Household Food Preservation System: Solar Dehydrator

Background:

Our team is tasked with developing a solution to extend the shelf life of at least two types of produce by a minimum of five days in the context of single family households. Therefore, the solution must not depend on wall-power and it must fit within 12 by 18 inches of countertop space. Although not required, the design should be easy to use, and portable to create a simple and pleasant user experience.

Understanding what causes fresh produce to go bad is an integral step in developing solutions to this problem. The main reason produce goes bad if not stored properly is microbial spoilage. This is caused by remaining water within the produce allowing bacteria or mold to grow. Therefore, to combat food spoilage, it can be seen that one of the most effective ways to preserve the produce could be to remove its moisture content, or water weight.

Post-harvest, every kind of fresh produce immediately begins its spoilage process since it is no longer connected to its plant, thus not receiving any nutrients or water needed to sustain cellular life. On top of this natural decay, other factors like microbial spoilage, enzymatic activity, and oxidation come into play (Jayakumar et al., 2022). Microbial spoilage comes from dangerous microbes entering the plant through exposed wounds where the produce was damaged or harvested and is a large cause for food borne illness (Jayakumar et al., 2022). Microorganisms that enter the produce create enzymes that then produce undesirable byproducts further contaminating the produce while causing enzymatic browning which has a similar effect as oxidation (Benner, 2024).

Water activity is a crucial factor influencing microbial growth. Microorganisms require a certain level of available water to grow and reproduce, which can lead to food spoilage. Water activity also interacts with various food preservation methods, such as low temperature and acidity, creating a synergistic effect that improves microbial stability (Tapia et al., 2020).

There are six nutrients that are required in large amounts for the survival of plant cells - nitrogen, carbon, hydrogen, potassium, phosphorus, and oxygen. These are known as primary nutrients (or macronutrients), and they must be broken down into their basic form as cation or anion to be used by plants (Provin et al., 2024). Dried fruits and vegetables are rich in bioactive compounds, which can help reduce the risk of cardiovascular diseases. Although the drying process may result in some loss of phytochemicals and vitamins, dried fruits and vegetables generally retain a higher level of essential nutrients compared to fresh storage (Morais et al., 2018).

Solar dehydration offers a simple and cost-effective method of food preservation. By harnessing direct sunlight, it provides a clean and sustainable solution that is accessible in many agricultural regions where crops are cultivated (Bolin et al., 1982). In a low-moisture environment, spoilage and pathogenic microorganism growth is inhibited (Chitrakara et al., 2018). Dehydration using natural sunlight preserves food without heavily altering sugar content or negatively affecting flavor. However, due to the high temperature, wait time, and oxidation, vitamin C content is compromised. Raised acidity levels also indicate that some fruits ferment when dehydrated via sunlight. (Gallali et al., 1999).

For the most effective solar dehydration system, it is desired to have the maximum amount of sunlight captured to increase the internal temperature. One of the factors that influences this is the angle at which the dehydrator faces the sun. In studies done by Robert Cathcart from Solar Fast, it has been found that the optimum angle and direction a solar device should face is 20 degrees from parallel and facing 180 degrees directly south (Cathcart, 2024). This will make it so that the dehydrator is directly facing the sun for the most amount of time it can in one day.

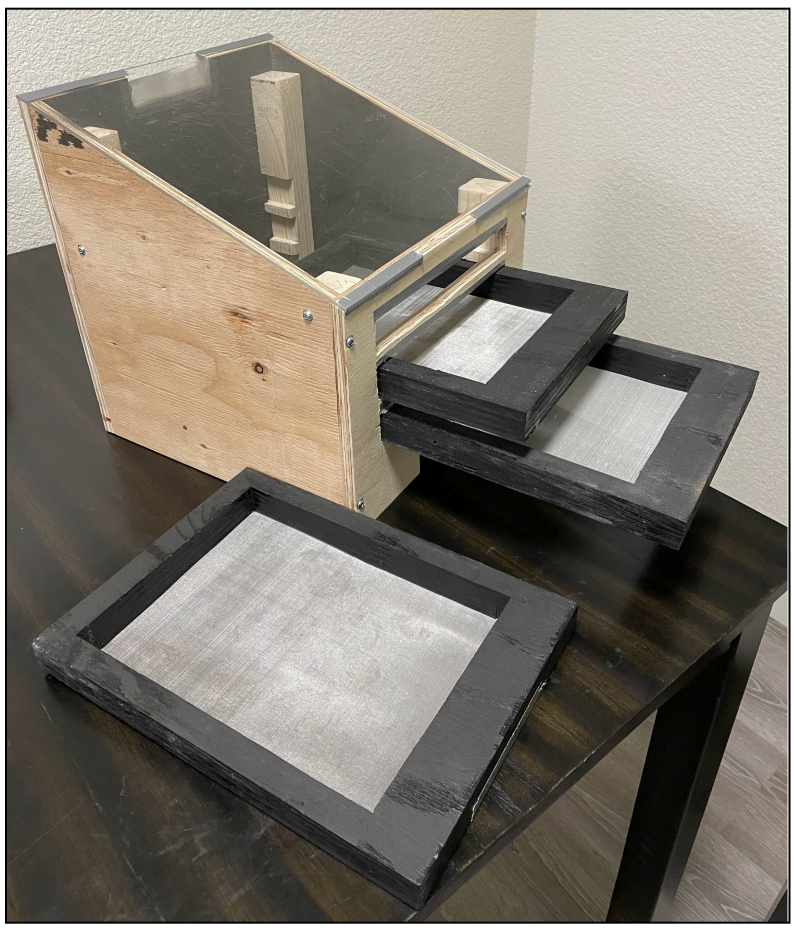
Problem Statement:

The design developed by our team must adhere to several required constraints for it to be considered a viable solution. It must be able to extend the shelf life of at least two different types of produce for a minimum of five days. It must be portable while taking up no more than 12 by 18 square inches of space and cannot rely on wall-power electricity for its operations. Additionally, our team wanted to have different sections as a way to keep the produce being preserved separate. Consequently, this allows for efficient use of the space within the design by maximizing the amount of produce that can be preserved.

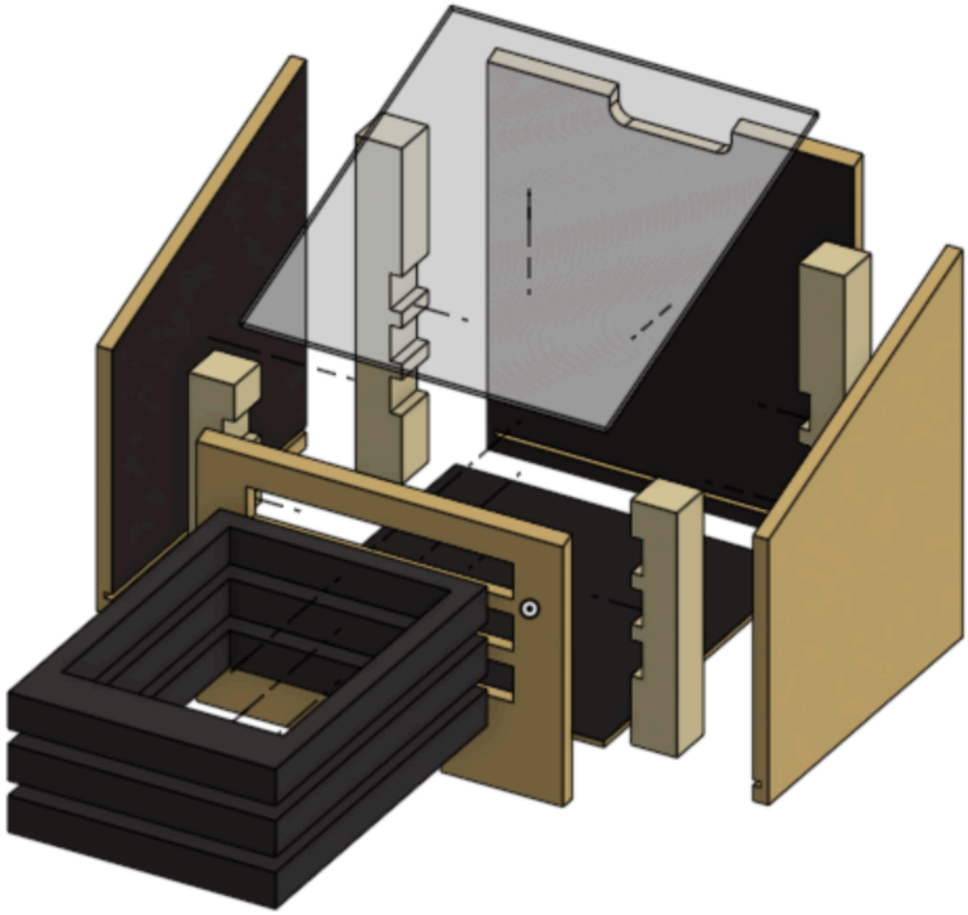
Given these constraints and the background knowledge on food preservation found via research of academic journals, our team decided to use a solar dehydrator as the design solution. Removing water from the produce is paramount to its preservation due to the fact that water allows for microbial spoilage to occur. Therefore, solar dehydration can be seen as one of the best ways to achieve the removal of water from the produce. This is because it removes the most amount of water from produce as compared to other methods of dehydration like salt or sugar preservation which alters the flavor of the produce. Although it can take up to 12 hours for a full dehydration cycle depending on the food, a solar dehydration system does not require any maintenance while in operation unlike alternative design solutions like cooling systems that would require input of refrigerant or ice.

Design Prototype Development:

The prototype was first designed in CAD using OnShape to an accurate scale model of the design prior to manufacturing. Dimensioned drawings of each individual part were then used to create a list of parts needed for the prototype's assembly. Over the course of a total of five hours across three days, our team worked in coordination with the BAE shop staff to cut these parts out of wood and acrylic. The walls were cut out of half inch plywood using a table saw with a 3/16 inch slot a half inch off the bottom of each interior side of the walls. The bottom piece was then inserted in this slot and glued in place to create a good seal for heat retention and raise the system off the ground by half an inch. The top of each side wall was cut with a 20 degree angle to create an optimal window that faces the sun. Next, the vertical supports were cut out of 4 pieces of 1.5 by 1.5 inch square stock wood using a table saw and slots for the trays were then cut into them using a router. Using a table saw, drill, and a jigsaw, three trays were cut out of inch thick plywood with 7.25 by 9.5 inch holes where wire mesh was then stapled to the bottom to hold the produce. A drill and jigsaw were then used to cut holes in the front wall for the tray to fit into the



dehydrator. Four inch by one inch vents were then cut into the top rear and bottom front of the dehydrator using a drill and jigsaw. This was done to utilize natural heat convection to create consistent airflow through the dehydrator. Wire mesh was then epoxied over the vents to block any pests or debris from entering. Lastly, the top window was cut out of clear acrylic and a fresnel lens was superglued to the center and attached to the dehydrator using duct tape to act as a hinge. However, the superglued degraded the acrylic and the lens ended up blocking light so it was removed from the final design.



Key features in the final design solution include a hinged clear top acrylic window angled at twenty degrees, wire mesh trays that slide into the dehydrator, vents, and a black interior. While the initial design used a fresnel lens to focus light into the dehydrator, it only ended up blocking sunlight so it was removed. This is because the light was concentrated into one point instead of filling the entire dehydrator, thus reducing the amount of heat produced. The trays were made to slide in and out of the dehydrator to allow for easy access to produce, and ease of use for the client. The slanted top ensures the maximum sun exposure throughout the day due to the sun's varying angle across the southern portion of the sky. The black interior absorbs heat energy from sunlight, allowing this heat to then radiate within the interior of the dehydrator thus increasing internal temperatures. The heat is then used to evaporate water out of the produce and put it in the air. The wire mesh trays and ventilation ensure that proper air convection occurs so that water vapor from the produce is removed through the vents. The vents are positioned at the top and bottom such that air flows through the dehydrator from bottom to top due to the fact that hot air rises, thus creating a pressure gradient drawing dry air in from the bottom. Although there was a slight build up of condensation on the side of the acrylic farthest from the top vent, it did not significantly affect the sunlight entering the dehydrator.

The main design challenges encountered in the development of this project were manufacturing the slots for the trays using the router, cutting the holes in the front face for the trays. The problem created at this step came from the imperfection of the holes cut due to using hand tools. These imperfections then cause slight misalignments in the slots where the trays slide into the dehydrator. To resolve this, several trails of sanding down materials in the way of the trays' path had to be done before they could fit into the holes and slide all the way back.

Design Use Instructions:

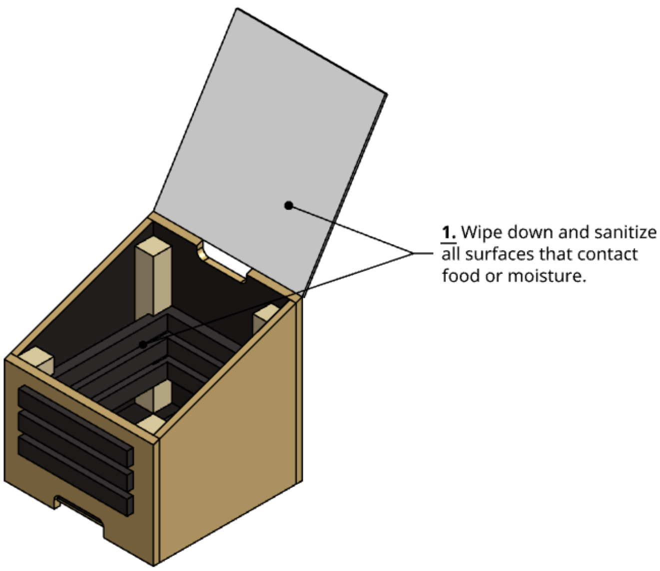
Since our target client was a single-income family household, we prioritized designing a user-friendly prototype. The following is a suggested procedure for using the dehydrator.

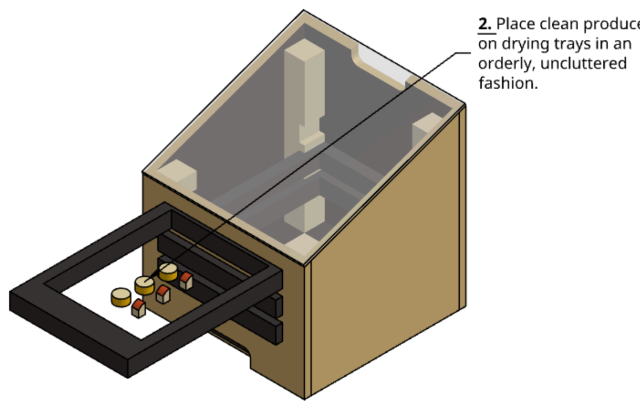
1. Wipe down the trays and interior surfaces with a damp cloth.
2. Sanitize any parts where food will contact a surface such as trays and mesh screens.
3. Allow all parts to dry thoroughly before use.
4. Prepare the Food:
    a. Wash all food items thoroughly to remove dirt, pesticides, or chemicals.
    b. Cut food into uniform pieces to ensure even drying. Recommended sizes for fruits and vegetables: 1/4 to 1/2-inch cubes or uniformly thin slices.
    c. Herbs: Leave whole or chop to preferred size.
    d. Meats: Thin, uniform slices (about 1/8 to 1/4 inch thick).
5. Lay the prepared food evenly across each tray. Avoid overcrowding the trays—foods should be spaced to allow air circulation for even drying.
    a. For fruits, it is helpful to place them on mesh liners or parchment paper if the items are sticky or small.
6. Place the dehydrator on a flat, stable surface in a location with full sun exposure. This can be inside or outside. Ensure the angled window is facing 180 degrees south for maximum sunlight energy absorption.

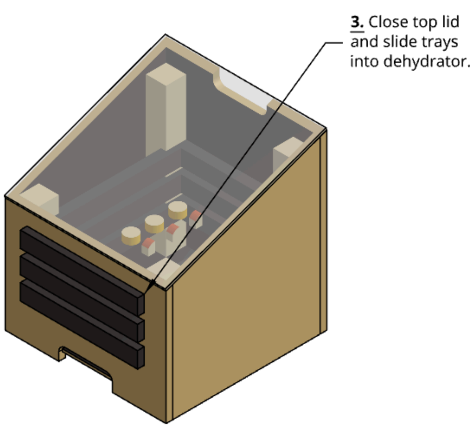
7. For best results, it is recommended to leave the dehydrator in direct sunlight for 8-12 hours, depending on the temperature, humidity, and type of food. The drying times will likely vary based on the food's moisture content.
8. After every use, clean the trays and interior in case of any food remnants.
9. Clean the lens regularly to remove dust, debris, and moisture, ensuring optimal sunlight absorption.

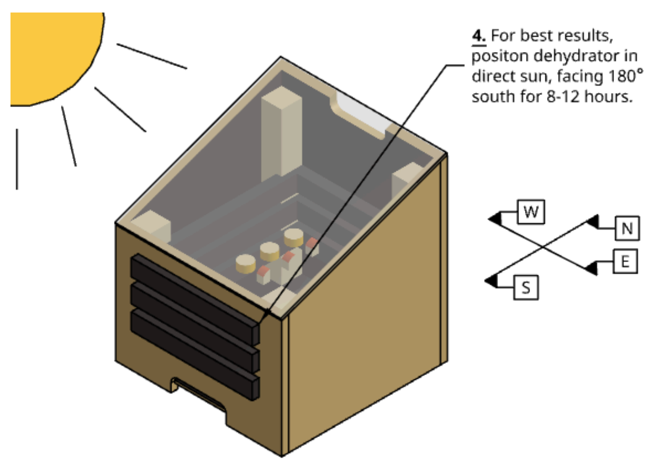
Safety Precautions:

1. Avoid using the dehydrator during non-suitable weather conditions, such as high winds, excessive cold, or heavy rain.
2. Monitor foods to prevent burning or overdrying.
3. Handle trays with caution, when inserting and removing food.









Budget:

Items	Actual Cost ($)	Hypothetical Cost ($)
Fresnel lens	8	8
Wire mesh	14	14
Labor, tools, and materials	0	520
Total Cost ($):	**22**	**542**

Staying within our $25 budget, a total of $22 was spent on our design. Wire mesh was purchased for $14 to create the trays where the produce sits. A fresnel lens was also purchased for $8 to focus the sunlight into the dehydrator.The shop staff charge $104 per hour for labor and materials, resulting in an additional hypothetical cost of $520 for the five hours spent using their time and supplies. Therefore, the total hypothetical cost of the design is $542 due to the usage of the materials, machines, and labor provided by the BAE shop. Whereas the actual total cost of the design, meaning the money we spent as a team, was only $22 and successfully within the $25 budget constraint.

Design Testing: Results & Analysis:

Three sets of tests were performed on the solar dehydrator each analyzing its efficiency in generating heat and humidity, as well as its ability to remove the sample's moisture content. In each of the three sets of tests, 12 pieces of 4.0g apple slices dehydrated for four hours. A control for the average water weight of a 4.0g apple slice was calculated using 6 samples that were totally dried using an oven. This was found to be 3.3g of water and 0.7g of dry weight. Over these four hours, the temperature and humidity were both measured inside and outside the dehydrator every 30 minutes to ensure there was a difference between the ambient conditions and the conditions within the dehydrator. Finally, after the four hours, the mass is re-measured and using the control, the mass of water removed can be calculated for each sample. These tests were conducted by team member Griffin Kriebel.

Average Dry Weight ($\overline{X}_D$): $\frac{(0.7+0.7+0.8+0.7+0.7+0.6)}{6}$ = 0.70g

Control Average Water Weight ($\overline{X}_C$): 4.0-0.70 = 3.30g

Standard Deviation (s_C): $\sqrt{\frac{\sum_{i=1}^{6}(Mi-\overline{X}D)^2}{5}}$ = 0.063g

Sunny Day 12/6/2024:

Produce Sample Number	**Water Weight Before (g)**	**Water Weight After (g)**	**Water Content Removed ($M = M_B - M_A$)**
1	3.3	1.3	2
2	3.3	1.3	2
3	3.3	.3	3
4	3.3	1.3	2
5	3.3	2.3	1
6	3.3	1.3	2
7	3.3	2.3	1
8	3.3	1.3	2
9	3.3	1.3	2
10	3.3	1.3	2
11	3.3	2.3	1
12	3.3	1.3	2

(Figure. 1.1)

Average Water Removed ($\overline{X}_1$): $\frac{\sum_{i=1}^{12}(Mi)}{12} = 1.83$g

Standard Deviation (s_1): $\sqrt{\frac{\sum_{i=1}^{12}(Mi - \overline{X}1)^2}{11}} = 0.577$g

Time	**Dehydrator Temperature**	**Outside Temperature**	**Temperature Difference**

	(°F)	(°F)	$(T_D - T_O)$
9:30am	74.7	62.7	12.0
10:00am	98.6	63.2	35.4
10:30am	117.8	64.3	60.5
11:00am	145.2	65.9	74.3
11:30am	139.5	67.8	68.7
12:00pm	128.3	68.5	59.8
12:30pm	121.9	64.6	57.3
1:00pm	118.1	62.4	55.7
1:30pm	119.0	63.1	55.9

(Figure. 1.2)

Time	**Dehydrator Humidity (%)**	**Outside Humidity (%)**	**Humidity Difference $(H_D - H_O)$**
9:30am	51	72	-21
10:00am	49	70	-21
10:30am	32	67	-35
11:00am	27	62	-35
11:30am	25	56	-31
12:00pm	25	51	-26
12:30pm	26	48	-22
1:00pm	28	45	-17

1:30pm	25	42	-17

(Figure. 1.3)

Hazy Day 12/7/2024:

Produce Sample Number	**Water Weight Before (g)**	**Water Weight After (g)**	**Water Content Removed ($M = M_B - M_A$)**
1	3.3	2.3	1
2	3.3	2.3	1
3	3.3	2.3	1
4	3.3	3.3	0
5	3.3	2.3	1
6	3.3	3.3	0
7	3.3	3.3	0
8	3.3	3.3	0
9	3.3	3.3	0
10	3.3	2.3	1
11	3.3	3.3	0
12	3.3	2.3	1

(Figure. 2.1)

Average Water Removed ($\overline{X}_2$): $\frac{\sum_{i=1}^{12} (Mi)}{12}$ = 0.50g

Standard Deviation (s_2): $\sqrt{\frac{\sum_{i=1}^{12} (Mi - \overline{X}2)^2}{11}}$ = 0.522g

Time	**Dehydrator Temperature (°F)**	**Outside Temperature (°F)**	**Temperature Difference (T_D-T_O)**
9:30am	77.8	63.5	14.3
10:00am	91.2	62.2	29.0
10:30am	94.8	64.0	30.8
11:00am	91.9	66.6	25.3
11:30am	97.5	68.2	29.3
12:00pm	102.7	68.7	34.0
12:30pm	99.6	63.1	36.5
1:00pm	87.2	61.9	25.3
1:30pm	87.8	62.0	25.8

(Figure. 2.2)

Time	**Dehydrator Humidity (%)**	**Outside Humidity (%)**	**Humidity Difference (H_D-H_O)**
9:30am	50	78	-28
10:00am	50	70	-20
10:30am	49	67	-18
11:00am	50	65	-15
11:30am	49	64	-15
12:00pm	44	64	-20
12:30pm	45	64	-19
1:00pm	49	66	-17

1:30pm	49	68	-19

(Figure. 2.3)

Sunny Day 12/8/2024:

Produce Sample Number	**Water Weight Before (g)**	**Water Weight After (g)**	**Water Content Removed ($M = M_B - M_A$)**
1	3.3	1.3	2
2	3.3	1.3	2
3	3.3	1.3	2
4	3.3	1.3	2
5	3.3	2.3	1
6	3.3	1.3	2
7	3.3	2.3	1
8	3.3	1.3	2
9	3.3	1.3	2
10	3.3	2.3	1
11	3.3	1.3	2
12	3.3	1.3	2

(Figure. 3.1)

Average Water Removed ($\overline{X}_3$): $\frac{\sum_{i=1}^{12}(Mi)}{12}$ = 1.75g

Standard Deviation (s_3): $\sqrt{\frac{\sum_{i=1}^{12}(Mi - \overline{X}3)^2}{11}}$ = 0.452g

Time	Dehydrator Temperature (°F)	Outside Temperature (°F)	Temperature Difference (T_D-T_O)
9:30am	71.6	62.4	9.2
10:00am	102.1	62.8	39.3
10:30am	141.8	64.2	77.6
11:00am	143.7	64.6	79.1
11:30am	132.2	64.9	67.3
12:00pm	126.8	66.6	60.2
12:30pm	122.1	67.8	54.3
1:00pm	117.1	69.8	47.3
1:30pm	126.8	72.3	54.5

(Figure. 3.2)

Time	Dehydrator Humidity (%)	Outside Humidity (%)	Humidity Difference (H_D-H_O)
9:30am	50	75	-25
10:00am	48	71	-23
10:30am	28	65	-37
11:00am	25	60	-35
11:30am	25	55	-30
12:00pm	28	52	-24
12:30pm	28	49	-21

1:00pm	29	46	-17
1:30pm	26	43	-17

(Figure. 3.3)

The data collected in each of the three tests demonstrates that the dehydrator is capable of generating internal temperatures up to 145 degrees Fahrenheit during hours of peak sunlight exposure (Figure. 1.2). This is around 80 degrees warmer than the ambient outdoor temperature meaning it is effective in heat absorption from sunlight (Figure. 3.2). However, as the sun gets lower on the horizon, the temperature inside starts to decline with the temperature outside but at a slower rate. This shows that it is able to retain some amount of heat but not for too long. This is also correlated by humidity data taken at the same time as the temperature. Humidity data shows that initially, the humidity is quite high around 50% but quickly lowers and levels off around 25-30% (Figure. 1.3). This is because as the temperature increases, so does internal convection which in turn cycles the humid air out through the vents without the need of a fan. However, the tests indicate that the dehydrator's effectiveness in removing moisture from the produce may be sub-par. With the average amount of water removed from the produce over all three tests being 1.36g of its total 3.30g of water content, the dehydrator has an efficiency of 41.2%.

Total Experimental Average Moisture Removed ($\overline{X}_E$): $\frac{(\bar{X}1)+(\bar{X}2)+(\bar{X}3)}{3}$ = 1.36g

Lastly, to confirm the results of these tests, a two sided 95% mean difference confidence interval is calculated to compare the difference between the control for water weight removed and the experimental water weight that was actually removed. Based upon the two populations' standard deviations, this calculation determines the true range of values that can be the difference between the two means with 95% confidence. This can be calculated using the following:

Total Experimental Average Moisture Removed ($\overline{X}_E$): $\frac{(\bar{X}1)+(\bar{X}2)+(\bar{X}3)}{3}$ = 1.36g

Experimental Standard Deviation (s_E): $\sqrt{\frac{\sum_{i=1}^{36}(Mi-\bar{X}E)^2}{35}}$ = 0.798g

Experimental Population (n_E) = 36

Control Average Water Weight ($\overline{X}_C$) = 3.30g

Control Standard Deviation (s_C) = 0.063g

Control Population (n_C) = 6

Degrees of Freedom = 6-1 = 5

95% Mean Difference Confidence Interval: $(\overline{X}_C - \overline{X}_E) \pm t_{critical}\sqrt{\frac{(s_C)^2}{n_C} + \frac{(s_E)^2}{n_E}} =$

$1.94 \pm 2.571(0.135)$ = [1.59, 2.29]

The 95% mean difference confidence interval demonstrates that the difference between the two averages is anywhere between 1.59g and 2.29g. Given that the interval is all positive, this tells us that the first population, the control average, is larger than the experimental average. From this, it can be concluded that the dehydrator in fact did not reach 100% efficiency further confirming the efficiency to be around the 41.2% that was previously calculated by comparing the mean water weight removed with the total water weight of a 4.0g apple slice. The causes for the lack of efficiency most likely come from the trail on 12/7/24 where the sky was quite hazy with smog creating unfavorable conditions for solar dehydration by blocking sunlight as is evident in its data (Figures. 2.1, 2.2, 2.3). Another cause for the lack of moisture removal could be the amount of time spent in the dehydrator while the sun is at its peak. With each test only being run for four hours, this was likely not enough time for the produce to be dried fully, hence the 41.2% efficiency. The lack of run time stems purely from personal schedule issues and the tests taking place in winter months that receive less sunlight during the day.

Future Recommendations & Conclusion:

After designing, building, and testing the prototype, it is evident where there are successes and where there are flaws in the design. It can be concluded that the dehydrator is fairly successful in heat generation and air circulation. However, it is rather unsuccessful when it comes to actually removing moisture content from the produce. Most likely, this is due to unfavorable weather conditions for heat generation and retention as well as the limited amount of testing run time caused by schedule conflicts. Longer testing periods would have allowed for more data to be collected over a more realistic time frame that would have aligned with the schedule of the client–a single family household. Given consistent and warmer weather, the results of the data would have been stronger and more consistent between each trial, the effects of the poor weather can be seen in the lower temperatures and higher humidity levels in the dehydrator on the 12/7/24 trial (Figures. 2.1, 2.2, 2.3).

A potential solution for unfavorable weather could be to add insulation thus improving the ability to retain heat and dehydrate the produce. While the build up of condensation on the lower part of the window could be solved by drilling vent holes in the top of the front wall to release this water vapor. To improve the dehydrator's overall ability to generate heat, it would be recommended that the system be designed to maximize sunlight contact surface area while minimizing the volume of air it must heat. In other words, the box would be thin in depth compared to the large area for sunlight to enter, similar to the shape of a pizza box. Lastly, a final recommendation would be to let the dehydration process run for around 8-12 hours in direct sunlight for results near 100% dehydration. This is determined by the 4 hour trials resulting in 41.2% moisture removed, therefore doubling this timeframe would in theory double the amount of water removed due to a fairly linear and slow drop off in temperature as the day goes on.

To decommission our project, it is necessary to unscrew the pieces from each other and return the screws, wood, mesh, and acrylic if salvageable. This way the overall waste is minimized since the parts can either be recycled or put to use for other projects. Since the dehydrator is mostly made of square cut plywood, it would be easy to be reused in future projects by other students by merely resizing the pieces to fit their needs.

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Appendices:

Meeting Minute Log

10/5/24	60mins (7:30pm-8:30pm)
10/10/24	60mins (6:00pm-7:00pm)
10/13/24	60mins (6:00pm- 7:00pm)
10/17/24	90mins (6:00pm- 7:30pm)
10/24/24	90mins (6:00pm- 7:30pm)

11/08/24	90mins (6:00pm- 7:30pm)
11/15/24	60mins (6:00pm- 7:00pm)
12/05/24	120mins (5:00pm- 7:00pm)
12/09/24	120mins (2:00pm- 4:00pm)
12/13/14	60mins (2:00pm- 3:00pm)