chosen.

Table 6: Conditions display

From	Sub Menu List	Info after pressing Right button
Conditions display	Temperature: 35 °C Humidity: 67 %	When the up button is pressed, upper sensor is shown
	Temperature: 35 °C Humidity: 65 %	When the down button is pressed, lower sensor is shown

Item 4: Diagnostics

This item will only fully diagnose Dryfoo when no process is running, so the user must wait until the process finishes. When not processing, it diagnoses the following components:

- Battery Voltage
- Servo Motor: setAngle and getAngleStatus
- Both sensors: see if they are getting (correct) results
- Fan: it may be measured through the power consumption (if stuck, higher power is drawn).
- LEDs: they light up in a specific order. The user presses "confirm" if they are working in the right way/order.

The diagnostics are shown with a visual delay in order, for the user, to see the results.

Item 5: Standby/Power saving

This item can only be chosen when no process is running. On the display is written: "Going in Standby…" (the wait is 2 seconds).
This option turns the Arduino in low power consumption. It stops both the fan and servo motor and turns off LCD-Backlight and the orange LED glows slightly.
To cancel this mode, the user must press any button.

Item 6: Stop Process

In this item, the user can cancel the time previous selected. If a process is going on, the user will be informed that it has been canceled and returns to the main menu after that.
In case of no time has been chosen Dryfoo will display a message informing the user of that impossibility.

Item 7: About…

This item presents information about Dryfoo. On the display is written: "Dryfoo : 1.0v Product by BeSol". There is a short delay for the user to see the information before it returns to the main menu.

4 Tests and results

Testing is a very important part of the project. It allows the team to see if the prototype is working properly and if not, make changes until everything works.

Temperature and Humidity Sensors

To measure the temperature and humidity, two DHT22 sensors were used. It consists of a humidity sensing component, an NTC (Negative Temperature Coefficient) thermistor and an IC (Integrated Circuit). To measure the humidity, two electrodes with moisture holding substrate are placed between a humidity sensing component. As the humidity changes, either the conductivity of the substrate changes or the resistance, between these electrodes, changes. This change in resistance is measured and processed by the IC, which makes it ready to be read by a microcontroller.
The NTC thermistor is used to measure the temperature. A thermistor is a variable resistor that changes its resistance with the change of the temperature. The DHT22's values were compared with different sensors' in order to better understand the reliability of these readings. No problem was detected.

Charging system

The charging system consists of using the energy of the Sun to power up the electrical components used in the circuit. To achieve that goal, a solar panel was connected to a charging battery, with a diode for protection between them, that works as a switch in order to continuously charge a 3,7 V battery. A voltage booster will ensure that the Arduino is powered up with 5 V, as showcased in Figure 13 below.

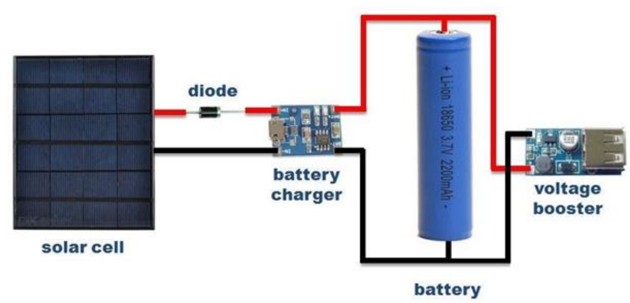

Figure 13: Charging wiring diagram

Tests were made to verify the effectiveness of the system. It was possible to conclude that, to voltages around 4,5 V in the solar panel, the battery stayed with 3,7 V as wished. In the case of the solar panel being covered up to simulate the dark of the night, the battery was able to power up a led for multiple hours without any significant changes.

Servo Motor

The servo motor tests ensure that the component reacts according to the demands of the program. No problem was detected.

Fan

For the fan to be powered up directly by the Arduino, it is necessary to be a 5 V fan. However, for sustainable and economical purposes, it was a reused small 12 V fan that was found in the storage department of ISEP. The fan was tested to ensure its capability to spin with the 5 V from Arduino. Once again, no problem was detected.

Dehydrator

The team tested the prototype by inserting food to dehydrate. Figure 14 shows the state of the different food before starting the dehydrating process.

Figure 14: Food before drying

Figure 15 shows their status after approximately seven hours.

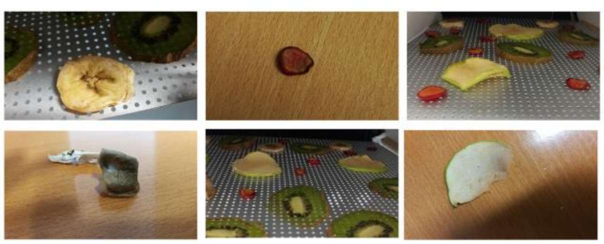

Figure 15: Food after drying seven hours

Besides the kiwi, all other types of food tested showed visible signs of dehydration. In the case of the cherries, mushroom, and bananas, these signs were significant. In the case of the apples, the drying process was about half-way done. The reason the kiwi hadn't yet shown much change is due to the fact that kiwi is made at 83 % of water.

5 Conclusions

This project was, for the whole team, a unique and enriching experience. It allowed every member to develop their skills in teamwork, autonomy and communication, through a multidisciplinary project. These disciplines, marketing, project management, sustainability and ethics, were taught by different teachers who also accompanied the students along the semester while giving advices and feedback on their work.

The project was successful. The semester went by smoothly and every deadline was respected thanks to the supervision the ISEP provided. The assembly was realized without major problem and the design was as expected. The requirements the team imposed on itself have all been filled. The product itself allows the consumer to dry any kind of food he or she wants in the shortest time possible for a solar dehydrator. This was made possible thanks to the technology implemented in the dehydrator: the temperature and humidity sensors, as well as the fan. Depending on the temperature and/or humidity measured, the fan can turn on or off and the vents, at the bottom of the product, can open or close. Finally, the interface allows the client to choose the temperature and drying time he desires to match with the food he or she wants to dry.

The main difficulties during this project was the choice of the product's name to make it match with the image the team had in mind, as well as the preparation of the bent parts of the product. These problems, though concerning important points, didn't have too much negative influence on the project and were solved without any more complications.

In any case, this project allowed each student to gain new knowledge on some subjects but also to deepen others and the experience was, all in all, very rewarding.

ACKNOWLEDGMENTS

First, the students of Team 2 would like to thank the Instituto Superior de Engenharia do Porto for the unique experience, this project gave them. The team also acknowledges the support of the supervisors who were constantly checking on the project and gave feedback and tips on the crucial moments during the development.

REFERENCES

1.European Project Semester. 2019. European project semester.eu. Retrieved May 29, 2019 from http://europeanprojectsemester.eu/

2.ISEP. 2019. EUROPEAN PROJECT SEMESTER AT ISEP (EPS@ISEP). isep.ipp.pt. Retrieved May 27, 2019 from https://www.isep.ipp.pt/Course/Course/44

3.WikiWand. Solar dryer. wikiwand.com. Retrieved March 12, 2019 from https://www.wikiwand.com/en/Solar_dryer?fbclid=IwAR3vbdk_wnP-bmgn9txcCJRAwKhjHR9QhUxygsIJ-BAgN7nemyKYu-Z_heg

4.A.K. Karthikeyan. 2013. A schematic of a Direct Solar Dryer. Retrieved April 10, 2019 from https://en.wikipedia.org/wiki/File:Direct_Solar_dryder.svg

5.Michigan State Universaty. 2015. Final Report Solar Dehydrator. egr.msu.edu. Retrieved April 10, 2019 from https://www.egr.msu.edu/sites/default/files/content/GLOBAL/ME491_FinalReport-Solar-Dehydration-May2015.pdf?fbclid=IwAR1eTB7gHDCgWVtEpqiyPLgp-C3AsPZF4cl936klRnkHK5gWx0a8vQsZbaI

6.Energypedia. 2018. Solar Drying. energypedia.info. Retrieved March 1, 2019 from https://energypedia.info/wiki/Solar_Drying?fbclid=IwAR0BKPOFAnjzw2A2LPhkIWYKGAD1PxFjvOXyiesYVuLgIGKPi-EZn2KLyFE

7.FANDOM. Solar food drying. fandom.com. Retrieved March 12, 2019 from https://solarcooking.fandom.com/wiki/Category:Solar_food_drying?fbclid=IwAR1DySrLHPwtZD6AeAUImoZxUqWQ6nFd6UToXJOUSmyZm9pXIQZuL12Fo7Y

8.Indian Solar Panels. 2017. BHARAT SOLAR ENERGY - The Renewable Energy Leader One-Stop Solar Shop of Diverse Solar Products & Services like Solar Panel, Solar Street Lights, Solar AC, Solar Fans, Solar Toto Riska, Solar Power Plant Resale, Hot Water System, Solar Water Pumps, Solar. bharatsolarenergy.com. Retrieved March 8, 2019 from http://www.bharatsolarenergy.com/1282-solar-fruit-dryer-india-solar-fruit-vege/details.html