[Solar Powered Fruit Dryer for Market Gardeners in Shelek, Kazakhstan]

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1. EXECUTIVE SUMMARY

The people of Shelek, Kazakhstan use their backyard gardens as a source of additional income in order to help combat the wealth disparities throughout the city. In the summer harvest seasons, there is an overabundance of fruit that needs to be sustained for potential sales. In order to preserve the surplus of fruit, the people of Shelek strongly desire a fruit dryer. Many residents of Shelek do not have access to electricity as it is too expensive to have electrical wiring connected to their homes from the existing poles. Therefore, a passive solar fruit dryer would be necessary to help the residents of Shelek preserve their surplus of fruit.

There have been many successful attempts at constructing a solar fruit dryer, however, the defining challenge is the cost and manufacturability of the product. Many designs include materials that may not be readily available or too expensive in Shelek. Through the process of benchmarking, concept generation, prototype builds, engineering analysis, risk assessment, and verification testing, we have created a successful to-scale indirect solar fruit dryer over the course of four months.

The majority of the materials for our prototype were purchased from re-use stores (Habitat for Humanity Reuse on Jackson Rd, and Ann Arbor Re-Use on S. Industrial) to replicate the quality of materials that might be found in Shelek and to reduce cost. The total cost of the fruit dryer is $300 with a life-span of 3-5 years.

The fruit dryer is composed of two main parts: a solar absorber and drying chamber, which are attached through a hinge and can be disassembled for storage. The absorber, which collects the heat for the system, is made of: 3'x4'wooden frames, an aluminum sheet for its conductivity, and an acrylic for its lower cost and ease of handling. It is filled with 50lb of sand to increase the heat mass of the system. It is oriented due south with a tilt angle of 35º from the horizontal for optimal solar exposure. Lastly, there are wheels at the base of the absorber, and handles at the top for easier transportation and mobility of the fruit dryer. The connection between the absorber and chamber is PVC piping, painted black, as it is a material that is readily available and cheap. Chamber dimensions were determined so that a female operator of a 5'0" stature can access all parts of design, based on ISO International Standards. The drying chamber is 3' by 3' frame constructed from 3/8" thick plywood sheets, with 2"x4" pieces used as connection brackets. Key features of the chamber include: sliding doors, mesh racks, tilted roof, and ventilation holes.

Initial testing of the dryer was completed indoors using two space heaters, a 200W induction lamp, thermocouples at the inlet of the absorber and tracked through a Labview program. Apple slices of 0.3"- 0.5" thickness were dried. After six hours, the bottom rack achieved the desired moisture level removal of 60% while the top and middle racks took 8-9 hours to dry.

This project will continue to be improved through the University of Michigan's BlueLab student design team. The team will continue working with the to-scale prototype to test in summer conditions, install additional features such as adjustability of ventilation and initial airflow, and potentially look at natural (and safe) materials to absorb moisture in the chamber such as coal or silica gels.

2. PROBLEM BACKGROUND

The villagers of Shelek, Kazakhstan live under resource-restricted conditions in which there is little to no electricity, and wealth disparities run rampant throughout the country. The men tend to work in Almaty, the nearest large city, which is an hour and a half drive from Shelek, and the women work as part-time educators. To spread the wealth among different families in the village, the women are hired to work roughly three hours a day. As a means for additional income to help support their families, many of the women in Kazakhstan tend to their backyard gardens to sell produce at local markets. The climate in Shelek is very similar to that in Michigan, and much of the produce grown here is grown in the backyard gardens. In times of surplus harvest, drying fruit as a method of preservation, is of utmost importance because it reduces waste and the dried fruit can be sold as a value added product at the markets. There is a desire to dry up to 2 tons of apples, pears, apricots, cherries, eggplants, tomatoes and greens throughout the harvest season.

Figure 1: A women seen selling grapes on the side of a street (left) and a typical fruit stand in a larger fruit market (right). [1]

The REFRESCH (Researching Fresh Solutions to the Energy/Water/Food Challenge in Resource Constrained Environments) organization through the Energy Institute at the University of Michigan has been tasked with the problem of providing a cost-efficient, easy-to-build fruit dryer for the residents of Shelek. This fruit dryer must be solar-powered because although a grid system exists, electricity is not a very viable source of power as residents cannot afford to pay for their own wiring from the city's electric poles to their homes. Additionally, frequent gusts of wind pose a safety concern to the electrical cables and wiring, causing the city turns off the electricity regularly. To cut down on costs of the dryer, it must be built using common available resources in the village.

3. LITERATURE REVIEW and BENCHMARKING

There are several solar food dehydrators on the market, however, none of these products are affordable to the residents of Shelek or utilize resources that are available to them. As shown in Figure 2 (pg. 3) typical household fruit dryers hold smaller amounts of food than is desired in Shelek, cost between $30 and $200, and run on electricity[1,2].

To help community in similar situations as Shelek, Kazakhstan, several types of fruit dehydrators have been invented using solar energy. These solar dryers can be divided into two categories: direct and indirect solar drying, as seen in Figure 3 (pg. 3). The direct solar drying uses solar radiation to evaporate the moisture inside the fruit while the indirect method uses convection heat transfer caused by solar radiation [3]. The main problem of the direct drying method is nutrient loss. The open-sun drying destroys up to 94% of beta-carotene (dietary source of vitamin A) and 84 % of vitamin C [4]. Since maintaining nutrients of fruit is a must for our villagers, indirect solar drying is a better solution to fit the needs of Shelek.

Figure 2: Typical single household-use electric fruit dryers. These dryers are inefficient in meeting our gardeners' needs because they are too small, require electricity, and are expensive. [5, 6]

Current indirect solar dryer designs and products have some limitations that would not make them suitable for our project. To facilitate maximum solar absorption, solar cells/panels and metal framing are desirable and utilized. Although these designs are effective, they are not viable for our design because of low income levels in Shelek.

Figure 3: direct (left) and indirect (right) solar dryers. Direct utilize an open surface for the sun to directly shine on the fruit, while indirect relies on heated, dry air to dry the fruit instead of sunlight. [7]

Similar project scopes have been undertaken in developing countries. For instance, an indirect solar dryer was constructed in Zimbabwe to dry fruit and coffee beans[8] (Figure 4, pg. 4). This dryer was successful, however setbacks were encountered: (1) poor drying performance under low sunlight conditions, including overnight drying, and (2) high relative humidity in the ambient air. Since the indirect method depends highly on the air flow rate, which is influenced by air temperature and ambient air humidity, the performance of the dryer can drop significantly during bad weather[8]. Thus, our design is required to find methods to solve these two design problems mentioned above.

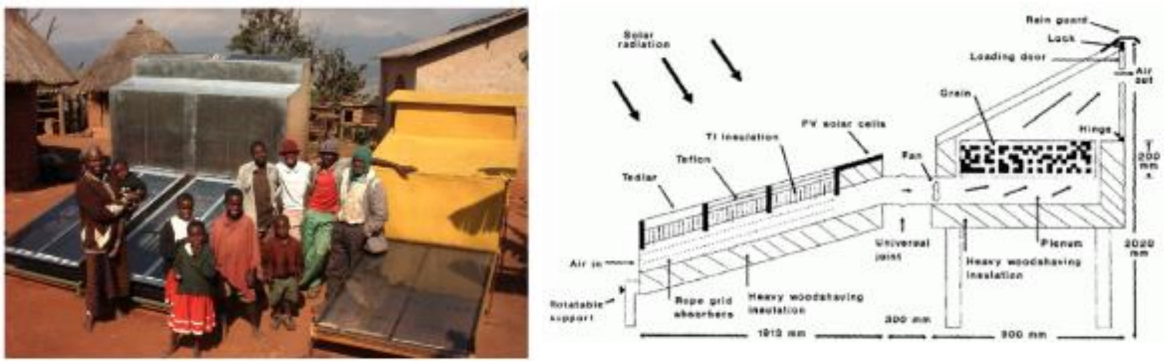


Figure 4 shows the indirect solar dryer to help dry fruit and coffee in Zimbabwe [8]. This dryer uses custom metal framework and solar panels which is too expensive for our desired design.

4. USER REQUIREMENTS & ENGINEERING SPECIFICATIONS

After conducting our initial sponsor interview, we were able to produce a list of engineering specifications to ensure our project meets the needs of the market gardeners. We developed requirements and specifications for operation/usability, quality, manufacturability, safety and power source. We considered each of the requirements and ranked them on a scale of 1 to 5. Specifications with a ranking of 1 are considered top priority and must be achieved in our final product design. Specifications with a ranking of 5 are part of our end design goal, but are not necessary for successful function and operation of the fruit dryer. Our complete list of user requirements and engineering specifications can be found below in Table 1.

Table 1: Engineering specifications stemming from user requirements.

System	User Requirement	Engineering Specification	Priority
Operation/ Usability	Women & children need to operate	Weight of door drying racks must not exceed 15 kg	2
	Hold large amount of fruit	Drying racks must collectively hold 18 kg of fresh fruit	4
	Utilize as much sun as possible	Absorb enough sun to remove 60% of moisture	3
Quality	Preserving nutritional content of fruit	Air temperature must not exceed 60 degrees Celsius	2
Manufacturability	Cost	Cannot exceed $400 class budget	1
	Size	Must fit within rectangular area of 3’x5’	5
Safety	Surfaces don’t promote bacterial growth	Temperature must not fluctuate by 20 degrees Celsius	1
Power Source	No electricity	Dryer must operate by passive solar energy	1

Operation/Usability

The operation and usability of the fruit dryer is an important consideration when we are evaluating the abilities of our user. We evaluated the physical abilities of the persons who will be operating the dryer to make sure they are able to safely and easily perform all necessary tasks associated with it. We gathered from our sponsor that a majority of the market gardeners in Shelek are women and that they often have help in the gardens from their children. Our design will be an appropriate size so that it is feasible for a child to operate it comfortably. Specifically, the weight of the door that seals the drying racks shall not exceed 15 kg. We justified this number with a study done on the evaluation of muscular strength of children between the ages of 6-12 years. The study, run at the University of Massachusetts, concluded that the average standing chest press of girls within that age range was 24.0±5.7 kg and the average standing chest press of boys within that age range was 24.6±7.7 kg [9]. Using this information, we concluded that a child within this age range would be capable of lifting a door that weighs less than 24 kg and determined that we would be able to feasibly manufacture a door that weighs 15 kg or less.

The fruit dryer must be capable of supporting a large amount of fruit. Typically, 12 lbs of fresh apples yields approximately 1¼ lbs of dried apples, 14 lbs of fresh pears yields approximately 1½ lbs of dried pears, and 14 lbs of fresh tomatoes yields approximately ½ lb of dried tomatoes [2]. Our sponsor informed us that the market gardeners would be willing to share the fruit dryer to reduce the cost, so we would like for our design to be able to support the produce of multiple market gardeners. Our design should be able to support 18 kg (~40 lbs) of fresh fruit at once. More than 18 kg of fresh fruit can lead to an overabundance of moisture within the dryer, potentially leading to the growth of bacteria[10].

Shelek experiences approximately 15 hours of sunlight per day in the summer months, with peak sunlight hours between 11:00 am and 3:00 pm. During peak hours of the day the angle of the sun with respect to the horizon ranges from approximately 68 degrees at 11:00 am to approximately 109 degrees at 3:00 pm, meaning the fruit dryer must be able to rotate approximately 41 degrees for the fruit to be exposed to the maximum amount of sunlight.

Quality

The ideal temperature for dehydrating fruits is 140 F (60ºC) with a minimum temperature of 50ºC [2]. Exceeding this temperature results in the risk of burning the fruit. Drying times depend on varying moisture content for different types of produce, atmospheric humidity and temperature, and sunlight exposure. Table 2 shows the approximate time it may take to dry the specific types of fruits that the market gardeners in Shelek grow [2, 11].

Table 2: Approximate drying times of specified fruit that will be dried in Shelek.

Fruit	**Time to Dry (hours)**
Apple	6-24
Pear	6-10 (slices), 24-36 (halves)
Apricot	24-36
Cherry	24-36
Eggplant	12-14
Tomato	6-24
Greens	6-10

Manufacturability
Although we are producing a fruit dryer for a low income environment, we are creating a fruit dryer that is at most $300 that can be easily manufactured by the operators in Shelek. The additional $100 of our budget will be used to create a scaled-down version of our prototype prior to building the "to-scale" size so we can conduct initial important testing, and get a better understanding of the ease of manufacturability of our design. We are designing this product in that it can be replicable in Shelek, therefore we need to ensure that assembly of the design is simple and straightforward.

Since the gardens are typically located in the back yard of small homes, a 2m x 2m floorplan area is an appropriate size for the fruit dryer.

Safety
Our design must be able to maintain a steady temperature to hinder the growth of bacteria on the produce. Frequent fluctuation in temperature can reintroduce moisture to the produce, causing bacteria to form. The ideal temperature for drying fruit is 60 degrees Celsius with no more than 20 degrees Celsius in temperature fluctuation to ensure that the produce does not develop any sort of bacteria [10].

Power Source
The market gardeners live in a very rural area of Kazakhstan and have very limited to no access to electricity [1]. The fruit dryer must run on 100% passive solar energy to meet the needs of our users.

5. DESIGN REVIEW PROJECT PLANS
Our documents that will keep us organized until the next Design Reviews are included in Appendix A of this document. We have completed Gant Charts, WBS, and RASIC tables to keep us on schedule.

6. CONCEPT GENERATION
To begin our concept generation, we first functionally decomposed our fruit dryer to make sure we would not look over any aspects of our product. As shown in Figure 5 (pg. 8), we came up with five main functions that our dryer needs to perform. As a "first round" concept generation exercise, we sat in a group each equipped with pencil and paper, called out each of the functions, and had five minutes to generate whatever came to mind. This was our basic brainstorming round of concept generation in which nothing was off-limits. A few of the results are shown in Figure 6 (pg.9), while the complete list can be found in Appendix B of this document.

After this first round of brainstorming, each of us came up with 20 concepts individually. A concept did not have to be a full design, however could isolate a certain part of the fruit dryer. These concepts were either drawn or written (depending on the comfort level of each team member), and shared with the team. Some of these results are shown in Figure 7 (pg. 9); the complete list of concepts can be found in Appendix B of this document.

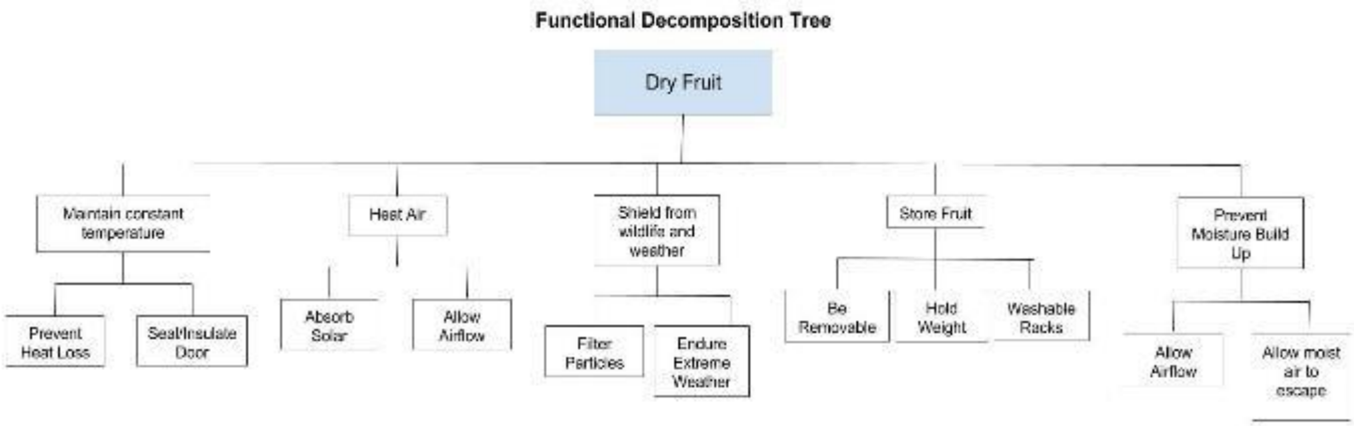


Figure 5: Functional decomposition of fruit dryer, highlighting the main tasks we need our product to accomplish.

Through our concept generation, we found that our fruit dryer would be comprised of three main parts: an *absorber* in which air is collected and heated due to solar radiation, a *drying chamber* in which food is stored and is dried through convection, and a *chimney* which encourages air flow and allows moist air to exit the system. A main difference between concepts was the direction of airflow to achieve fruit drying: up-flow and down-flow. These two concepts are shown in Figure 8 (pg. 9). The advantages of a down-flow dryer would be that the chamber would sit relatively low to the ground, which would allow our users (women and children) to more easily operate our product. The downsides to this type of product is that it will be harder to force hot air to flow downwards which would lead to longer drying times. Additionally, the direct contact of the chamber with the ground could lead to infestation in the chamber and rotting of the wood due to moist ground. The opposite is true for advantages and disadvantages of an-upflow chamber. The elevation prevents insect/weathering of the chamber and warm air will rise to fill the chamber. The disadvantage would be that the structure could be too tall for women and children to operate comfortably.

Three novel ideas that came about during concept generation were: (1) a "heat storage" compartment (2) a common and affordable heat absorber, and (3) a design to allow improved air circulation. These ideas can be incorporated into the design of the solar absorber and are explained in detail in Figure 9 (pg. 10) below. The heat storage solution to allow heat generation even after the sun has directly passes over the solar absorber. This consists of a combination of sand, gravel, and aluminum shavings underneath the metal of the solar absorber. The idea is based off walking on the beach and burning your feet on the sand. To absorb heat, black spray painted aluminum cans with both ends cut off can be strung together to form a channel for heated airflow. This is a cost-effective solution that uses common materials. To improve air circulation, the cross sectional area of airflow should increase as approaching the drying chamber from the absorber, as well as exiting the chamber to the chimney. This change in area will affect the velocity of air and keep air moving through our system. An idea that needs to be explored more is the addition of a "moisture absorbing" material in the dryer chamber. This could include coal or rice on designated shelves of the drying chamber. Each team member was tasked with creating his/her own "final design" based on the discussion following the 20 concepts each member previously generated based on the discussion of up flow vs down flow, ease of manufacturability, and some of the novel ideas mentioned. These final designs are found in Appendix B.3 of the document.

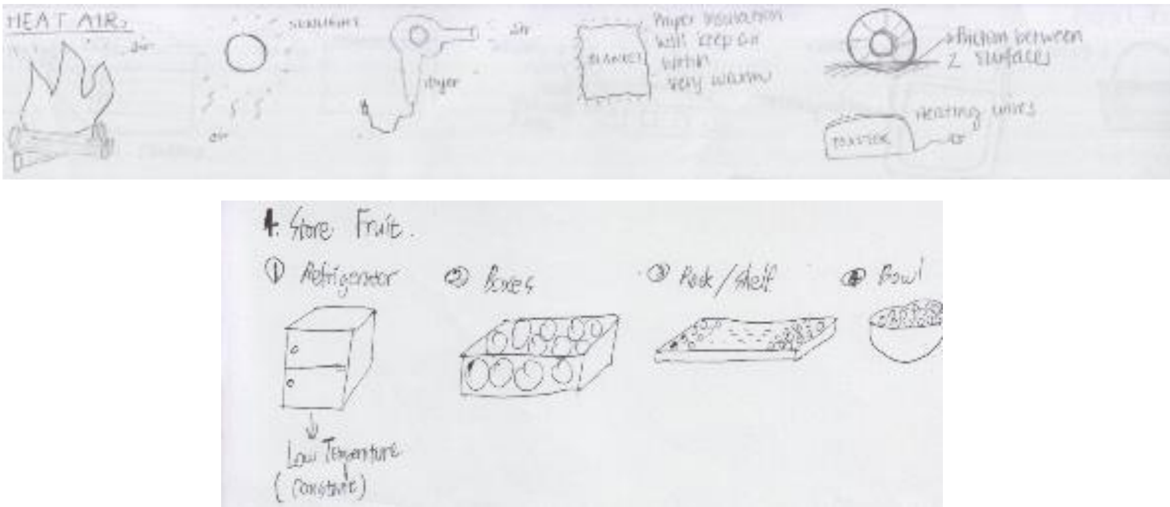


Figure 6: Initial concept generation for each subfunction determined by our group. The functions of "Heat Air" and "Store Fruit" are shown below, and a complete generation of concepts can be found in Appendix B.1.

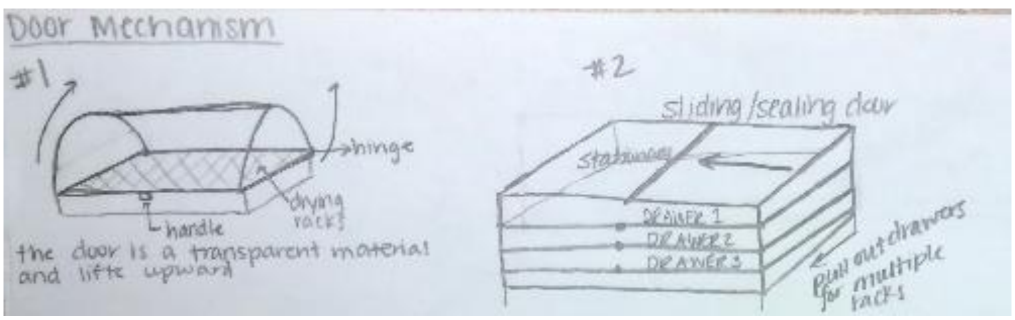


Figure 7: A sample of concept generation sketches during design development process. All concepts during this stage can be found in Appendix B of the document.

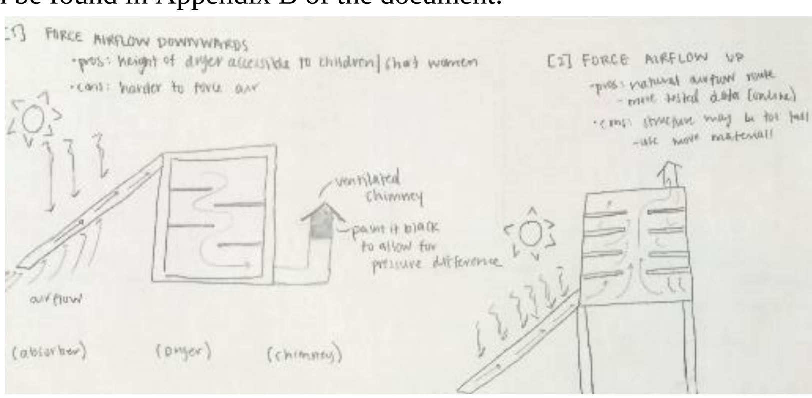


Figure 8: Concept 1(left) looks to force air downward through a magnified pressure difference to dry fruit. Air flowing down was considered in order to house the fruit storage area of the product at a reasonable height for woman and children to operate easily. Concept 2 (right) depicts a fruit dryer that allows air to move upward to dry fruit—the natural direction of warm air flow.

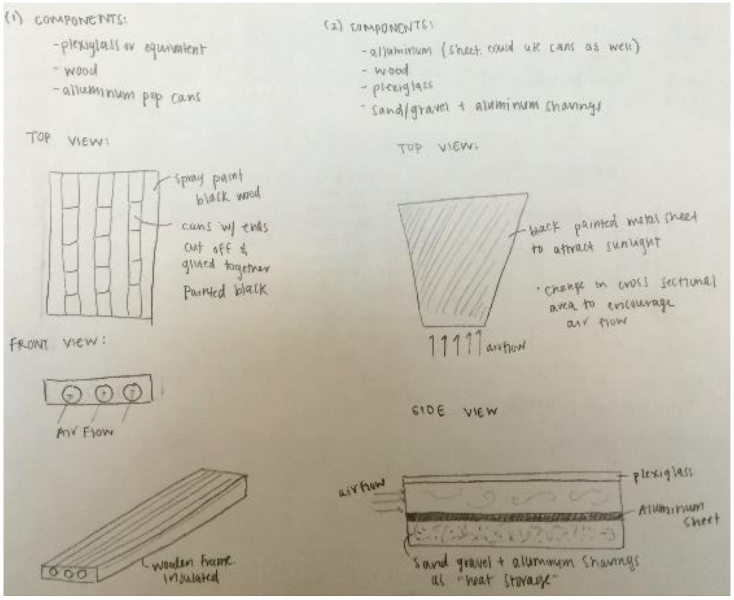


Figure 9: Novel ideas for (1) a solar absorber made from sand, (2) increased airflow due to change in cross sectional area or absorber channel (3) heat circulation through aluminum can design.

7. CONCEPT SELECTION

We created a list of attributes of our design that would signify the feasibility of manufacturing and meeting our most important user specifications. We considered each of the attributes and weighted them on a scale of 1 to 5. An attribute with a weight of 1 is considered least important and are part of our end design goal, but are not necessary for successful function and operation of the fruit dryer. Attributes with a weigh of 5, must be fulfilled in order for our design to be built and function successfully. We took the first concept as our base and gave it a scoring of 0 for meeting the desired attributes. The remaining four concepts were scored with a -1, 0, or +1, depending on if it achieved the desired attribute worse, the same, or better than the base concept. The score for each attribute was multiplied by the weight, and then added for all attributes. The concept with the highest score would be selected as the final concept. Table 3 (pg. 11) shows our full Pugh Chart, illustrating the aforementioned selection method.

Table 3: Pugh Chart used for concept selection.

Attribute	Weight	Concept 1	Concept 2	Concept 3	Concept 4
Manufacturability	5	0	1	1	1
Weather Resistant	1	0	0	0	0
Amount of Sun Exposure	5	0	-1	-1	-1
Ease of Operation	4	0	0	1	0
Storage Capacity	3	0	0	0	0
Mobility	2	0	0	0	0
Cost	5	0	1	1	1
Ability to Direct AirFlow	5	0	0	-1	0
Ability to Absorb Condensation/Moisture	3	0	0	0	0
Easy to Clean	2	0	0	0	0
	TOTAL	**0**	**5**	**4**	**5**

The results of our Pugh Chart indicated that a hybrid with the best attributes from each concept would be selected for our final design.

8. FINAL CONCEPT

Based on each team member's concept generation and design, and selection method (Pugh Chart), a final design was decided selecting all the advantageous ideas and parts. The final design consists of two main components to improve dryer performance. The first part is the solar absorber (Fig. 10). It will implement aluminum cans which are cost-efficient and have higher heat conductivity than wood. The pipe made of aluminum cans will help to increase the airflow rate, and temperature. Also, it will be beneficial in forcing the direction of air upward.
The next part is the compartment of sand below the aluminum pipes and solar collecting plate, which is a cost-effective material that maintains air temperature. By containing the sand under the pathway of airflow, it will help regulate air temperature even when there is a hot, cloudy day.

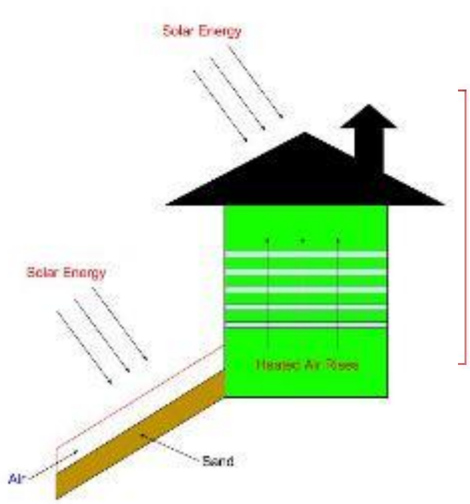


Figure 10: (Left) Finalized concept which includes: up-flow design, aluminum cans as solar absorbers, sand beneath the cans to act as heat storage, and a roof to shield against the weather. (Right) Top view of aluminum cans insight the solar absorption portion of the fruit dryer.

9. PRIMARY DESIGN DRIVERS

Up to this point, our primary design drivers have remained consistent, however our final design addresses alternative solutions than our final concept to achieve the design drivers.

Solar Absorption and Air Flow: To optimize the air convection drying process, the absorber for solar energy is important. For the absorber in our concept design, aluminum cans were used to increase the air flow rate and solar absorption. However, due to the difficulty in manufacturability with aluminum cans, a single aluminum metal sheet will be used instead. The sheet metal is relatively inexpensive due to our increase in budget allowance, and does not require tedious manufacturing. Also, sand will be placed beneath the aluminum sheet to functions backup heating after solar energy is not available. The size of the absorber was determined by calculating the expected duration of drying process (see Engineering Analysis Section, page 18). Theoretical analysis will be performed by applying heat/mass transfer principles and validated by testing the actual dryer. Since our dryer will be run by passive solar energy, it does not possess a function to control the air temperature or air circulation. While higher temperature will help the drying process, it might also have potentials to harm the fruit quality. To prevent the problem, manually-controlled venting system will be used. By adjusting the position of the vent door, users will be able to control the amount of air flow, which will change the drying performance. This will be validated by testing our prototype dryer.

Fruit Storage: The amount of fruit stored is critical for our design process. Since the user produces 2 tons of fruits during the entire harvest season, we need to accommodate drying large volumes of fruit at one time. Based on the information about the total production of fruits, the available floor plan area in Shelek, and the daily/monthly sun hours in Almaty, the size of the chamber was determined as 1 x 1 m (1 m^2). Also, the number of rack levels was analyzed to be 7, and to hold 9.5 kg per day for 1000 kg of fruit during the entire harvest season. Validation will be conducted by loading sliced fruit into our prototype. Additionally, material selection of the racks needs to be considered in more detail based on the properties of conductivity, sanitation, and durability.

Size of Dryer & Loading Mechanism: Since the users for the dryer are women and children, it is important to build the device considering their height and carrying capacity. Users will interact with the solar fruit dryer by placing fruit onto racks and transporting the racks to and from the drying chamber of the fruit dryer. The size of the dryer will be updated to compensate the expected shorter stature of women and children. The height of the dryer was determined to be 1.7 m according to the international anthropometric data of women and children. We expect the majority of women to have an eye height of about 1.55m which would mean that we should build a structure no taller than 1.7m [12]. From a study done at the University of Massachusetts, we discovered that children are capable of doing a standing chest press of 24kg [9]. Assuming that women can lift more than a child, we want our design to incorporate racks that weigh no more than 20kg with fruit. This will help maximize the ease of use and safety of users. While pulling or lifting door has potential danger to harm women and children, a sliding mechanism for the door reduces this risk to "pinching of fingers". Possible issues with leakage and sealing of the drying chamber needs to be addressed moving forward. Based on the data about muscular/strength analysis for women/children our final dimensions of the dryer will be further analyzed.

Mobility: Finally, while our users have requested our design to hold a large amount of fruit at once, they also want the dryer to be mobile and portable. The option of mobility has not been solved or decided thus far, but feasibility assessments about moving a large device safely will be taken into consideration.

Table 4 summarizes these main design drivers; these are the critical aspects of our design that need to be met in order to have a successful fruit dryer.

Table 4: Design drivers importance, analysis, and validation.

Design Drivers	Description	Importance	Design Driver Analysis	Validation
Solar Energy Absorption & Airflow	Solar energy is required to increase the temperature of air, and create the air flow through the dryer	To dry the moisture of the produce, it is critical to reach the target temperature and airflow rate to use optimal air convection	Literature review about the moderate temperature for different types of fruit. Thermodynamic and heat/mass transfer analysis for the amount of air flow rate	Test of actual fruit dryer

Fruit Storage	2 tons of fruits are required to be dried during the entire harvest season	To dry 2 tons of fruit total during the harvest season, 20 kg of fruits per day should be dried, considering the solar fruit dryer will not operate under overcast days.	Based on the data of weather conditions during the harvest season and the amount of fruit produced, fruit amount can be calculated	Test of actual fruit dryer
Compact Size	The fruit dryer will be operated mostly by women and children, so it must be short enough for a small child to reach and the drying racks must be easy to remove	To maximize ease of use, to ensure product safety (something too large or too heavy can potentially be dangerous)	Based on studies regarding muscular analysis of small children, appropriate weights for the moveable parts of the dryer (doors, racks, etc.) can be determined	Siemen's Jack Model
Mobility	Fruit dryer is required to deal with the varying position of sun, and the external circumstances	To optimize the solar energy absorption, and avoid potential damages from external circumstances, it is important to have a function to move the dryer	Based on the position of sun, the position of a dryer can be calculated/analyzed	Test of actual fruit dryer

10. FINAL DESIGN

For our final design, the two biggest changes from our final concept involve the solar absorber and the door. Our Final design utilizes an aluminum sheet for solar absorption, two sliding doors that are easier to operate for children, narrower racks for easier insertion and removal, and adjustable ventilation, as shown in Figures 11-17 in the following pages.

The final dimensions of our design were based on the ISO/TR 7250-2 basic human body measurements for technological design report. We were unable to find existing data of body dimensions for Kazakhstan so we focused on relevant dimensions of the lower fifth percentile of Japanese women between the ages of 20 and 65, who, on average, have a more petite frame. This was a valid basis to construct our design since our operators would be both women and children. Based on the required height for improved air/heat flow, we designed with the intention that children could assist in drying fruit under supervision and assistance from parents, but could not operate all functionalities of the device. Table 5 indicates the relevant dimensions of our design to user dimensions. A concern we still have for sizing is the depth of the racks, in which the racks may be too long to comfortably hold by a single user. We will need to do further simulations with Siemen's Jack software.

Table 5: Body dimensions of lower fifth percentile Japanese women, and dimensions of fruit dryer, referenced from ground[12].

Human Measurement	Human Dimensions (mm)	Product Equivalent Measurement	Dimensions (mm)
Elbow Height	889	Base of Drying Chamber	950
Elbow-Elbow Breadth	322	Width of Rack	470
Elbow-Grip Length	282	Depth of Rack	960
Shoulder Height +Elbow-Grip	1182 +282	Height of Top Rack	1450

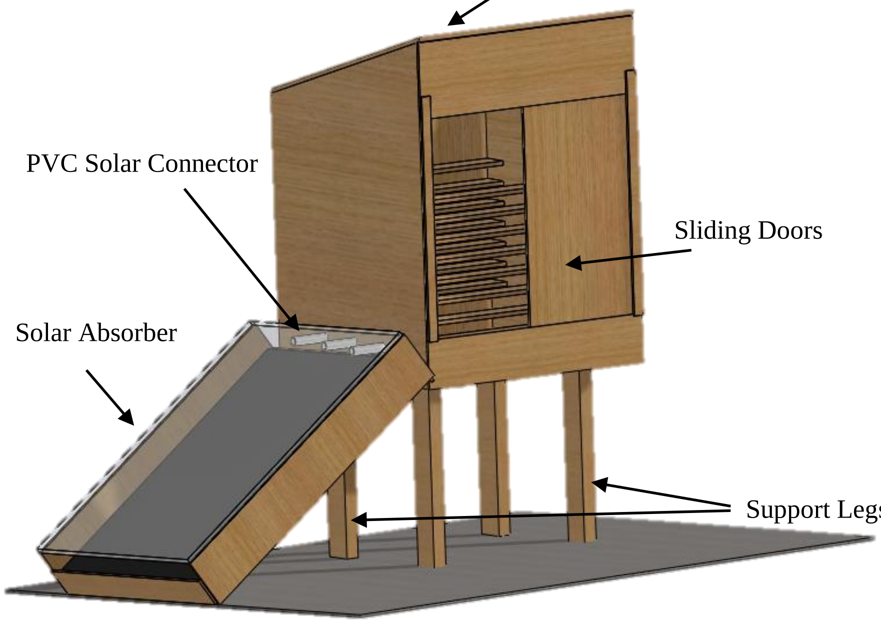


Figure 11: Final design of fruit dryer. The key features of this design are the sliding doors, the roof slanting in one direction to minimize material usage, and the large are for solar absorption.

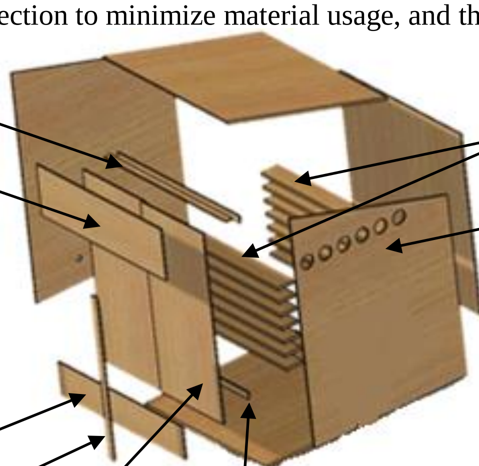


Figure 12: Exploded view of chamber. Parts include: rack supports, drying racks, 3/8" thick plywood walls and sliding doors all made of plywood.

Solar Absorber Modifications

Originally, we thought to use aluminum cans strung together to make a channel for air flow, however we decided to use a flat sheet of aluminum that can be purchased at the hardware store instead (See Appendix D for Bill of Materials). Cutting the aluminum cans, stringing them together, and ensuring the junction between the cans is sealed, requires extensive and tedious manufacturing. Due to our new project scope involving a larger budget to construct a more effective fruit dryer, we are able to spend the money on an aluminum sheet with the same conductivity for heat transfer, but will be easier to manufacture and assemble.

Additionally the inlet and outlet of the absorber will be narrower than the frame of the absorber to encourage air flow. A faster velocity at both the inlet and outlet of the absorber are desired for air to keep flowing through the absorber and into the drying chamber. Based on Eq. 1 below, a smaller cross sectional area, A, will increase the volume of fluid flow.[13] Solar Absorber is shown in Figure 13 pg. 15. Similar to having adjustable ventilation for our design, we will incorporate adjustable inlet area reach the proper air circulation for fruit drying depending on the temperature and weather. This adjustability is not shown as it was just thought of prior to this design review and will be updated for Design Review 4.

$$A_1 v_1 = A_2 v_2 \quad \text{(Eq. 1)}$$

The tilt angle for the solar absorber is 35º from the horizontal since the preferred angle for greater solar absorption is the latitude of the location ±10º for the winter and summer months (Shelek has a latitude of 43N).[8] Additionally, the solar absorber of the fruit dryer should be oriented due south to increase the amount of sun exposure.[8]

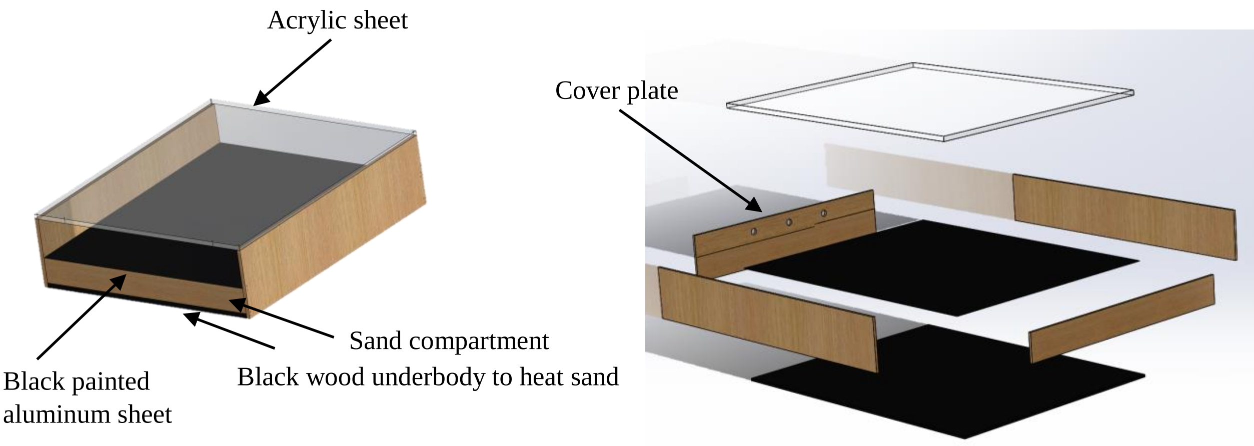


Figure 13: Solar absorber of fruit dryer with aluminum sheet used as heat absorber and variable cross sectional area to encourage airflow. Exploded view (right) shows cover plate with holes for PVC pipe connection from absorber to chamber.

Finalized Rack Configuration

Our final rack design consists of two racks per each level, which allows a single user to insert and remove the racks. Because the width of the drying chamber is 1m, a single operator would not be able to comfortably carry such a wide rack, which led us to "divide" the racks. From Table 5 above, the elbow to elbow breadth is 322 mm, and the width of each rack is 470mm which allows the user to comfortable grip the rack and insert/remove the rack into the fruit dryer with arms slightly extended from the center of the body. The material of the mesh will be steel to further heat the fruit as well as resist corrosion due to the acidity of the fruit.

We still need to finalize the support for the racks. We are considering two bars underneath each level that run perpendicular to the racks, as shown in Figure 14 pg. 16. Another design consideration is to have slots in the side walls and create a wall in the middle with slide to hold each set of racks, however, the addition of a wall in the center of the drying chamber would inhibit air circulation.

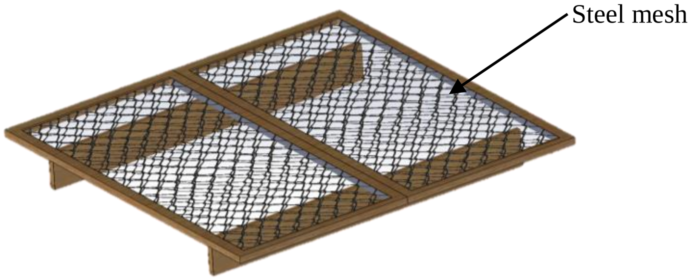


Figure 14: Drying racks of drying chamber. Support for the racks still needs to be finalized. Slots in the exterior drying chamber walls will be made to slide the racks in and out.

Door Modifications

After creating our risk analysis, we decided to change the design of our door. Our final concept utilized a door hinged on a single side that required to be pulled in order to open. The user would then operate the racks with the door opened, and there could be a potential for wind to close the door on the operator. In order to eliminate this risk, our final design will have a pair of sliding doors on separate tracks. These sliding doors will also be easier to operate for smaller women and children. We are investigating the best method to manufacture and install these doors to our design, so have not created a full functioning 3-D model.

Adjustable Ventilation

To prevent food spoilage, adjustable ventilation will be implemented to regulate temperature in the solar dryer. Currently, our design can be adjusted by hand, but will require a person of a height of 1.5~1.7 m to adjust the ventilation. We have considered options of creating a handle near the bottom of the dryer and connecting a belt to the vent cover, however this will increase cost of device. We must decide if the cost benefit will be worth it to create an easier method of operation of the ventilation cover.

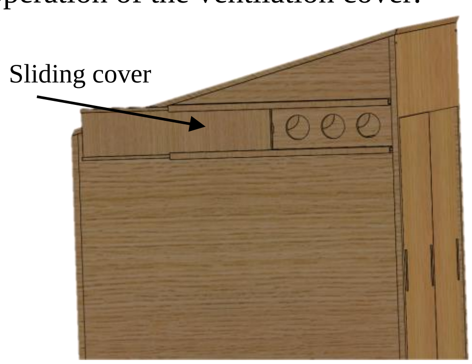


Figure 15: Adjustable ventilation on one side wall to help circulate airflow and avoid food spoilage.

11. MANUFACTURING

The solar absorber, chamber with three racks, and connection are fully constructed as shown in Figure 16 (pg.16). The majority of the materials for our prototype were purchased from re-use stores (Habitat for Humanity Reuse on Jackson Rd, and Ann Arbor Re-Use on S. Industrial) to replicate poorer-quality materials that might be found in Shelek. Our goal is to check that even when using these materials, our design is still effective. The total cost for materials (including nails, screws, and excess material) is $345. The absorber and connector are attached through a hinge that secures into the side wall of the chamber and bottom wood plate of the absorber. The fruit dryer can easily be disassembled when the bottom screws of the hinge from the absorber are removed.

While manufacturing our final design, we learned a few tricks to save money during construction as well as some design improvements. Since some of our large wood sheets were warped, instead of using custom L-brackets from the hardware store to ensure the sides connect together, left-over 2” x 4”s were cut into 2” thick pieces and placed in the corners of the chamber box and used to screw in the thin wood of the walls to one another. These wood pieces as support helped with the sturdiness of the chamber. Likewise for the absorber, we used left-over 2”x4”s as spacers to hold up the aluminum sheet as well as the acrylic sheet.

The weight of the absorber is roughly 60lbs due to the 50lbs of sand as additional heat mass and the weight of wood. The absorber therefore will be heavy for users to transport for storage, therefore wheels were added to the bottom and handles to the top to move more easily. Although mobility is not a key design, the ability to move the solar absorber will aid in connecting the absorber to the drying chamber, and to disassemble the two parts for storage.

Figure 16: Manufactured first prototype of fruit dryer. Support cross-bars were included to the legs for additional stability.

For our prototype, we determined that it was not necessary to construct all of the racks as our time would be more valuable in focusing on testing. Three racks, that can be positioned in various shelf locations in the chamber is all we need for testing. The racks are made of thin wood pieces (3/4”) connected together with L-brackets. Alternatively, wood pieces in the corner could be used similar to those used in constructed the chamber. An additional support in the middle was nailed to the frame to reduce “sagging” of mesh in the middle due to weight of fruit, as shown in Figure 17. The mesh was cut oversized from the rack frame, and folded over to the correct length so the final edge was smooth to avoid injury. A thin layer of hardboard was stapled over the mesh so the mesh would not wear over time from being placed in and out of the rack.

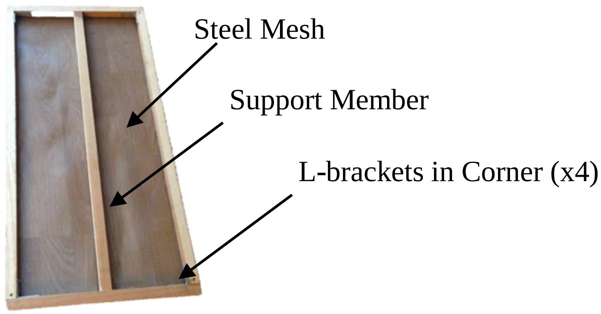


Figure 17: Manufactured rack of fruit dryer including mesh, support member, and hardboard on the underbody to reduce wear of mesh.

12. VERIFICATION AND VALIDATION TESTING

The equipment for testing includes a 200W induction lamp, two space heaters, a National Instruments, NI-9211 Thermocouple Module, 2 K-type thermocouples, and a laptop with Labview software, as seen in Figure 18 below. The testing protocol is found in Appendix G of this document.

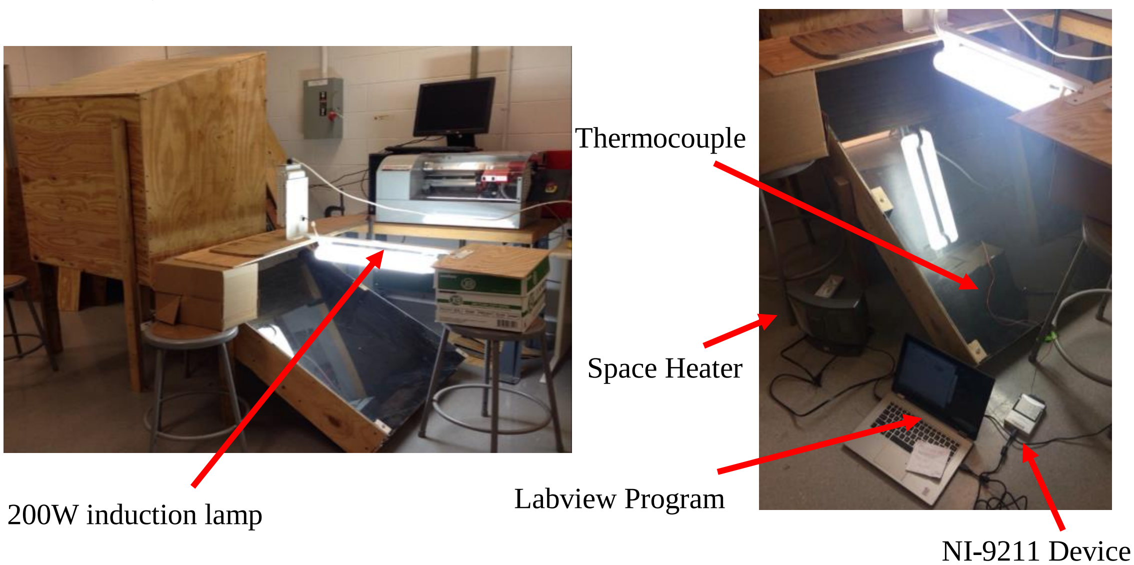


Figure 18: Test set up of initial verification testing for fruit dryer.

For testing, our original test set-up was not adequate to replicate the temperature and outside conditions that our fruit dryer would operate under. We attempted testing by solely utilizing an induction lamp placed above the solar absorber, however after four hours, the temperature at the inlet of the absorber only increased by 3ºC. The temperature in the room was only 68F (20C), and so the light was heating up the room first and not our absorber. Also, the light was focused on a small area of the absorber, the rest of the chamber wasn't exposed to any heating, and therefore more difficult to heat up. Lastly, the room was very stagnant without any airflow or "wind" which prevented air circulation. To alleviate some of these testing concerns and create a more realistic environment, we utilized space heaters. These heaters allowed the temperature of the room be more replicable of summer conditions, allowing for air circulation and a warmer environment for the chamber. Temperature was recorded at both inlet of solar absorber and inside drying chamber through thermocouples connected to NI-9211 and Labview. With this new test set up the room temperature during testing increased from 20ºC (68ºF) to 23ºC (74ºF), temperature in the absorber stabilized to 55ºC (131ºF) and chamber to 29ºC (84ºF).

Two apples were sliced between 0.3"- 0.5" thickness and the mass of the slices were measured prior to drying. They were placed in the dryer, and re-weighed at 30min time increments as shown in Figure 19 below. After six hours, the bottom rack achieved a moisture level removal of 60% (40% of fruit mass remained), while the top and middle racks would take 8-9 hours to dry the fruit.

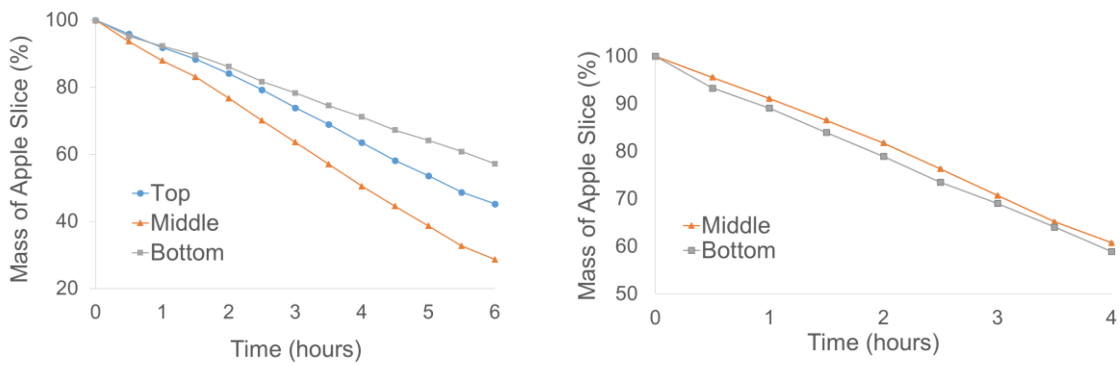


Figure 19: Mass of apples recorded prior to drying and at set time intervals during drying process to test moisture removal. Bottom rack exhibited worse moisture removal due to larger starting mass of slice (left). Additional testing of moisture removal of fruit with similar starting mass indicates that the bottom rack will dry fruit of the same moisture content more quickly than middle and top rack (right).

13. ENGINEERING ANALYSIS of DESIGN DRIVERS

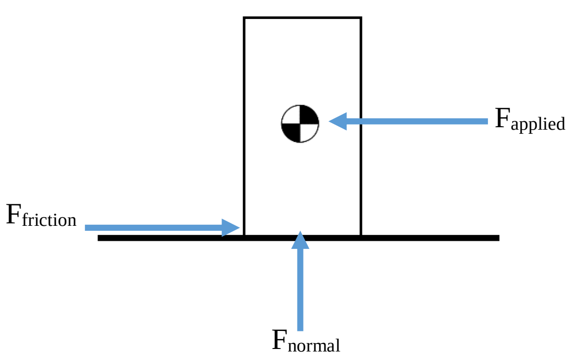
Multiple approaches need to be evaluated in order to ensure our dryer meets our user requirements and key design drivers. Our main focuses of this design review were: fruit storage and sizing of drying chamber, size of the solar absorber, convective heat transfer coefficient, and a mass transfer analysis.

Addition of Heat Mass: Through empirical testing and mock-up construction we were able to quickly decline what seemed to be a promising design. Similarly to adding heat mass in the solar absorber with the addition of sand, we wanted to test if the same principle applied to the drying chamber. This option also seemed promising due to the added weight of the structure. Since Shelek experiences strong gusts of wind, we want to ensure that the fruit dryer would not blow away. The added weight of the sand would ground the fruit dryer, just like how sand is put into basketball hoops to prevent them from falling over during storms.

We constructed two mock-ups with the same drying chamber volume, however, one had legs as at the base with no storage underneath, while the other had a base full of sand that could "heat up" (See Figure 20). The same solar absorber were used on both mockups to ensure that the only test variable was the drying chamber of the device. We used an electric hairdryer on the hottest temperature and fastest flow, and measured the time it took for the inside of the chamber to reach 60 °C. The ambient temperature inside the chamber was initially measured, and a thermocouple was placed inside the chamber for the duration of the test. The temperature inside the drying chamber with the sand did not increase as quickly, and maintained at a temperature of 48 °C. More energy was required to heat the sand first, and then flow into the drying chamber which would increase drying time and cause ineffective heating on cooler days when the sand cannot be completely heated.

Figure 20: Testing of sand as additional heat mass for drying chamber. Results showed slower heat-up time with addition of sand.

Operability of Door: The coefficient of static and kinetic friction, μ_s *and* μ_f, of wood on wood are 0.25 and 0.2 respectively which is relatively low compared to other common materials such as aluminum, glass, and copper[14]. The calculated amount of force required to open a 3kg door would be approximately 7N which is less than the equivalent weight a child can bench of 24 kg[9] (See Figure 21 below). We approximating the bench-press motion of a child would be similar to a child sliding the door open from the side.



$$\sum F_x = 0$$

$$F_{applied} = F_{friction}$$

$$F_{friction} = \mu_s F_{normal}$$

$$F_{normal} = mg$$

$$F_{applied} = \mu_s F_{normal} = 7.4\ N$$

Figure 21: Calculated force required to slide door open is 7.4 N for a 3kg door.

Further analysis of the operability of our design is optional and can be conducted using Siemen's Jack. Now that we have the CAD model complete, we can import our dryer into Jack and ensure that our dryer can be operated as expected.

Sizing of Drying Chamber & Fruit Storage: To determine the optimal size of the dryer, it is required to consider not only the amount of fruit to be dried per day, but also the dimensional constraints of the size of our dryer. Several important factors were included in our design process for the size of the dryer:

1. Based on sponsor information, the maximum size of the dryer must not exceed 4 m^2.
2. Out of 2 tons of total produces from May to September, 1000 kg will be dried.
3. During the harvest season, average sun hours per month from May to September are 300 hours. [15]

Using the information of daily sun hours of 14.2 from May to September (Table 6), the available days to dry fruit per month are estimated as 21, and will be our assumption for analysis. During the entire harvest season, 1000 kg require 105 days to be dried. Therefore, at least 9.5 kg of fruit need to be dried per day.

Table 6: Average daily sun hours in Almaty, Kazakhstan from May to September. [16]

	May	June	July	August	September	Average
Daily Sun (hrs)	14	15	15	14	13	14.2

To determine the specific size of the drying chamber, several assumptions have been made.

1. Calculations based off of an apple with a mass of 150 g. Therefore, 64 apples are required for 9.5 kg of fruit in a day. [17]
2. The diameter of an apple is 100 mm, and each apple will be sliced into 10 pieces of 10 mm thickness, as shown in Figure 19 below.

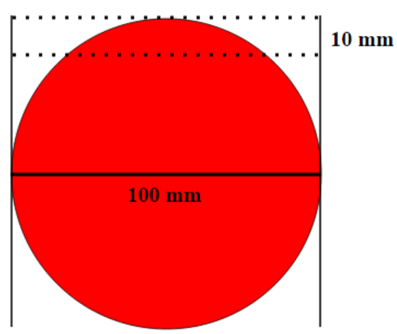


Figure 22: Assumption for the volume of an apple and the size of each slice

Since one apple produces 10 slices, 640 slices will be dried in a day. Using 7 racks, each rack is required to contain 91 slices. The shape of a rack is a square, so the slices will be mounted in 9.5

slices x 9.5 slices. Since the diameter of an apple is 100 mm, one side of a rack needs to be at least 95 cm long. Therefore, the size of the drying chamber will be 1 x 1 m (1 m^2)

***Sizing of Solar Absorber and Drying Time*:** To determine the surface area of the absorber, two important factors were considered: the amount of moisture to be dried, and the duration of drying process. Based on the optimal water moisture content for the fruit quality, 60 % of water needs to be dried out of the fruit. Also, the average sun hours available per day is 14.2 (Table 6 pg.20).

Using the information above, the size of the absorber is determined by Eq. 2 below, where

$$\delta = \frac{m h_{fg}}{I A_c \eta_c \eta_d} \quad [17] \qquad \text{(Eq. 2)}$$

δ = drying time [sec]
m = is the amount of moisture to be dried $[kg]$,
$h_{fg} = 2442.3 \left[\frac{kJ}{kg}\right]$ is the heat of vaporization of water at 25 °C,
$I = 227.9\ [W/m^2]$ = solar insolation in Almaty from May to September [18]
$A_c\ [m^2]$ = the area of the solar absorber,
η_c = the efficiency of the absorber
η_d = efficiency of the drying chamber

Assuming the efficiency of the absorber and drying chamber be 100 %, and the amount of moisture to be dried be 5.7 kg (60 % of 9.5 kg), $\delta = \frac{61084.3}{A_c}\ [sec]$.

Since the constraint in the area in Shelek is 2 x 2 m (4 m^2), and the chamber size is 1 x 1 m (1 m^2) already, few options remains. The absorber will be positioned in angle, so the area of the absorber is 1 x 1.5 m (1.5 m^2).

The estimated drying duration with the 1.5 m^2 absorber, then, is 40722.8 sec (11.3 hr).

Sizing of Solar Absorber Inlet: Since our design only uses passive solar energy due to unavailability of electricity, it is not possible to use electric controllers to maintain air temperature. To regulate the maximum air temperature, and prevent the potential damage in fruit quality, the air flow rate will be controlled by changing the area of the air inlet.

Based on the average wind velocity information in Almaty, Kazakhstan, several assumptions were built.

1. Average wind speed in Almaty from May to September is 7 mph (3.13 m/s). [19]
2. The wind speed determines the air velocity, and is constant.
3. All solar insolation will be used to heat up the air in the absorber, and no heat loss exists
4. Based on the previous engineering analysis, the solar insolation is 227.9 $[W/m^2]$, and the area of the absorber is 1.5 $[m^2]$. The heat transfer into the absorber is 0.341 $[kW]$.

Applying a control volume around the absorber (see Fig. 20, pg 20), the established thermodynamic equation to solve is:

$$\dot{Q} = \dot{m} C_p (T_o - T_i) \qquad \text{(Eq. 3)}$$

The relationship between the mass flow rate and the area of the inlet vent will be:

$$\dot{m} = \rho A_i v \quad \text{(Eq. 4)}$$

where, the air density at 25 °C, $\rho = 1.2\ [kg/m^3]$, the area of the inlet air vent $A_i\ [m^2]$, and the inlet air velocity $v = 3.13\ [m/s]$.

$$T_o = T_i + \frac{\dot{Q}}{\dot{m}C_p} = T_i + \frac{\dot{Q}}{\rho v C_p} \cdot \frac{1}{A_i} \quad \text{(Eq. 5)}$$

As shown in Eq. 5, the outlet temperature is inversely proportional to mass flow rate and area of the inlet vent. To create the outlet air temperature of 60 °C from 25 °C inlet air, it is required to have the inlet air vent $A_i = 0.0027\ [m^2]$. As the inlet air vent size increases, the mass flow rate into the absorber under the constant air velocity will increase. This will decrease the outlet temperature under the constant heat transfer of solar energy. For example, If the inlet air vent size increases to 0.0036 $[m^2]$, the outlet temperature of the air will be 50 °C. Therefore, our design for the absorber will implement the adjustable inlet air vent to control the inlet air temperature indirectly.

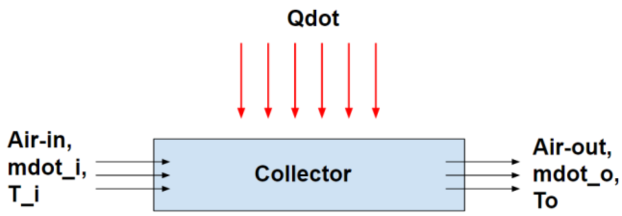


Figure 23: Control volume around the absorber with solar absorption to increase the temperature of the air.

Convection Heat Coefficient: To model the heat/mass transfer that occurs within the dryer, the convection heat coefficient of air (h_c) is required. To find the specific value of the coefficient for our application, dimensional analysis has been performed.

Assuming the heated fluid (air) moves above the flat plate in the solar absorber, Nusselt number (Nu), Rayleigh number (Ra), Grashof number (Gr), and Prandtl number (Gr) are defined in Eq. 6, 7 and 8. [18] All properties of air were evaluated at T_f, which can be found in Appendix C. The air and produce temperature were assumed as 60, and 25 °C respectively [20].

$$Nu_L = \frac{h_c D}{K_a} = 0.15 Ra^{\frac{1}{3}} \quad \text{(Eq. 6)}$$

$$Ra = Gr_L \cdot Pr_L, \;\; Gr = \frac{g\beta\rho_a^2 D^3 \delta T}{\mu}, \;\; Pr = \frac{\mu C_p}{K_a} \quad \text{(Eq. 7)}$$

$$\delta T = T_a - T_p, \;\; T_f = \frac{T_a + T_p}{2} \quad \text{(Eq. 8)}$$

$D = \frac{length+width}{2}\ [m] = characterestic\ dimenion,$
$g\ = gravity[m/s^2],$
$T_a = ambient\ air\ temperature\ \ [K]$
$T_p = fruit\ produce\ temperature[K]$
$T_f = average\ film\ temperature\ [K]$

$\beta = \frac{1}{T_f} =$ thermal expansion coefficient $[1/K]$
$\rho_a =$ density of air $[kg/m^3]$
$\mu =$ dynamic viscosity of air $[kg/m \cdot s]$
$C_p =$ specific heat of air $[kJ/kg \cdot K]$
$K_a =$ conductivity of air $[W/m \cdot K]$

Therefore,

$$h_c = \frac{K_a}{D}(0.15)Ra^{\frac{1}{3}} \quad \text{(Eq. 9)}$$

The calculated convection heat coefficient (h_c) is 5.89 $[W/m^2 \cdot K]$.

Mass Transfer Analysis
During the drying process of fruit, external and internal mass transfer occur due to the gradient of partial pressures of water vapor. To calculate the amount of evaporation at the surface of the fruit, several assumptions have been made for simpler analysis:

1. At the moment of evaporation, the ambient temperature is 60 °C.
2. The fruit temperature internally and at the surface are uniform at 25 °C.
3. Evaporation occurs at the surface temperature of the fruit.
4. Diffusion mechanism and porosity of the fruits are not included in this analysis.
5. Heat loss through the dryer chamber walls is neglected.

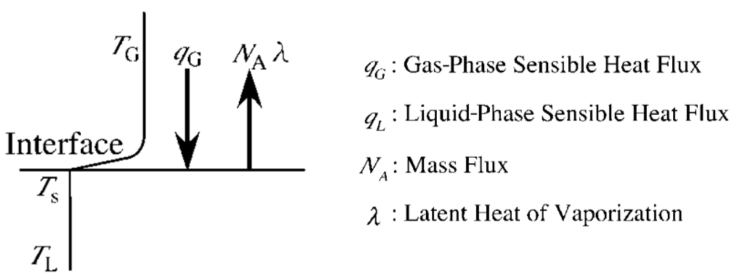


Figure 24: Schematics of heat/mass transfer at the surface of the fruits. [21]

$$q_G = \lambda \cdot N_A \quad \text{(Eq. 10)}$$

$$q_G = h_c(T_a - T_p) \quad \text{(Eq. 11)}$$

$$N_A = \frac{h_c}{\lambda}(T_a - T_p) \quad \text{(Eq. 12)}$$

whereq_G $[W/m^2]$ is the gas-phase sensible heat flux, and $\lambda = 2442.3\ kJ/kg$ is the latent heat of vaporization at 1atm, 25 °C. The calculated mass flux is $N_A = 8.44 \times 10^{-5}$ $[kg/m^2 \cdot s]$. On a 1 m^2rack, the entire mass flow rate will be 8.44×10^{-5} $[kg/s]$.Since our target amount of moisture is 60%, 5.7 kg of water need to be evaporated. Therefore, the total time duration of drying is expected to be 67535.5 sec = 18.8 hr.

Limits of Analysis and Potential Improvements**:** Based on two different analysis, we had a varied drying time of 11.3 to 18.8 hours. Several possible reasons explain the large variation in our analysis:

1. Unlike the assumption that heated fluid (air) moves across the flat plate (fruit), the air will dry the fruit through up-flow, through the rack and fruit, which will affect the convection heat coefficient.
2. Assumptions do not include the heat loss or heat addition through the walls of the chamber and absorber, which will affect the drying times.
3. To calculate the convection heat coefficient, we assumed that the air temperature be 60 °C, and the fruit temperature be 25 °C. This also might increase the error in the analysis.

Moving forward, more accurate theoretical analysis will need to be obtained by researching the following:

1. Finding the accurate model of the Nusselt number for drying mechanism will help increase the accuracy of the convection heat coefficient.
2. Diffusion mechanism within the fruit slices and porosity of the fruit.
3. Error will be minimized by including the potential heat loss/addition through the walls of the chamber and absorber.

Moving forward with our engineering analysis, we have created a verification and validation plan (Appendix G) to test our design and see how our current base design meets our engineering specifications and how adjustable ventilation and inlet flow will affect our drying time.

14. RISK and FAILURE MODE and EFFECTS ANALYSIS

Tables 7 and 8 below explain the risks and failure modes of our fruit dryer.

Table 7: Risk Analysis of Fruit Dryer

Hazard	Hazardous Descriptions	Likelihood	Impact	Technical Performance	Schedule	Cost	Action to minimize hazard
Burning	In the peak time of solar energy absorption, the temperature of the dryer and air would reach about 60 C. It might have a potential danger to burn the users' body	Low	Minor	Minimal or no technical performance	Minimal or no impact	Minimal or no impact	Possible parts which will have contact with the users must have low thermal conductivity
Food Spoilage	If food sits out for a long time without properly drying at a high temperature or if the food cools down overnight and moisture builds up within the drying chamber, food can potentially spoil	Medium	Serious	Minimal or no technical performance	Able to meet key date	Budget or unit cost increase	Materials (sand or rock) to keep the temperature of the air constant longer.

Contamination	If vents on the drying chamber as well as the inlet is not properly sealed with mesh, sand or insects may potentially disturb the fruit	Low	Minor	Minor reduction in technical performance or supportability	Minimal or no impact	Budget or unit cost increase	Proper design of the air paths and prevention method (mesh) can prevent the risk
Hazard	**Hazardous Descriptions**	**Likelihood**	**Impact**	**Technical Performance**	**Schedule**	**Cost**	**Action to minimize hazard**
Falling Racks	When racks are lifted with too much fruit on them, the load could hinder the user's ability to hold the racks and this could potentially lead to the rack being dropped in a manner that would harm the user	Low	Minor	Significant degradation in technical performance or major shortfall in supportability	Able to meet key date	Budget or unit cost increase	Accurate design and theoretical analysis can prevent the failure of the drying rack
Structure Collapse	When trying to move the dryer it may collapse on the user or it may just collapse from failure of structure	Low	Serious	Significant degradation in technical performance or major shortfall in supportability	Able to meet key date	Budget or unit cost increase	Accurate design and theoretical analysis can prevent the failure of the structure
Door Shutting on User	When opening the door and operating racks, door may swing closed and contact user	Low	Moderate	Significant depredation in technical performance or major shortfall in supportability	Able to meet key date	Budget or unit cost increase	Accurate design and theoretical analysis can prevent the door from swinging back

The highest risk with the most significant impact for our design is food spoilage. Food spoilage can occur if the air inside the chamber is too moist or if temperature fluctuates. There is a medium likelihood of this failure, and consequences can be fatal in case food with bacterial growth is consumed. Another consequence includes loss of produce and profits if a batch of produce spoils in the dryer and cannot be consumed. In order to minimize this risk, we have incorporated adjustable ventilation into our system. Based on testing that we will conduct as the term progresses and additional theoretical calculations, we can indicate in our user guide the correct amount of ventilation given the ambient temperature outside. Adjusting ventilation will effect airflow and temperature inside the drying chamber, which if controlled correctly, will reduce food spoilage.

Another preventative measure to reduce the risk of food spoilage is to insert a material inside the drying chamber that will act as a moisture absorber. Typically, silica gels are used to maintain dry air in surroundings, however, we must use the correct materials based on food regulations. Moving forward, we must familiarize ourselves with health codes in order to determine if there are any materials we can use for minimizing moisture that can be safe to handle and place around food.

Additionally, as a group we were concerned with the risk of a hinged door closing on a user while operating the racks. After conducting the risk assessment, we redesigned our door mechanism to consist of sliding doors rather than a pull door. The risk with a sliding door reduces to pinching of fingers which is a significantly lower impact than an entire door shutting on the body of the operator during a strong gust of wind. Having the sliding door design allows for a less sever risk of injury (finger pinch) which is an acceptable risk for our design.

Table 8: FMEA of Fruit Dryer

Item	**Function**	**Potential Failure Mode**	**Potential Effects of Failure**	**Severity of Effect**	**Potential Causes of Failure**	**Occur within year**	**Current Design Controls**	**Detection**	**RPN**	**Recommended Action**
Drying Racks	Holding the fruit while being dried	Fracture of drying racks	Amount of dried fruit decreases	7	Heavy weight of loaded fruit	3	Perform strength calculation	1	21	Research/choose appropriate material and design. (Safe for food)
		Yield of the mesh on the drying racks	Amount of dried fruit decreases	7	Heavy weight of loaded fruit	3	Perform strength calculation	1	21	
	Absorbing solar energy to	Air temperature exceeds the maximum level which fruit can withstand	Burned fruit and decreased fruit quality	7	Excessive amount of sunlight	7	Adjustable vent system	1	49	Guide users to take proper actions to cope with the failure

Solar Absorber	dry the moisture from the fruit	Fracture of absorber	Drying process stops	8	External impacts (storm, rain) or decrease in material durability	2	Perform strength calculation	1	16	Choose appropriate seal for materials in solar absorber, research weather and environment effects
Solar Absorber	Absorbing solar energy to dry the moisture from the fruit	Damaged mesh	Decreased fruit quality	7	External impacts (storm, rain) or decrease in material durability	2	Choose proper material	1	14	Choose appropriate seal for materials in solar absorber, research weather and environment effects
		Dampening of sand used to increase temperature	Increase in drying time, potential spoilage of fruit, build up of bacteria	8		1	Durable seal within solar absorber	1	8	
Roof	Absorb solar energy, and prevent rain from damaging the dryer	Leakage of rain into the dryer		7	External impacts (storm, rain) or decrease in material durability	4	Choose proper material	3	84	Choose appropriate seal for materials, research weather and environment effects
Handle	Help users move the dryer to the target location	Fracture of the grip	Decrease mobility of the dryer	4		3	Perform strength calculation	1	12	

15. FURTHER WORK

This project will continue to be improved through the University of Michigan's BlueLab student design team. The team will continue working with the to-scale prototype to test in summer conditions, install additional features such as adjustability of ventilation and initial airflow, and potentially look at natural (and safe) materials to absorb moisture in the chamber such as coal or silica gels.

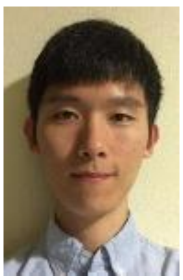
16. MANUFACTURING PLANS and BILL of MATERIALS

The complete bill of materials can be found in Appendix D and a list of manufacturing plans for each part can be found in Appendix E of the report.

17. AUTHORS

The following team member make up Team 12 of the ME 450 Senior Design class. We are all very excited to be working on this project.

Donovan Colquitt is pursuing his Bachelor's degree with a concentration in energy during his last year at the University of Michigan. He has been interested in working on Sustainable Energy Systems and has spent his last summer working in GM's Brownstown Battery Assembly Plant. Throughout his years as an undergraduate, Donovan has taken leadership roles in the National Society of Black Engineers, the Michigan Gospel Chorale and the Center for Educational Outreach. He is interested in pursuing a graduate degree in higher education administration.



Iljin Eum is finishing his undergraduate study in Mechanical Engineering in December 2015, and will start his Master in January 2016 here at the University of Michigan. His interests lie in thermal science: thermodynamics, heat transfer, and IC engines. He has been involved in several projects related to the internal combustion and aftertreatment system of engines. He is pursuing his research in thermal science.

Caitlin Millis is entering her final year at the University of Michigan pursuing a Bachelor's degree in Mechanical Engineering. She is interested in the Oil and Gas Industry and spent the past summer interning for Schlumberger on a drillship in the Gulf of Mexico. Her most valuable learning experience was a Well Control class that was required to work offshore. She also previously interned with Bosch, an automotive supplier, in their braking division. Caitlin has been heavily involved with her sorority, Phi Sigma Rho, and is currently serving the second half of her term as Chapter President. She is an avid Detroit sports fan and hopes to watch the Tigers play in every ballpark.

Sarah Yaqub is completing her final semester at the University of Michigan with a degree in Mechanical Engineering. The past four years, she has been involved in the Society of Women Engineers (SWE), in which her largest leadership role was directing the 30th Annual SWE/TBP Career Fair. She is a sports fanatic, and played rugby for the University of Michigan Women's Team as both a flanker and scrum half. Sarah has previous internship experience in the automotive and biomedical fields, and hopes to pursue a career in the biomedical field. Wherever she ends up, Sarah would like to be a market gardener and volunteer in her local Food Policy Council.

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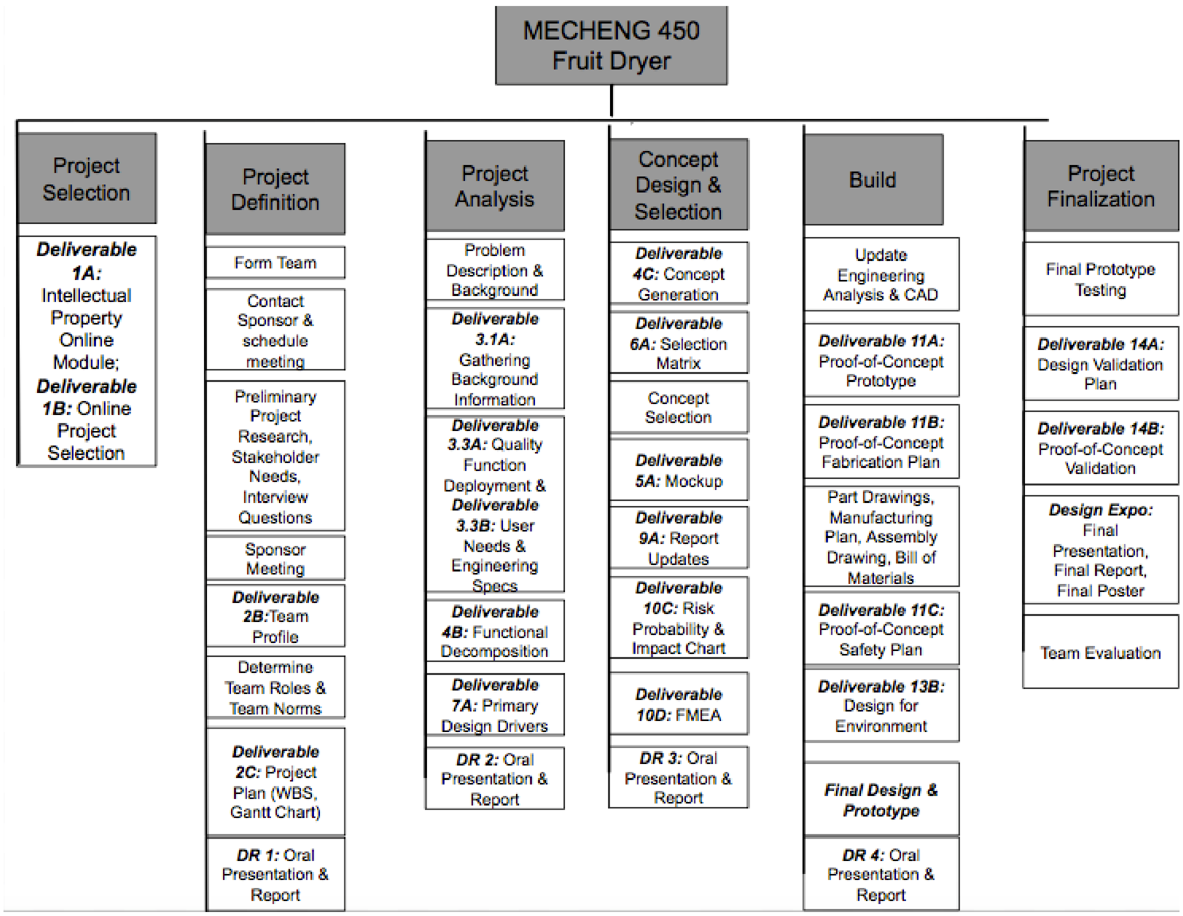
APPENDICES

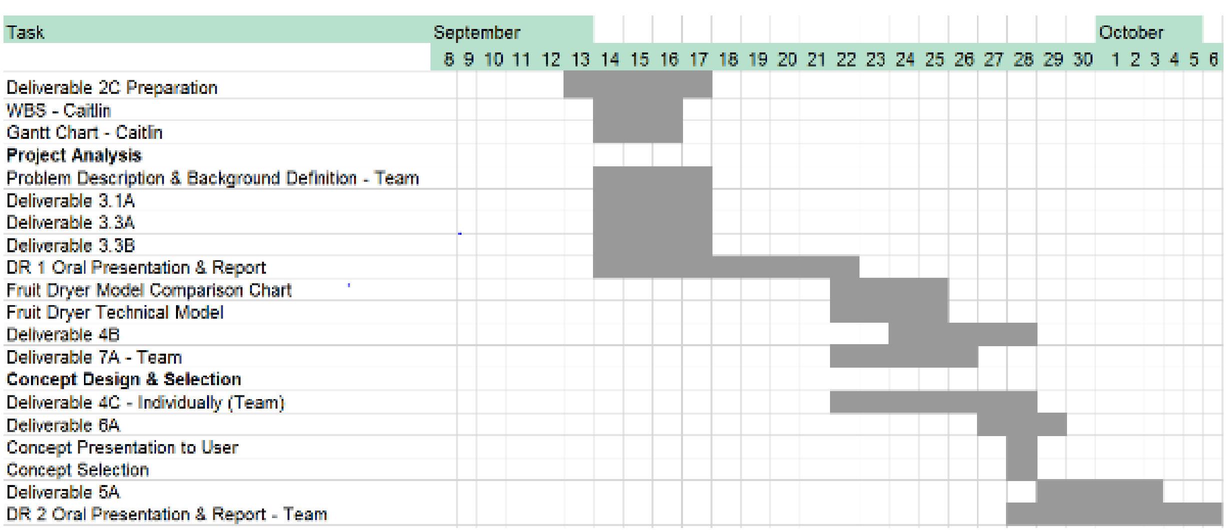
Appendix A

The following Appendix includes documents such as a work breakdown structure (WBS), Gant Chart, and RASIC table for our time management and tasks between Design Review 1 through Design Review 5.

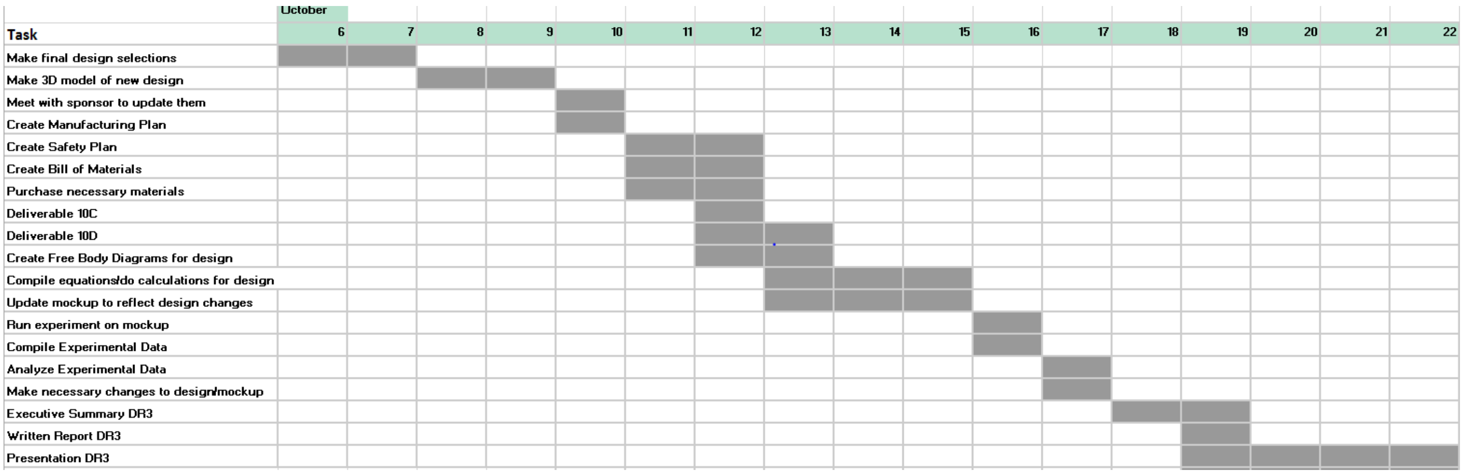
Work Breakdown Structure, DR1-DR5



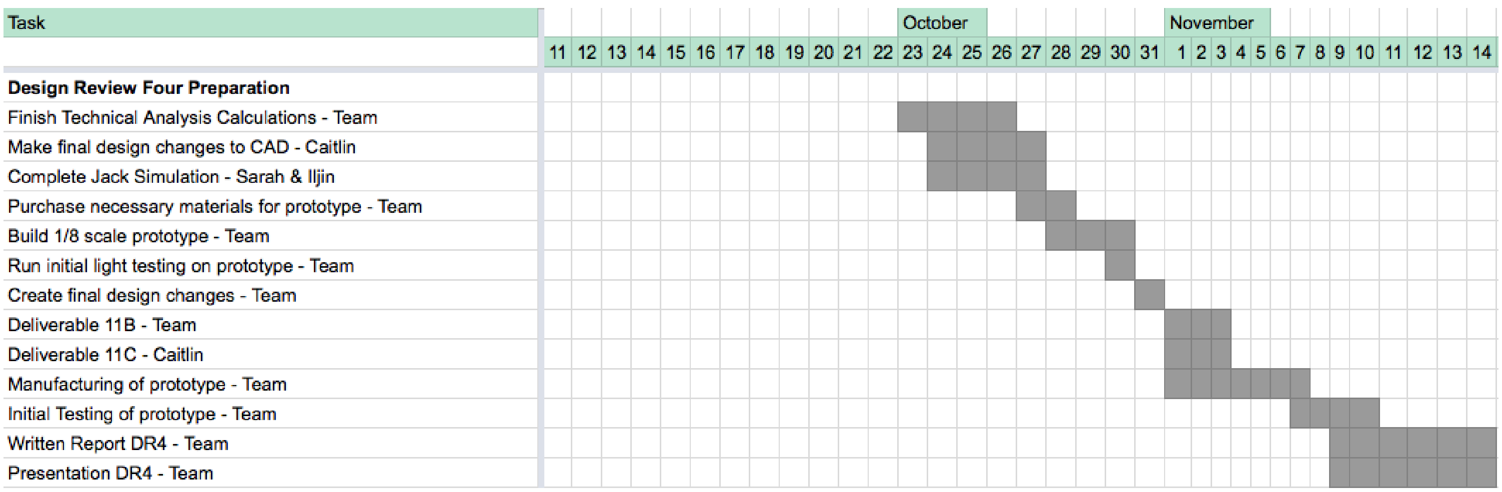
Gantt Chart, DR 1-2



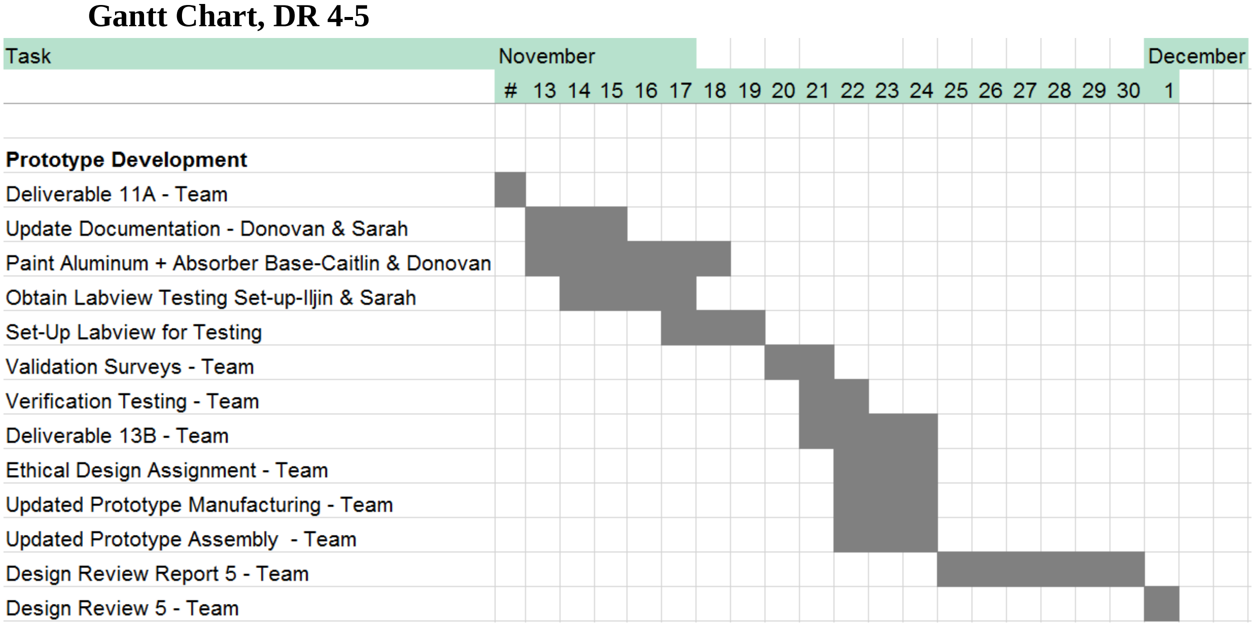
Gantt Chart, DR 2-3



Gantt Chart, DR 3-4



Gantt Chart, DR 4-5



RASIC Table, DR1

RASIC Chart	Team Member/Staff				
Task	Caitlin	Donovan	Iljin	Sarah	Sponsor
Deliverable 3.3A (QFD)-Ongoing	S	A	R	A	I
Deliverable 3.3B (User Needs and Specs)-Ongoing	R	A	S	A	I
Deliverable 4B (Functional Decomposition) Define overall function, subfunctions, and inputs of indirect solar fruit dryer. Use the Zimbabwe model as base. *Sept 24th*	A	S	R	A	I
Meet with Rachel to learn about fruit drying techniques.	A	A	S	R	I
Deliverable 4C (Concept Generation) Each member will design a concept based on a combination of different design he/she finds useful, beneficial. Inclusion of a "creative" solution to main problems of overnight drying and sunlight exposure should be taken into consideration. *Sept 29th*	R	R	S	S	S,I
Deliverable 7A (Primary Design Drivers) Research standards for current food dryer to be sold. Look at industry-standards for quality testing of dried fruit (GFSI, OSHA) *Oct 1*	S	S	R	R	S,I
Determine which materials are feasible for our design (based on cost and availability). Stated they don't have any materials, communicate with Ardak/sponsor, and research.	R,A	R,A	S	S	I,C
Determine size of fruit dryer based on amount gardeners would like to dry at once.	S,A	S,A	S,A	R	
Deliverable 6A Create a Pugh chart on excel based on available concepts. Selection must be approved by all team members. Fusion of designs is an option. (Selection Matrix) *Oct 1*	S,A,R	S,A	S,A	S,A	I
Determine size and scaling for prototype based on finalized size of proposed design.	S	S	R	R	
Check inventory of ME shops, labs for materials we can use to construct prototype. Other members can check tools, material access outside of classroom.	S	R	S	S	S,I
Order materials we need for prototype construction.	S	S	S	R	
Deliverable 5A (Mockup)Complete online module *October 6th*	R,A	R,A	R,A	R,A	I,C
Deliverable 9A (Report Updates)	A	A	A	R	I

R = Responsible, A = Approval, S= Support, I = Inform, C = Consult

RASIC Table DR 2-4

RASIC Chart	**Team Member/Staff**				
Task	Caitlin	Donovan	Iljin	Sarah	Sponsor
Deliverable 3.3A **(QFD)-Ongoing**	S	A	R	A	I
Deliverable 3.3B **(User Needs and Specs)-Ongoing**	R	A	S	A	I
Deliverable 4B **(Functional Decomposition)**	A	S	R	A	I
Meet with Rachel to learn about fruit drying techniques.	A	A	S	R	I
Deliverable 4C **(Concept Generation)**	R	R	S	S	S,I
Deliverable 7A **(Primary Design Drivers)**	S	S	R	R	S,I

Determine which materials are feasible for our design (based on cost and availability). Stated they don't have any materials, communicate with Ardak/sponsor, and research.	R,A	R,A	S	S	I,C
Determine size of fruit dryer based on amount gardeners would like to dry at once.	S,A	S,A	S,A	R	
Deliverable 6A Create a Pugh chart on excel based on available concepts. Selection must be approved by all team members. Fusion of designs is an option. (Selection Matrix) Oct 1	S,A,R	S,A	S,A	S,A	I
Determine size and scaling for prototype based on finalized size of proposed design.	S	S	R	R	
Check inventory of ME shops, labs for materials we can use to construct prototype. Other members can check tools, material access outside of classroom.	S	R	S	S	S,I
Order materials we need for prototype construction.	S	S	S	R	
Deliverable 5A (Mockup)Complete online module October 6th	R,A	R,A	R,A	R,A	I,C
Deliverable 9A (Report Updates)	A	A	A	R	I
Deliverable 3.3A (QFD)-Ongoing	S	A	R	A	I
Deliverable 3.3B (User Needs and Specs)-Ongoing	R	A	S	A	I
Deliverable 10C (Risk Probability & Implact Chart)	A	S	R	A	I
Detailed engineering design of absorber, drying chamber, and chimney	A	A	S	R	I
Deliverable 10D (FMEA)	R	R	S	S	S,I
CAD	S	S	R	R	S,I
Determine which materials are feasible for our design (based on cost and availability). Stated they don't have any materials, communicate with Ardak/sponsor, and research.	R,A	R,A	S	S	I,C
Determine size of fruit dryer based on amount gardeners would like to dry at once and also based on size,weight of operators.	S,A	S,A	S,A	R	I
Second Mock-Up	S,A,R	S,A	S,A	S,A	I
Determine size and scaling for prototype based on finalized size of proposed design.	S	S	R	R	I
Order materials we need for prototype construction.	S	S	S	R	I
Manufacturing Plans and Drawings	R,A	R,A	R,A	R,A	I,C
Approval Sheets for drawings	R,A	R,A	R,A	R,A	I
Safety Sheets for construction	R,A	R,A	R,A	R,A	I
Deliverable 9A (Report Updates)	A	A	A	R	I
Finish Technical Analysis Calculations	R	R	R	R	I

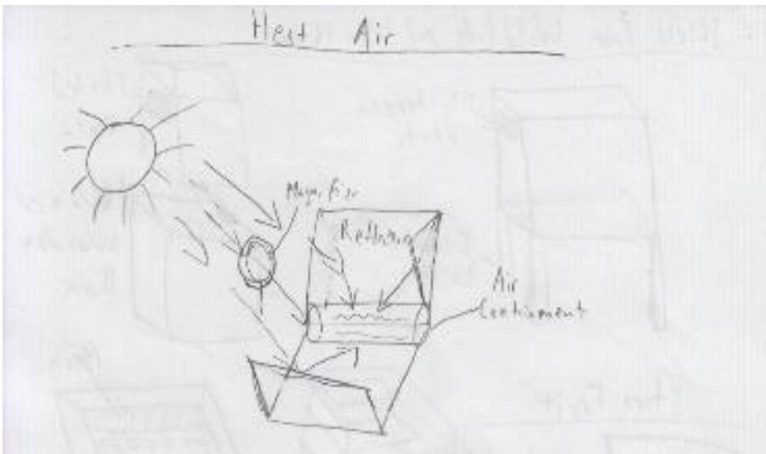
Final CAD Design Changes	R	A,S	A,S	A,S	I
Complete Simulation	A,S	A,S	R	R	I
Purchase prototype materials	S	R	S	R	I,C
Build 1/8 scale prototype	R,A	R,A	R,A	R,A	I,C
Run initial light testing on small prototype	R,A	R,A	R,A	R,A	I,C
Deliverable 11B	R,A	R,A	R,A	R,A	I
Deliverable 11C	R	A	A	A	I
Manufacturing full-scale prototype	R,A	R,A	R,A	R,A	I,C

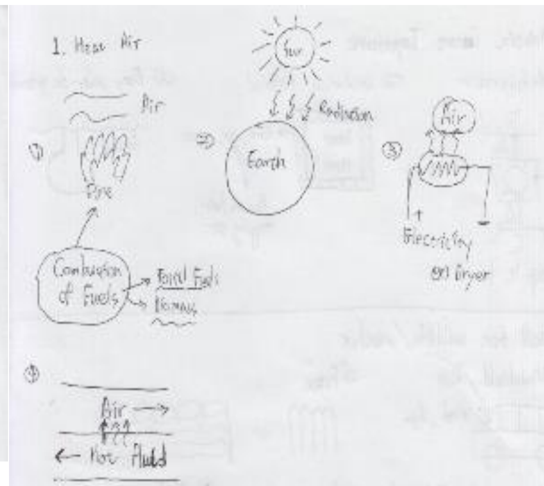
APPENDIX B

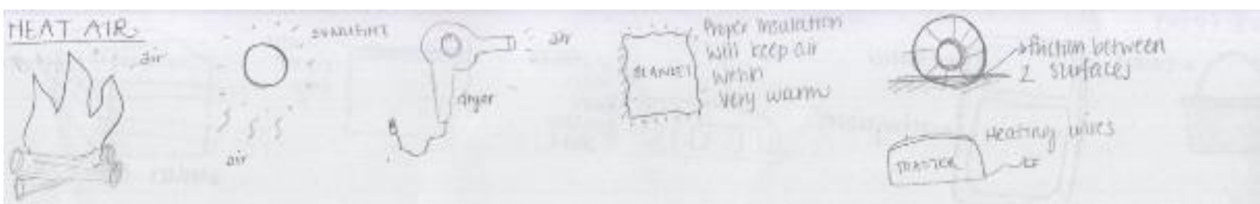
B.1 First Round Concept Generation

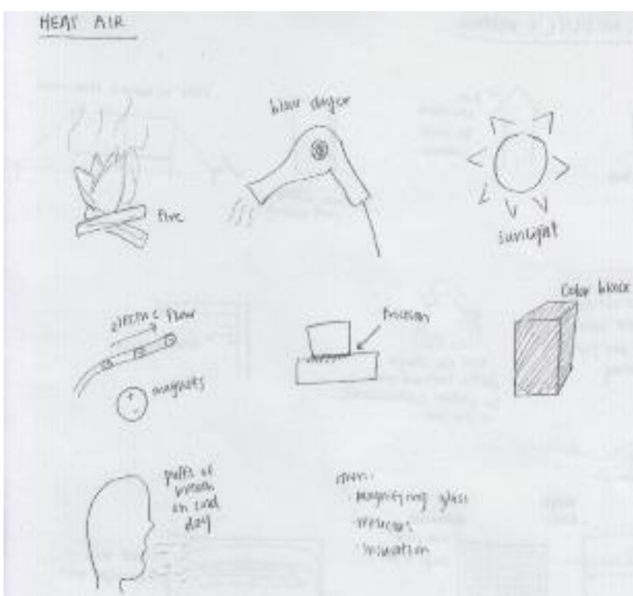
These next images are first-round thought process into our concept generation process in which we focus on ideas that can accomplish each functional group. The ideas did not have to relate specifically to our design.

Functional Decomposition: Heat Air

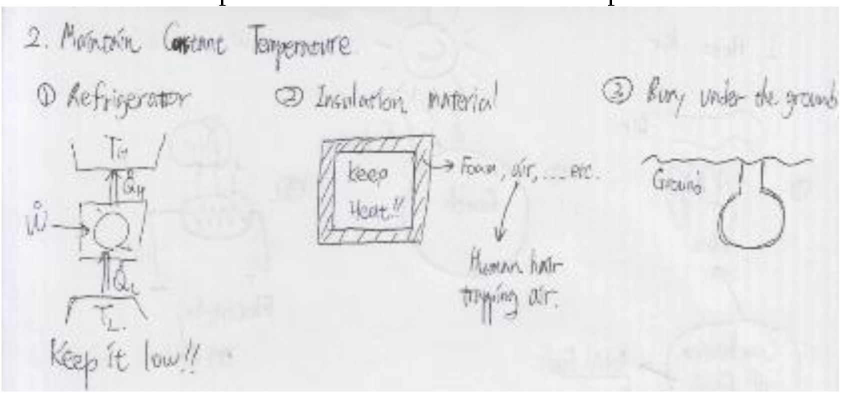


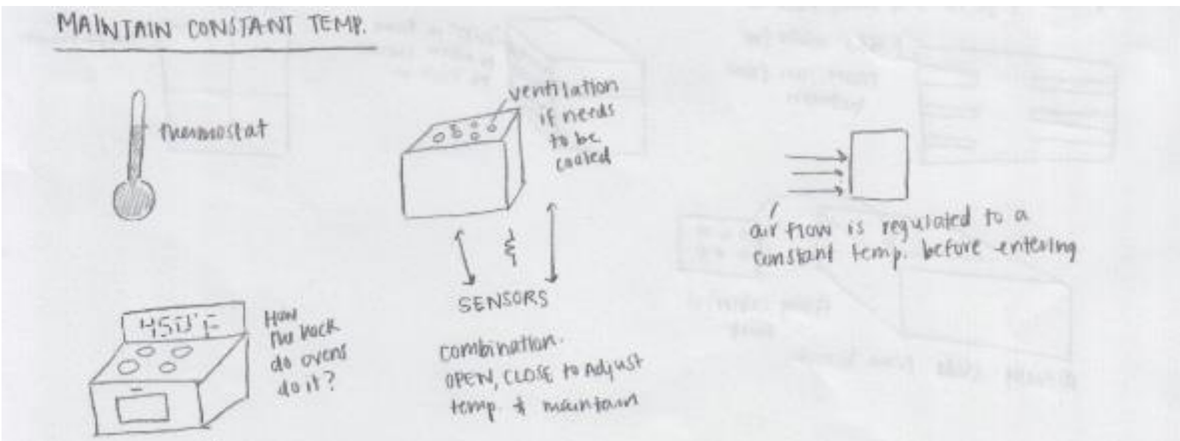


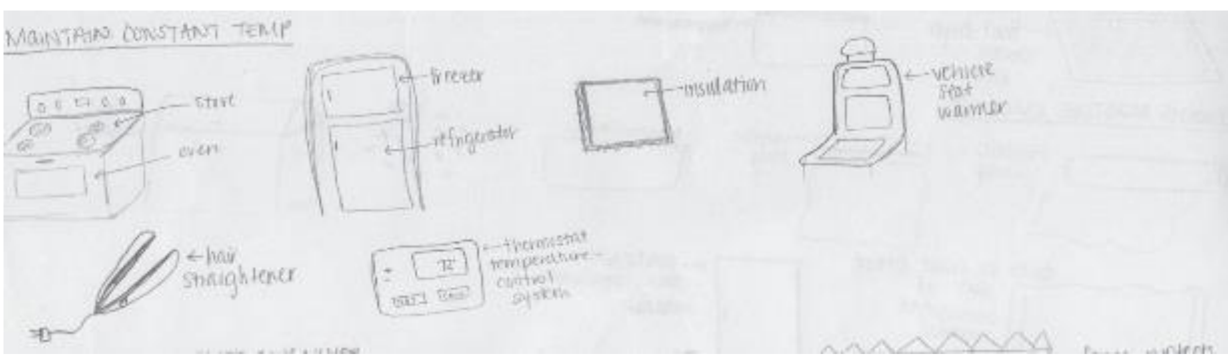




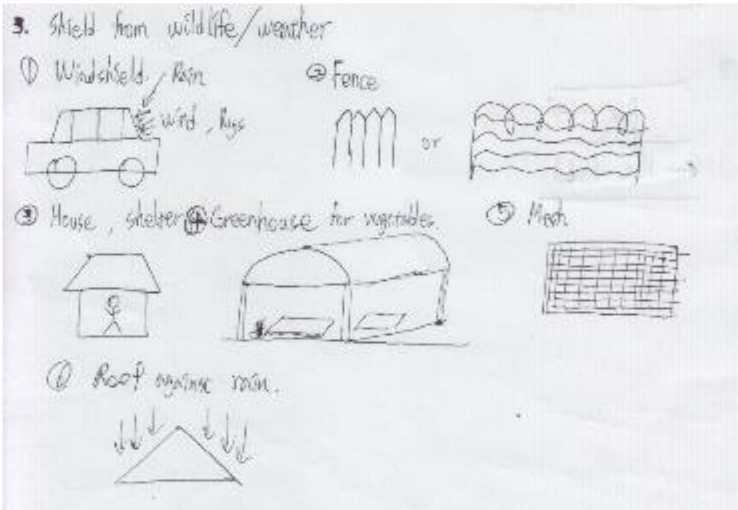
Functional Decomposition: Maintain Constant Temperature

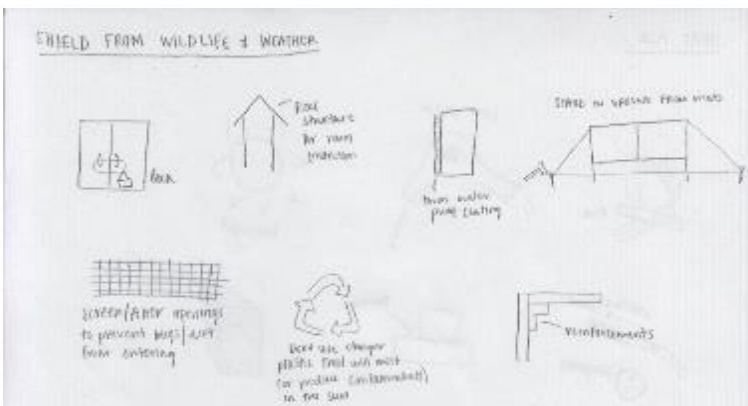


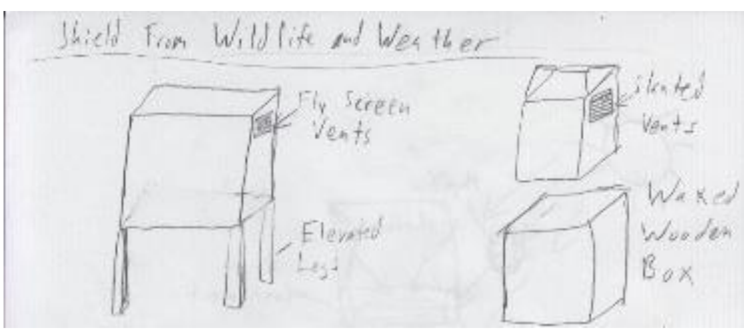


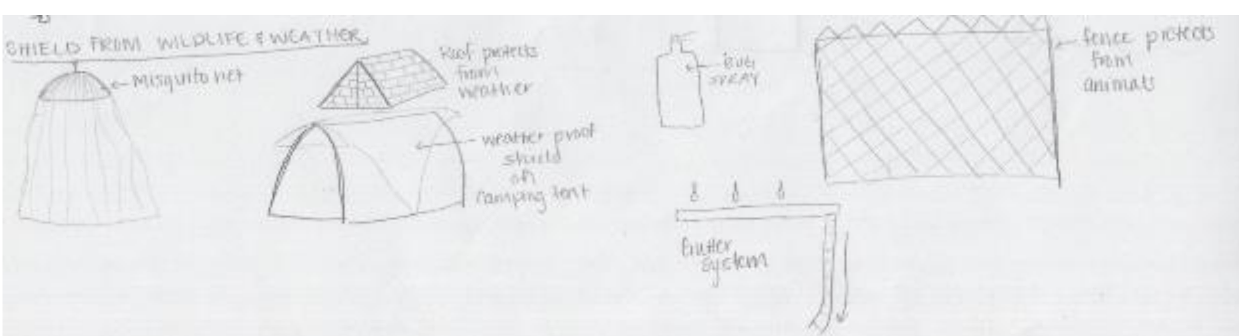


Functional Decomposition: Shield from Wildlife/Weather

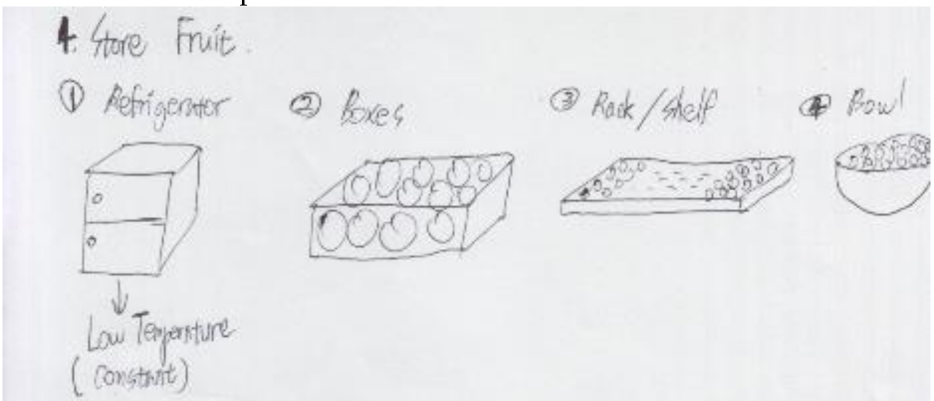


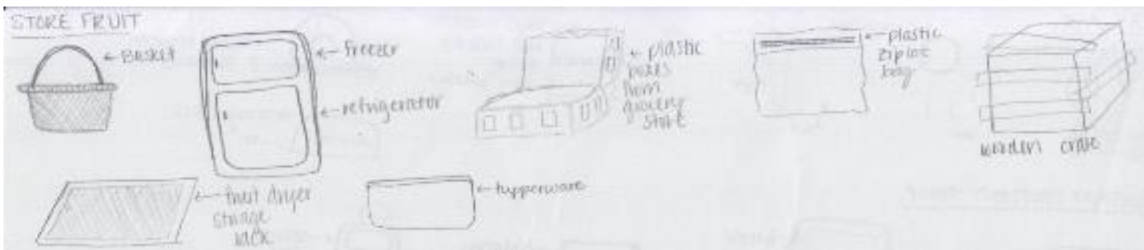


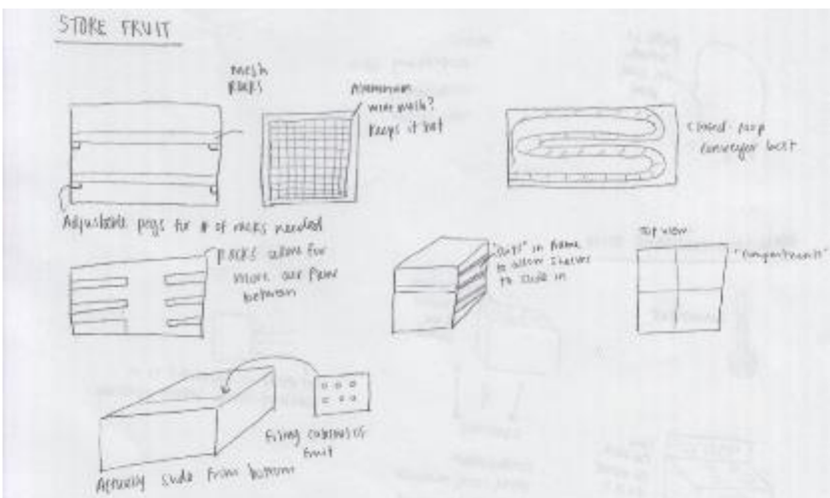




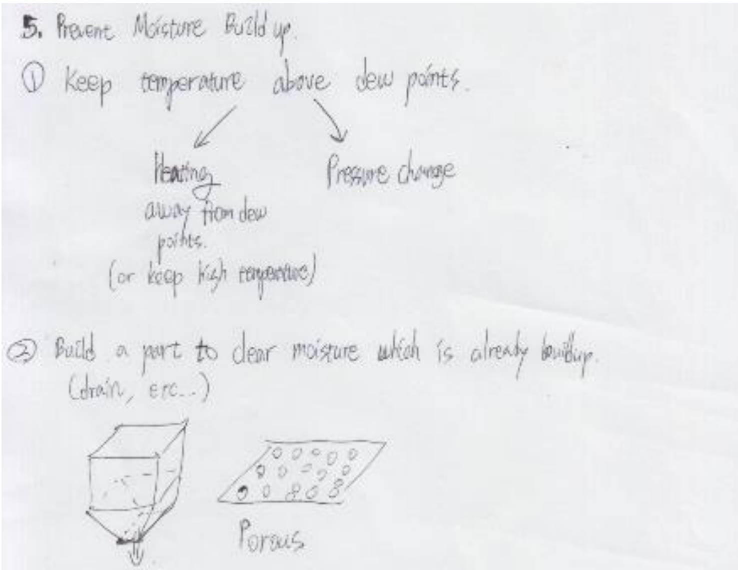
Functional Decomposition: Store Fruit

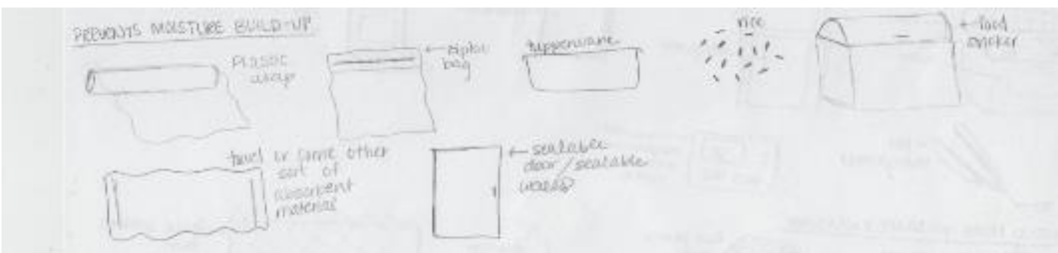


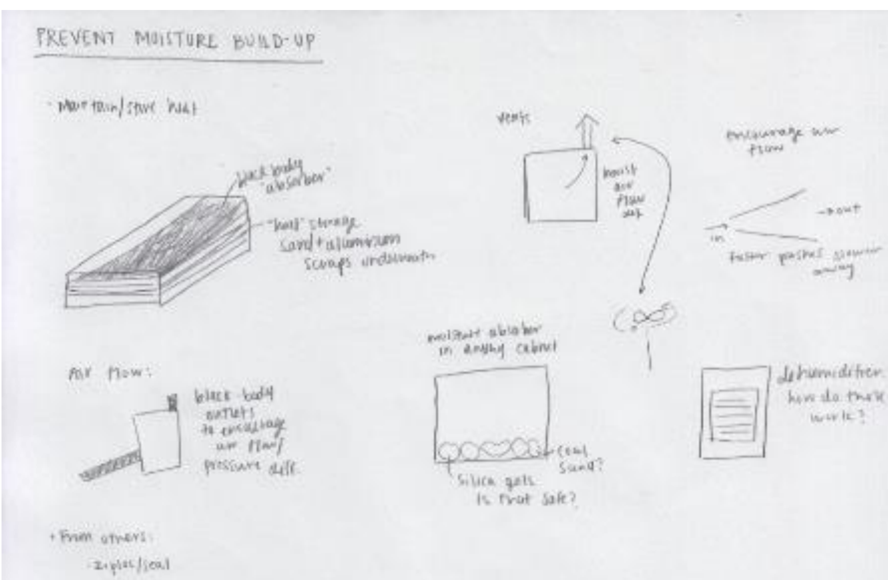




Functional Decomposition: Prevent Moisture Build Up

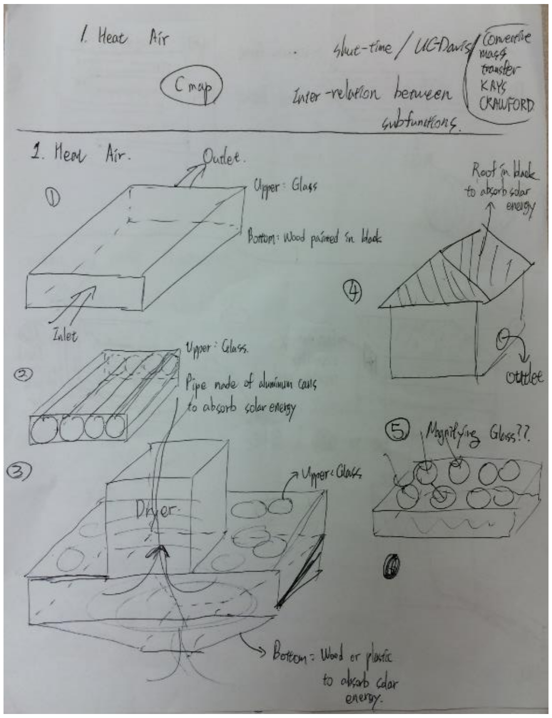


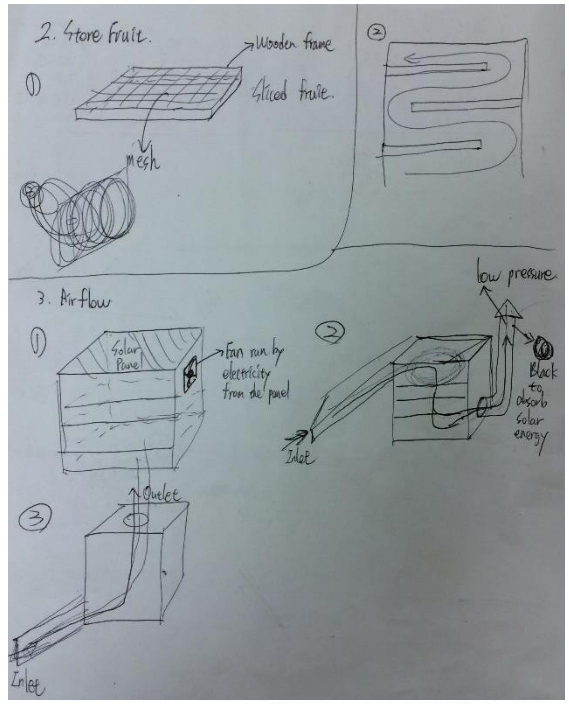


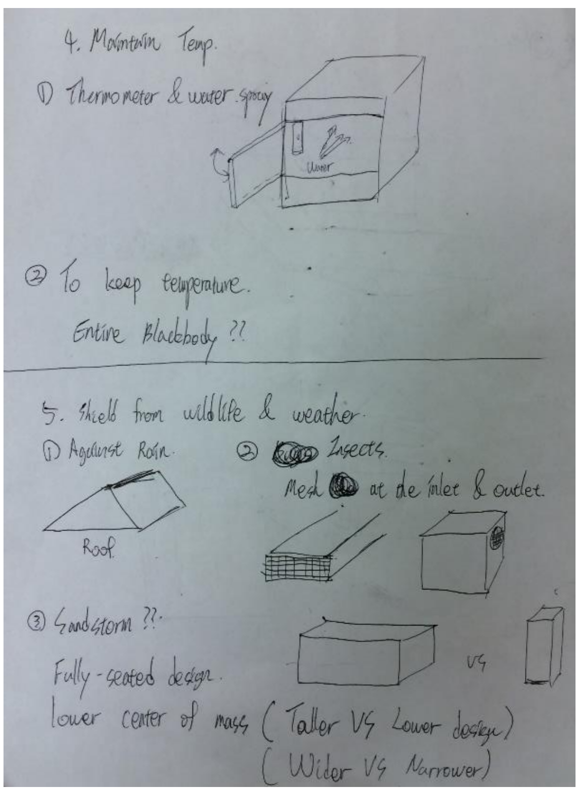


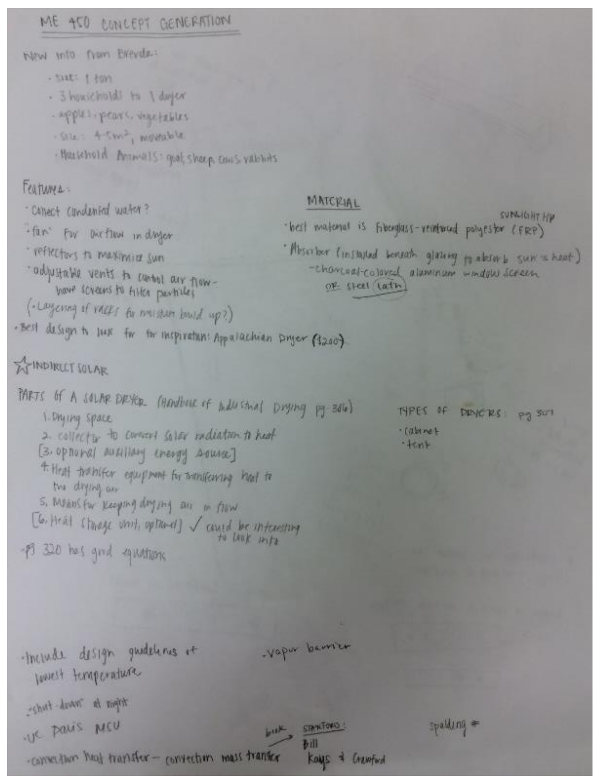
B.2 Second Round Concept Generation

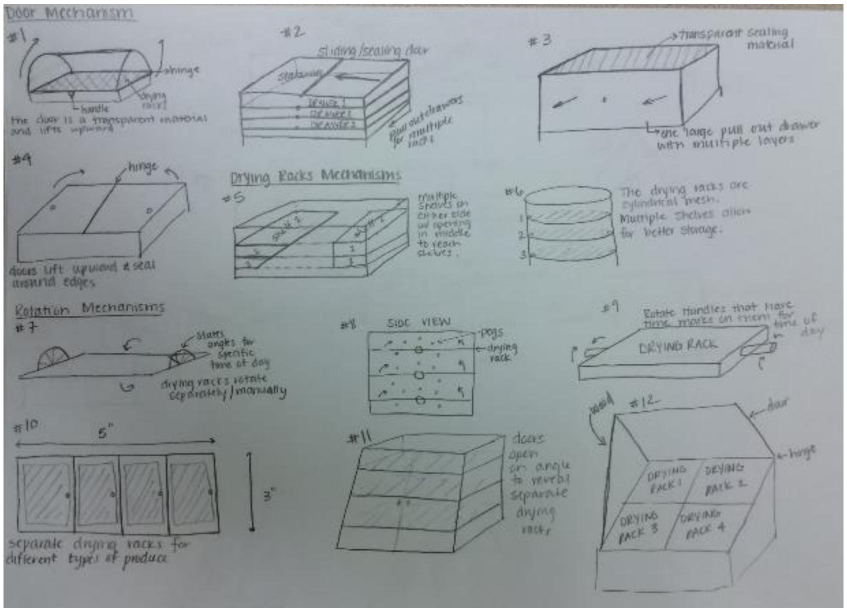
The next images show the concepts generated by each group member that pertain specifically to our design and work to achieve each of our sub functions.

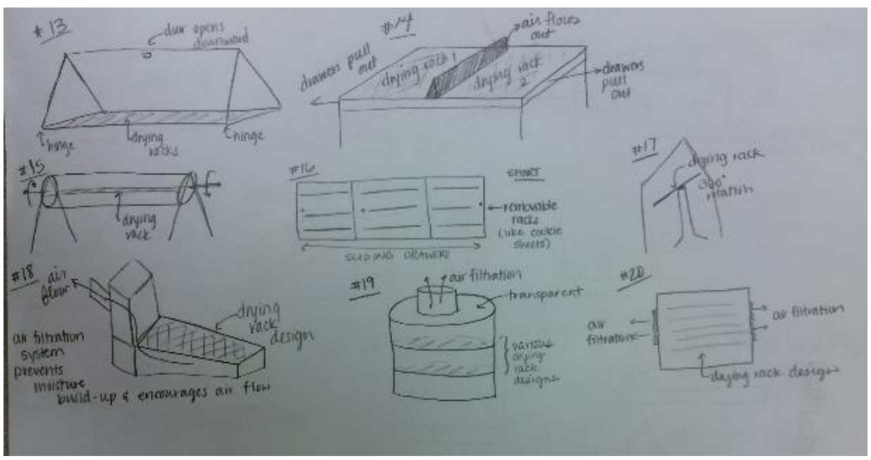

1. Heat Air
C map
Shut-time / UC-Davis
Convective mass transfer KAYS CRAWFORD
Inter-relation between subfunctions.
1. Heat Air.
Outlet.
Upper: Glass
Bottom: Wood painted in black
Inlet
Roof in black to absorb solar energy
outlet
Upper: Glass.
Pipe made of aluminum cans to absorb solar energy
Upper: Glass
Dryer
Magnifying Glass??
Bottom: Wood or plastic to absorb solar energy.

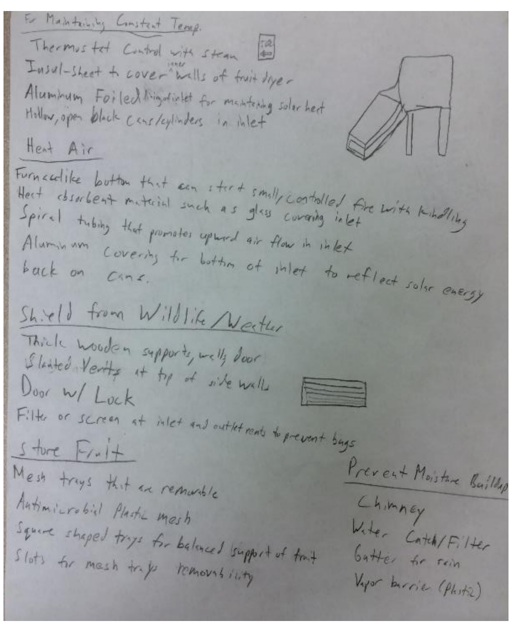

2. Store Fruit.
Wooden frame
Sliced fruit.
mesh
3. Airflow
Solar Panel
Fan run by electricity from the panel
low pressure
Black to absorb solar energy
Inlet
Outlet
Inlet


4. Maintain Temp.
① Thermometer & water spray
② To keep temperature.
Entire Blackbody ??
5. Shield from wildlife & weather.
① Against Rain.
Roof
② Insects.
Mesh at the inlet & outlet.
③ Sandstorm ??
Fully-sealed design.
lower center of mass (Taller VS Lower design)
(Wider VS Narrower)
VS


ME 450 CONCEPT GENERATION
New info from Brenda:
· size: 1 ton
· 3 households to 1 dryer
· apples, pears, vegetables
· size: 4-5m², moveable
· Household Animals: goat, sheep, cows, rabbits
Features:
· Collect condensed water?
· fan for airflow in dryer
· reflectors to maximize sun
· adjustable vents to control air flow - have screens to filter particles
(· Layering of racks for moisture build up?)
· Best design to look for for inspiration: Appalachian Dryer ($200)
MATERIAL
· best material is fiberglass-reinforced polyester (FRP)
· Absorber (installed beneath glazing to absorb sun's heat)
- charcoal-colored aluminum window screen
or steel lath
INDIRECT SOLAR
PARTS OF A SOLAR DRYER (Handbook of Industrial Drying pg 306)
1. Drying space
2. collector to convert solar radiation to heat
[3. optional auxiliary energy source]
4. Heat transfer equipment for transferring heat to the drying air
5. Means for keeping drying air in flow
[6. Heat storage unit, optional] ✓ could be interesting to look into
TYPES OF DRYERS: pg 307
· cabinet
· tent
- pg 320 has good equations
· Include design guidelines of lowest temperature
- vapor barrier
- shut-down at night
· UC Davis MSU
· convection heat transfer - convection mass transfer
book
STANFORD:
Bill
Kays & Crawford
spalding


Door Mechanism
#1
hinge
handle
drying rack
the door is a transparent material and lifts upward
#2
sliding/sealing door
#3
transparent sealing material
one large pull out drawer with multiple layers
#4
hinge
doors lift upward & seal around edges
Drying Racks Mechanisms
#5
multiple shelves on either side w/ opening in middle to reach shelves.
#6
The drying racks are cylindrical mesh. Multiple shelves allow for better storage.
Rotation Mechanisms
#7
drying racks rotate separately/manually
#8
SIDE VIEW
pegs
drying rack
#9
Rotate Handles that Have time marks on them for time of day
DRYING RACK
#10
5"
3"
separate drying racks for different types of produce
#11
doors open on angle to reveal separate drying racks
#12
door
hinge
DRYING RACK 1
DRYING RACK 2
DRYING RACK 3
DRYING RACK 4

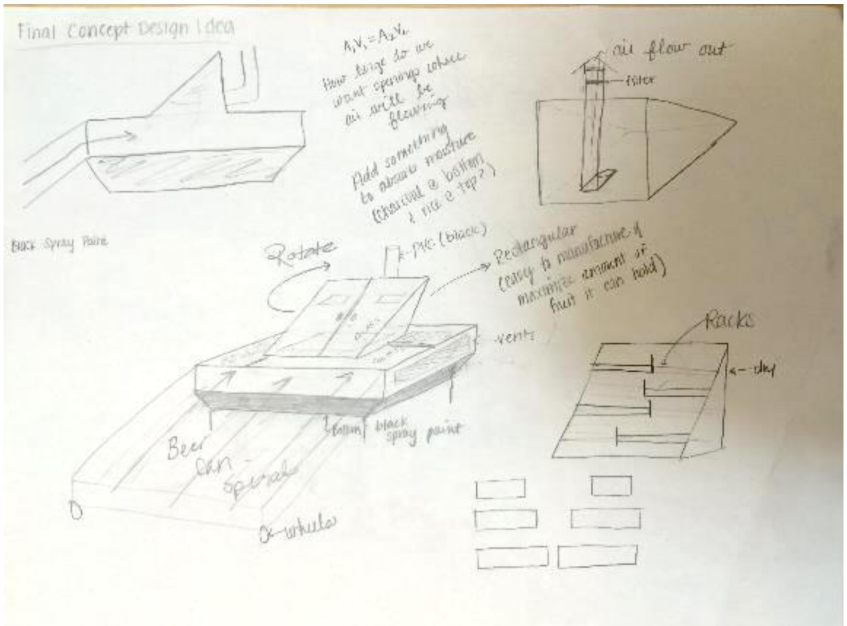

#13
door opens upward
hinge
drying racks
hinge
#14
air flows out
drawers pull out
drying rack 1
drying rack 2
drawers pull out
#15
drying rack
#16
removable racks (like cookie sheets)
SLIDING DRAWER
#17
drying rack
360° rotation
#18
air flow
drying rack design
air filtration system prevents moisture build-up & encourages air flow
#19
air filtration
transparent
various drying rack designs
#20
air filtration
air filtration
drying rack design


For Maintaining Constant Temp.
Thermostat Control with steam
Insul-Sheet to cover inner walls of fruit dryer
Aluminum Foiled lining of inlet for maintaining solar heat
Hollow, open black cans/cylinders in inlet
Heat Air
Furnacelike bottom that can start small, controlled fire with kindling
Heat absorbent material such as glass covering inlet
Spiral tubing that promotes upward air flow in inlet
Aluminum covering for bottom of inlet to reflect solar energy back on cans.
Shield from Wildlife/Weather
Thick wooden supports, walls, door
Slanted Vents at top of side walls
Door w/ Lock
Filter or screen at inlet and outlet vents to prevent bugs
Store Fruit
Mesh trays that are removable
Antimicrobial Plastic mesh
Square shaped trays for balanced support of fruit
Slots for mesh trays removability
Prevent Moisture Buildup
Chimney
Water Catch/Filter
Gutter for rain
Vapor barrier (Plastic)

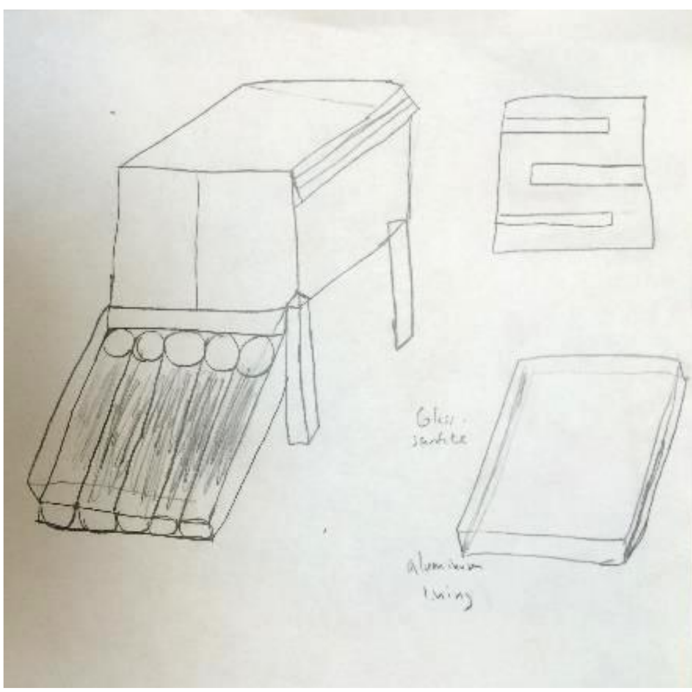
B.3 Final Round Concept Generation

The following four design were the main concepts considered for our Pugh chart in selecting our final design.

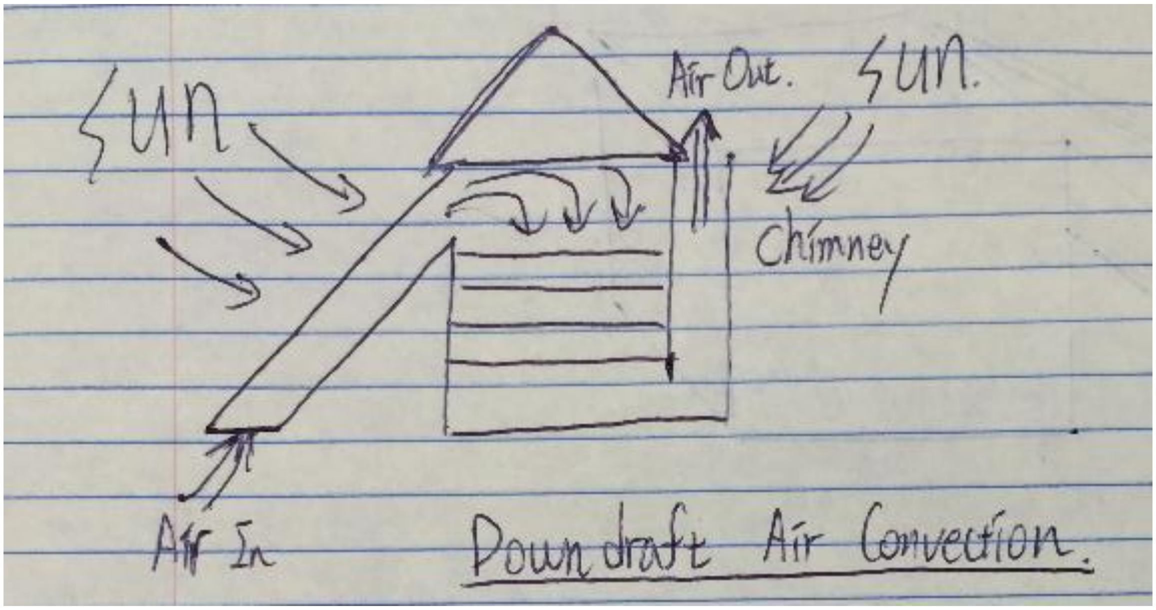
Concept 1



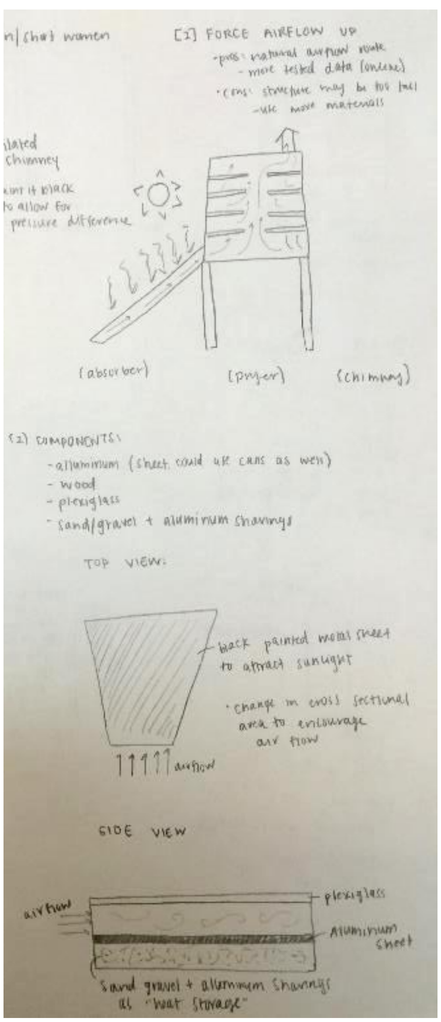
Concept 2



Concept 3



Concept 4



APPENDIX C

Air properties and constants used in heat/mass transfer calculation at 315.5 K

Properties		**Values**
Density,	$\rho_a\ [kg/m^3]$	1.13
Gravitational Acceleration,	$g\ [m/s^2]$	9.81
Dynamic Viscosity,	$\mu\ [kg/m \cdot s]$	1.91E-05
Thermal Expansion,	$\beta\ [1/K]$	3.14E-03
Specific Heat of Air,	$C_p\ [kJ/kg \cdot K]$	1.005
Thermal Conductivity of Air,	$K_a\ [W/m \cdot K]$	2.71E-02

APPENDIX D:Bill of Materials

Material	***Picture***	***Manufacturer***	***Model #***	***Cost***	***Quantity***	***Manufacturing***	***Assembly***
1.5" x 2.5" x 8'		Ann Arbor Re-use	-	$6 Total	5	Cut	Wood Screws
Plywood .375" x 4' x 8'		Habitat for Humanity Re-use Store + Home Depot	-	$45 $20	5	Cut	Wood Screws
Wooden Dowels (assorted sizes)		Habitat for Humanity Re-use Store	-	$2	1 bundle	Cut	Nail
Construction Sealant		Sikaflex	90618	$5.78	2	-	-
Wire Mesh Steel 1/4 "x 3' x5'		YardGard	308232HD	$13.24	5	Cut	Nails
Aluminum Sheet 36" x 36"		Alro Steel, Ann Arbor	-	$21.98	1	Cut/Drill	Screws
Acrylic		Alro Steel, Ann Arbor	-	$35.94	1	Cut/Drill	Screws
Window Seal 17'		MD Buliding Products	4267	$7.86	1	Cut	-

Screen 36' x 84"		New York Wire	FCS8558-M	$6.98	1	Cut	Nails

APPENDIX E: Manufacturing plans

Manufacturing Plan

Part Number: **1**

Subfunction: Solar Absorber
Part Name: Absorber Base
Team Number: 12-Fruit Dryer

Raw Material Stock: 3/4" Thick Plywood

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)
1	Clamp down plywood on table	-	Clamp	-	-
2	Mark plywood for 1m of width and 1.2m of length	-	Clamp	Marker	-
3	Use circular saw to cut along marked lines	Circular Saw	Clamp	-	Hi-Speed

Part Number: **2**

Subfunction: Solar Absorber
Part Name: Absorber Edge
Team Number: 12-Fruit Dryer

Raw Material Stock: 3/4" Thick Plywood

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)

1	Clamp plydown down to table	-	Clamp	-	-
2	Mark plywood into a square that is 0.3m wide and 1.22m long	-	Clamp	Marker	-
3	Cut along marked lines with Circular Saw to cut to size	Circular Saw	Clamp	-	Hi-Speed
4	Mark plywood into a square that is 0.3m wide and 1.22m long	-	Clamp	Marker	-
5	Remove clamp and reaffix to drill press table	-	Clamp	-	-
6	Mark the plywood with the four holes according to drawing	-	Clamp	Marker	-
7	Predrill the four holes	Drill Press	Clamp	7/64 No. 6 Drill Bit	Hi-Speed

8	Drill through-holes	Drill Press	Clamp	9/16" No. 6 Drill Bit	Hi-Speed

Part Number: **3**

Subfunction: Absorber
Part Name: Absorber Aluminum
Team Number: 12-Fruit Dryer

Raw Material Stock: Aluminum Sheetmetal

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)
1	Affix sheetmetal to table	-	Clamp	-	-
2	Mark the sheet metal for cutting according to drawing	-	-	Marker	-
3	Use bandsaw to cut to size	Bandsaw	-	-	2000

Part Number: **4**

Subfunction: Solar Absorber
Part Name: Base Connector
Team Number: 12-Fruit Dryer

Raw Material Stock: 3/4" Thick Plywood

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)

1	Affix to table using clamp	-	Clamp	-	-
2	Mark plywood for length and width	-	Clamp	Marker	-
3	Cut to size with circular saw	Circular Saw	Clamp	-	Hi-Speed
4	Reaffix to drill press table	-	Clamp	-	-
5	Mark plywood for six holes according to drawing dimensions	-	Clamp	Marker	-
6	Drill hole six holes with drill press	Drill Press	Clamp	9/16 Drill Bit	Hi-Speed

Part Number:	**5**
Subfunction:	Drying Chamber
Part Name:	Chamber Bottom Plate
Team Number:	12-Fruit Dryer
Raw Material Stock:	3/4" Thick Plywood

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)
1	Clamp down onto table	-	Clamp	-	-
2	Mark the plywood for 1.04m of length and 1m of width	-	Clamp	Marker	
3	Cut to size with circular saw	Circular Saw	Clamp	-	Hi-Speed
4	Reaffix to drill press table	-	Clamp		
5	Drill 8 through-holes into plywood according to drawing	Drill Press	Clamp	9/16 Drill Bit	Hi-Speed

Part Number:	**6**
Subfunction:	Drying Chamber
Part Name:	Chamber Front Plate
Team Number:	12-Fruit Dryer
Raw Material Stock:	3/4" Thick Plywood

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)

1	Affix plywood to table with clamp	-	Clamp	-	-
2	Mark plywood for 1m length and 1m width	-	Clamp	Marker	-
3	Cut along marked lines with circular saw	Circular Saw	Clamp	-	Hi-Speed
4	Reaffix onto drill press table	-	Clamp	-	
5	Drill four 9/16" holes into plywood using the drill press	Drill Press	Clamp	9/16 Drill Bit	Hi-Speed

Part Number: 7

Subfunction: Drying Chamber
Part Name: Chamber Roof
Team Number: 12-Fruit Dryer

Raw Material Stock:

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)

1	Affix plywood to table with clamp	-	Clamp	-	-
2	Mark plywood for 1.07m length and 1m width	-	Clamp	Marker	-
3	Cut along marked lines with circular saw	Circular Saw	Clamp	-	Hi-Speed
4	Reaffix onto drill press table	-	Clamp	-	-
5	Drill four 9/16" holes into plywood using the drill press	Drill Press	Clamp	9/16 Drill Bit	Hi-Speed

Part Number: **8**

Subfunction: Drying Chamber
Part Name: Chamber Back Plate
Team Number: 12-Fruit Dryer

Raw Material Stock: 3/4" Thick Plywood

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)
1	Affix plywood to table with clamp	-	Clamp	-	-

2	Mark plywood with exterior and interior lines for cutting as well as four holes according to drawing	-	Clamp	Marker	-
3	Cut along exterior lines with circular saw	Circular Saw	Clamp	-	Hi-Speed
4	Cut interior lines with jig saw	Jig Saw	Clamp	-	Hi-Speed
5	Reaffix to drill press table with clamp	-	Clamp	-	-
6	Drill four through holes with drill press into plywood according to drawing	Drill press	Clamp	9/16" Drill Bit	Hi-Speed

Part Number: **9**

Subfunction: Solar Absorber
Part Name: Chamber Side Plate w/ Absorber
Team Number: 12-Fruit Dryer

Raw Material Stock: 3/4" Thick Plywood

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)

1	Affix plywood to table with clamp	-	Clamp	-	-
2	Mark plywood with exterior and interior lines for cutting as well as four holes according to drawing	-	Clamp	Marker	-
3	Cut along exterior lines with circular saw	Circular Saw	Clamp	-	Hi-Speed
4	Cut interior lines with jig saw	Jig Saw	Clamp	-	Hi-Speed
5	Reaffix to drill press table with clamp	-	Clamp	-	-
6	Drill six holes to a depth of 1 3/4 inch with drill press into plywood according to drawing	Drill press	Clamp	2" Drill bit	Hi-Speed
7	Drill six through holes with drill press according to drawing	Drill press	Clamp	80mm Wood Drill Bit	Hi-Speed

Part Number: **10**

Subfunction: Drying Chamber
Part Name: Chamber Side Plate without Absorber
Team Number: 12-Fruit Dryer

Raw Material Stock: 3/4" Thick Plywood

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)
1	Affix plywood to table with clamp	-	Clamp	-	-
2	Mark plywood with exterior for cutting as well as twelve holes according to drawing	-	Clamp	Marker	-
3	Cut along exterior lines with circular saw	Circular Saw	Clamp	-	Hi-Speed
5	Reaffix to drill press table with clamp	-	Clamp	-	-
6	Drill six holes to a depth of 1 3/4 inch with drill press into plywood according to drawing	Drill press	Clamp	2" No. 6 Drill bit	Hi-Speed
7	Drill six through holes with drill press according to drawing	Drill press	Clamp	80mm Wood Drill Bit	Hi-Speed

Part Number: **11**

Subfunction: Drying Chamber
Part Name: Plate Under Aluminum in Absorber
Team Number: 12-Fruit Dryer

Raw Material Stock: 3/4" Thick Plywood

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)
1	Affix plywood to table with clamp	-	Clamp	-	-
2	Mark plywood with lines for cutting to size according to drawing	-	Clamp	Marker	-
3	Cut along marked lines with circular saw	Circular Saw	Clamp	-	Hi-Speed
4	Reaffix to drill press table with clamp	-	Clamp	-	-
5	Drill four holes to a depth of 44.45mm according to drawing with drill press	Drill Press	Clamp	2" No. 6 Drill Bit	Hi-Speed

Part Number: 12

Subfunction: Drying Chamber
Part Name: Sliding Door
Team Number: 12-Fruit Dryer

Raw Material Stock:

Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)

1	Affix plywood to table with clamp	-	Clamp	-	-
2	Mark plywood with lines for cutting to size according to drawing	-	Clamp	Marker	-
3	Cut along marked lines with circular saw	Circular Saw	Clamp	-	Hi-Speed
4	Shave off end of plywood according to drawing using router	Router	Clamp	2" mill	Hi-Speed

Part Number: 13

Subfunction: Drying Chamber
Part Name: Rack Support
Team Number: 12-Fruit Dryer

Raw Material Stock:

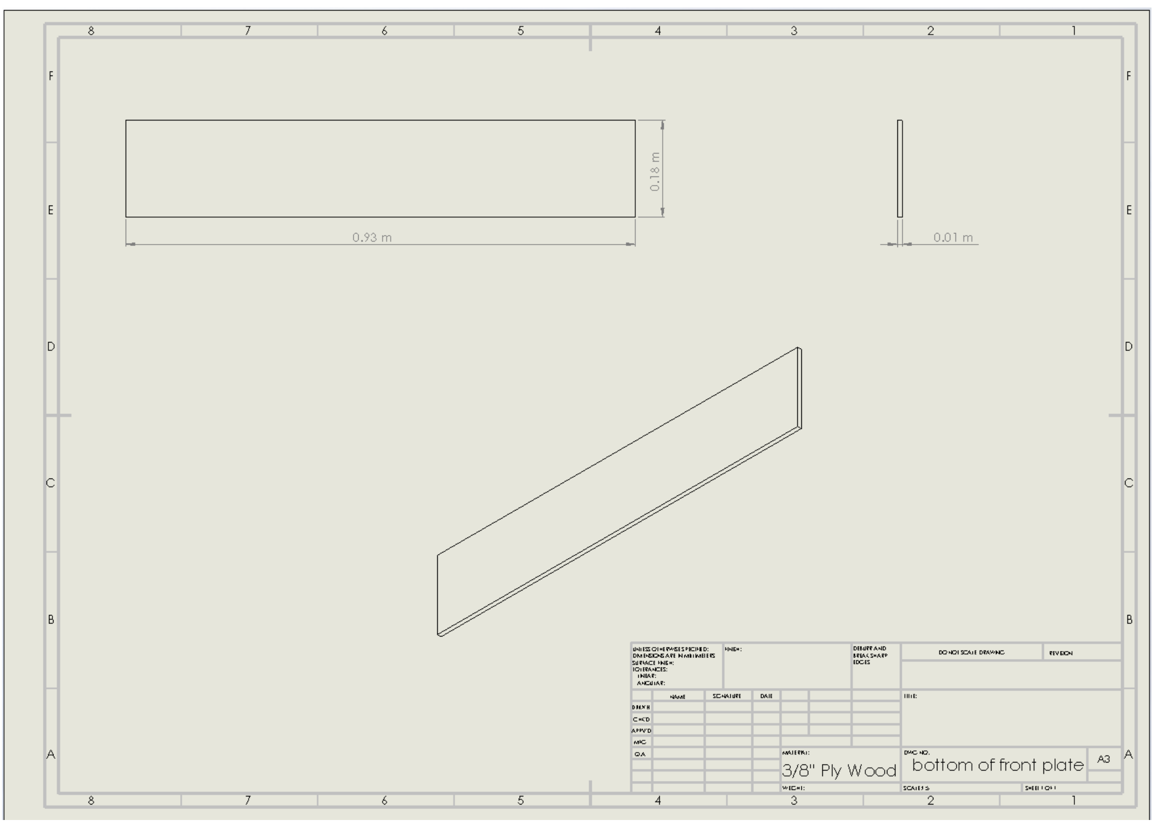
Step #	Process Description	Machine	Fixtures	Tool(s)	Speed (RPM)
1	Affix plywood to table with clamp	-	Clamp	-	-
2	Mark plywood with lines for cutting to size as well as markings for four holes according to drawing	-	Clamp	Marker	-

3	Cut along marked lines with circular saw	Circular Saw	Clamp	-	Hi-Speed
4	Reaffix plywood to drill press table with clamp	-	Clamp	-	-
5	Drill four holes to a depth of 44.45mm using drill press	Drill Press	Clamp	2" No. 6 Drill Bit	Hi-Speed

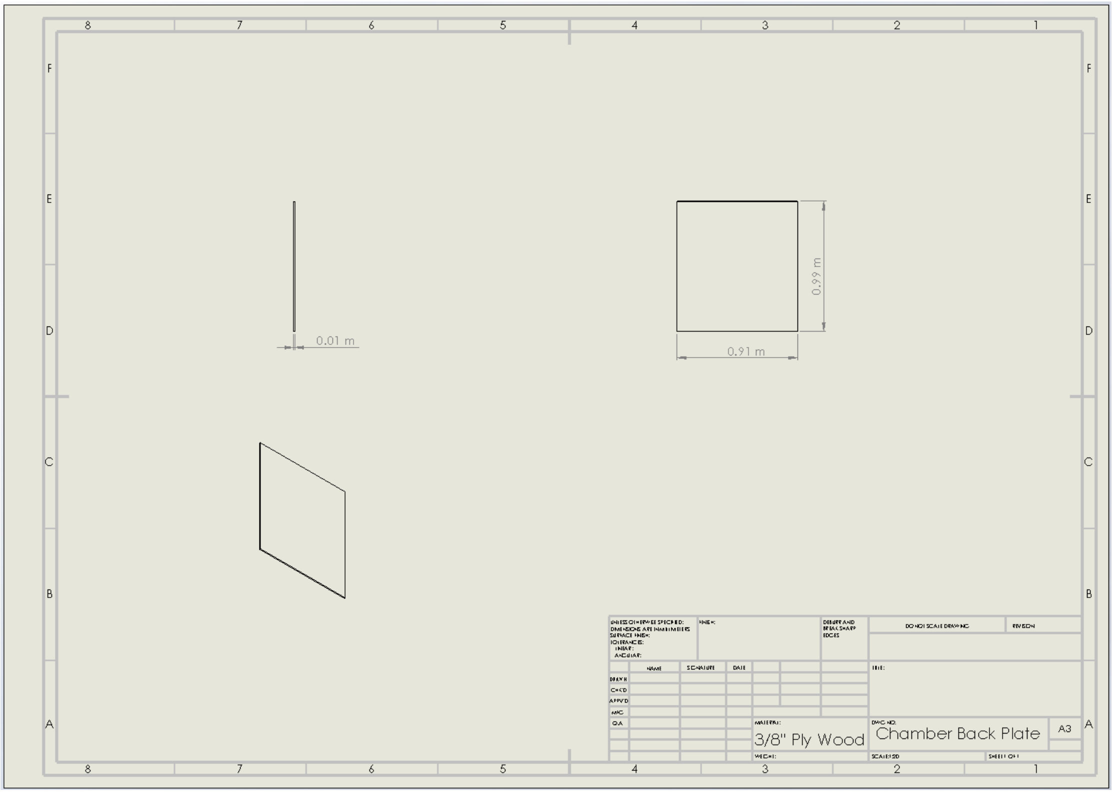
APPENDIX F: Part Drawings

Chamber

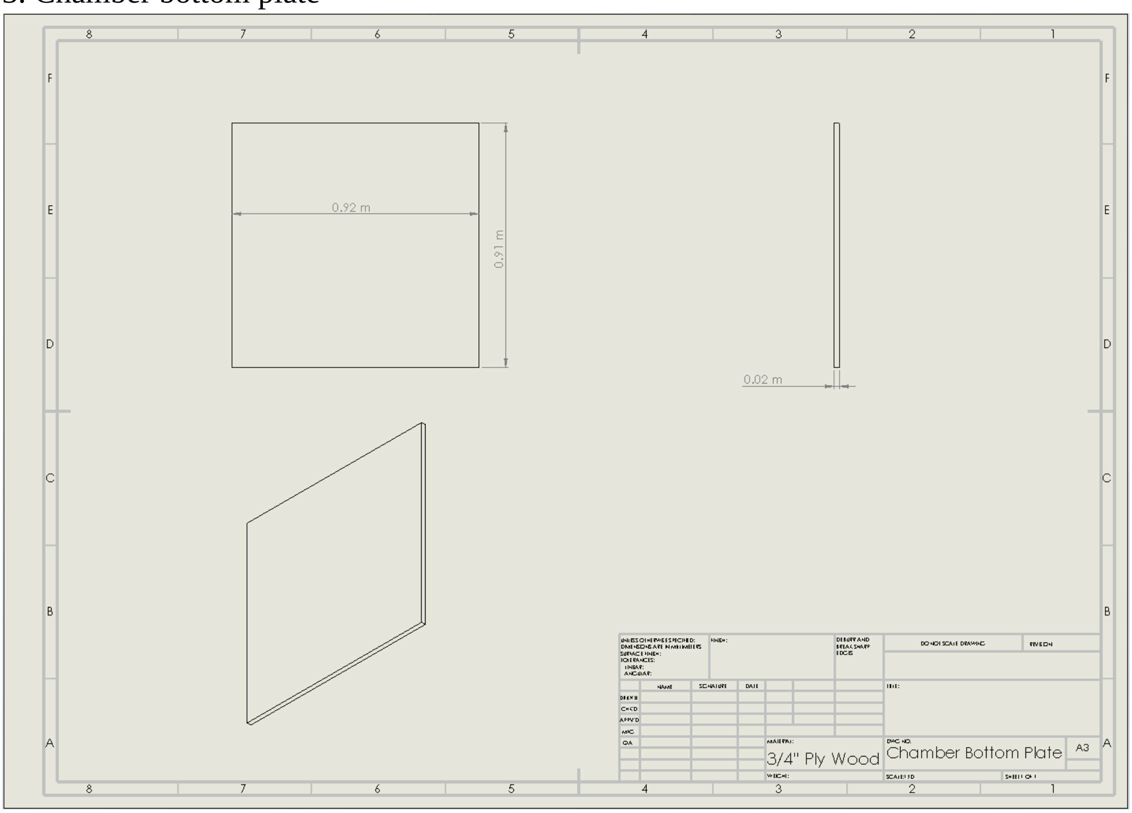
1. Bottom of front plate



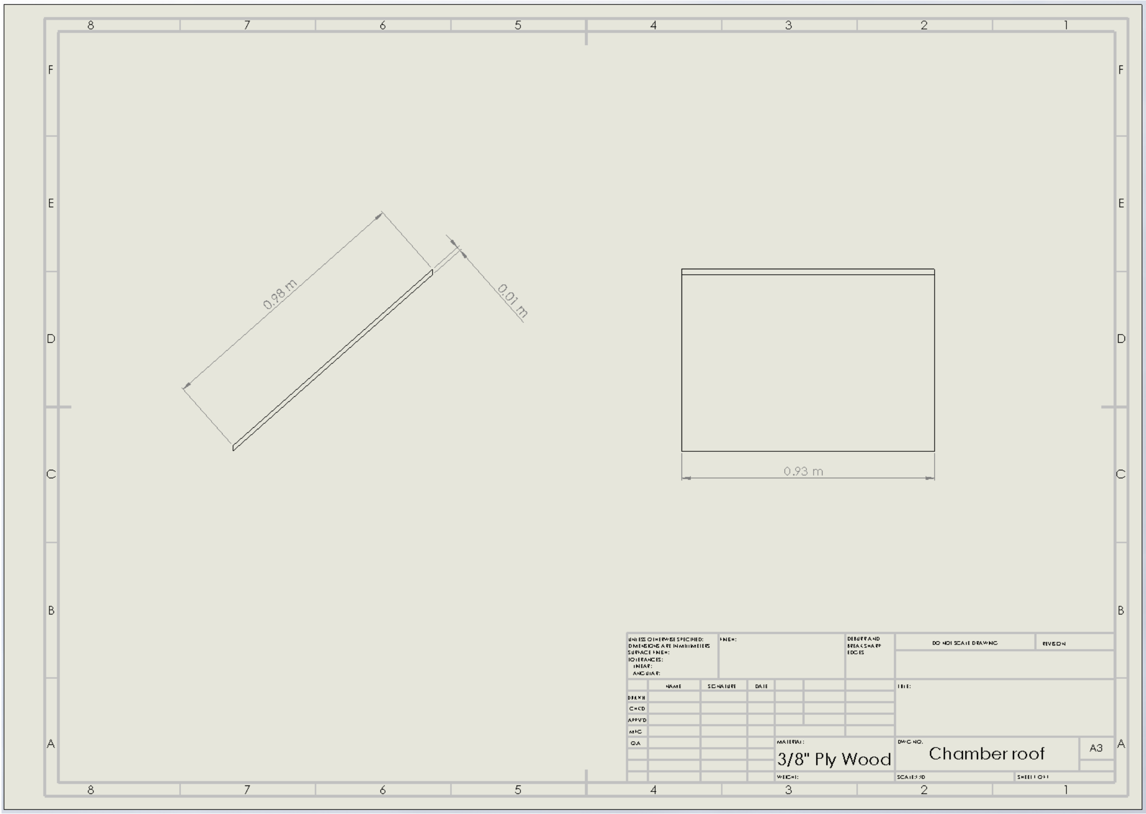
2. Chamber back plate



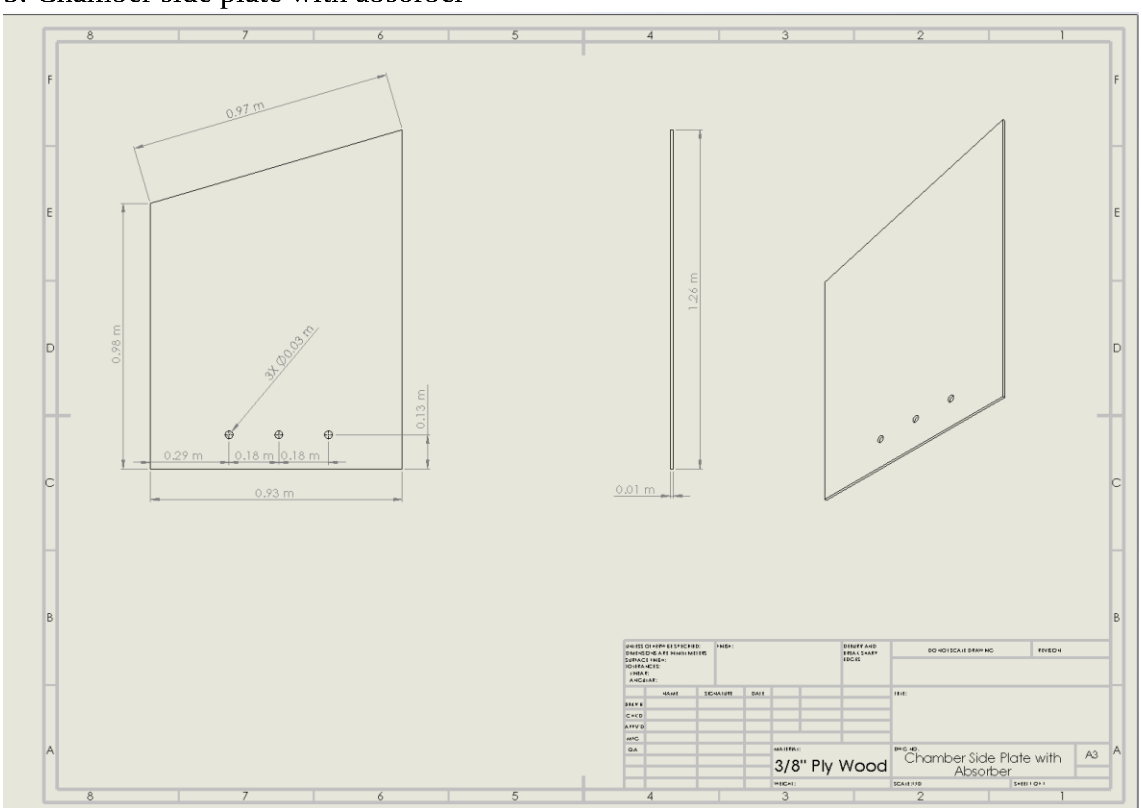
3. Chamber bottom plate



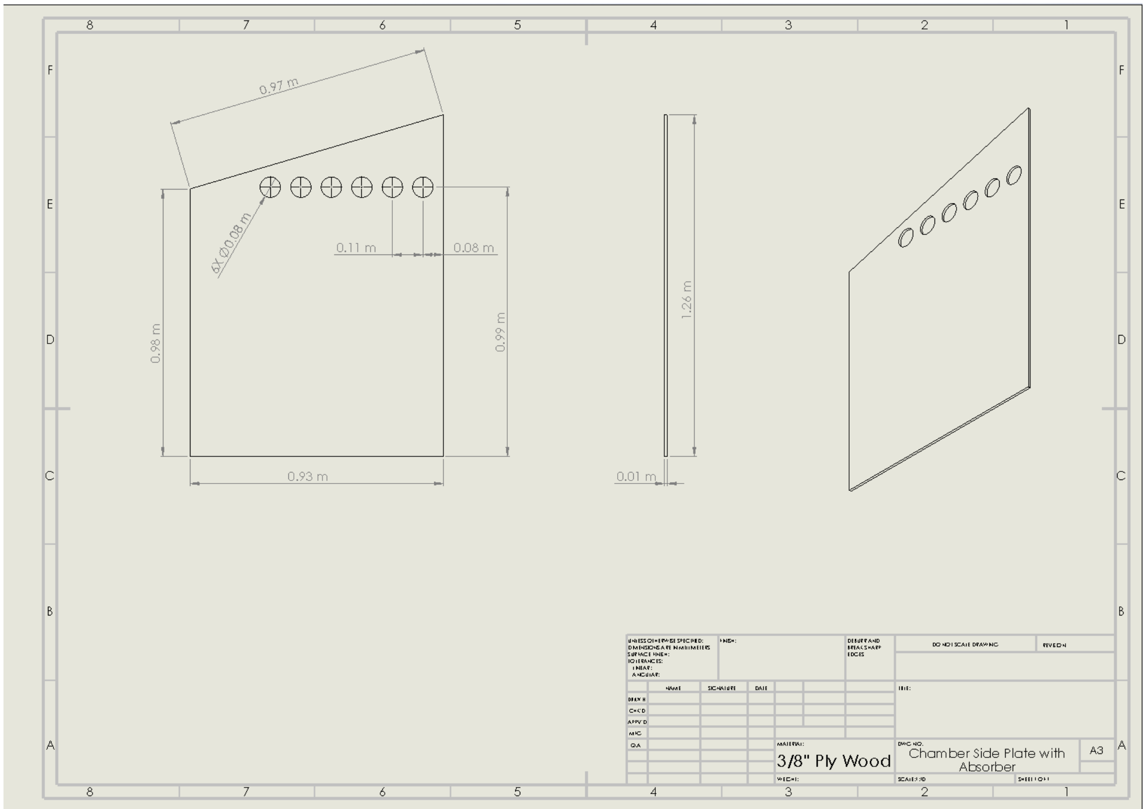
4. Chamber roof



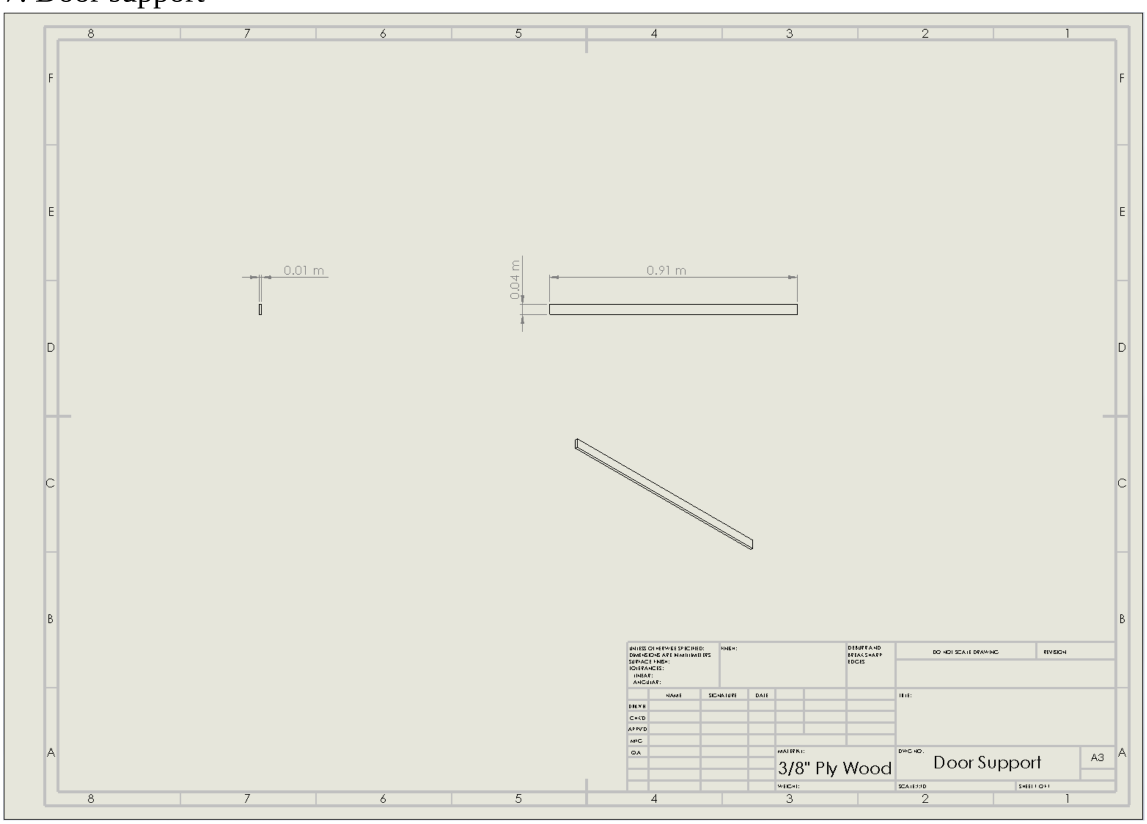
5. Chamber side plate with absorber



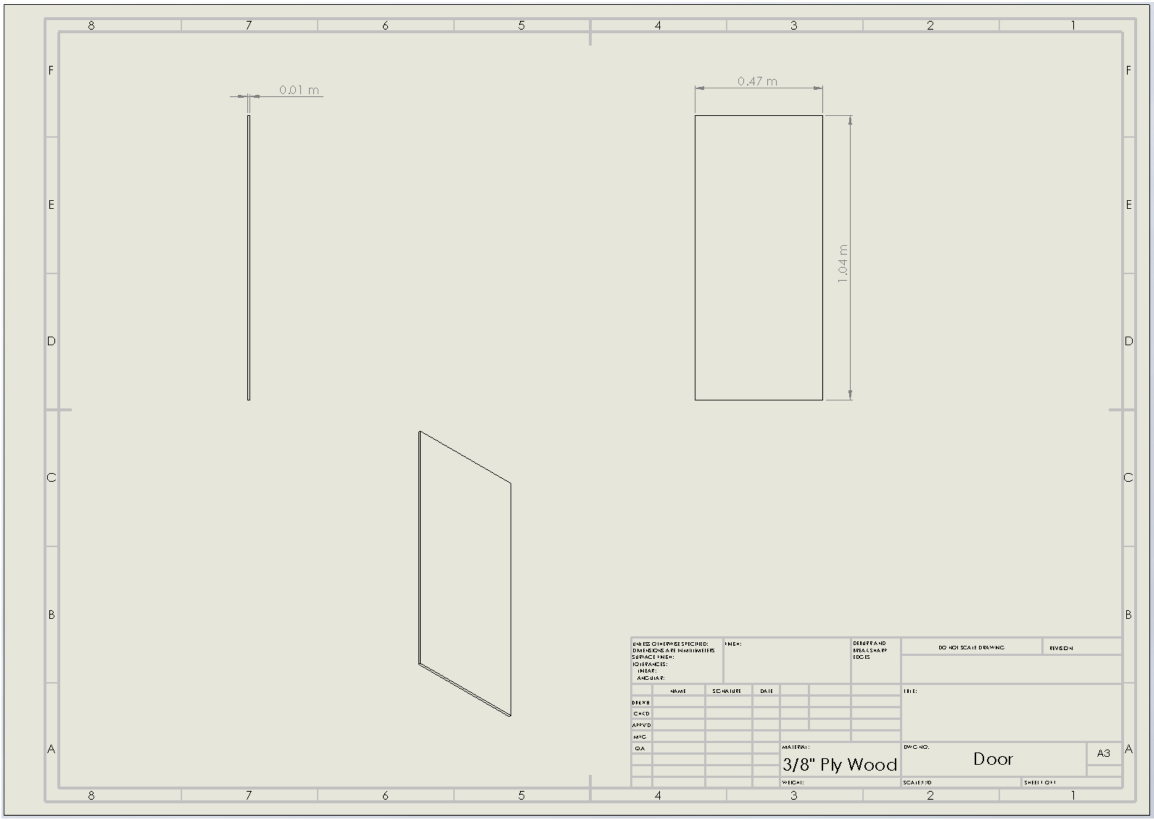
6. Chamber side plate without absorber



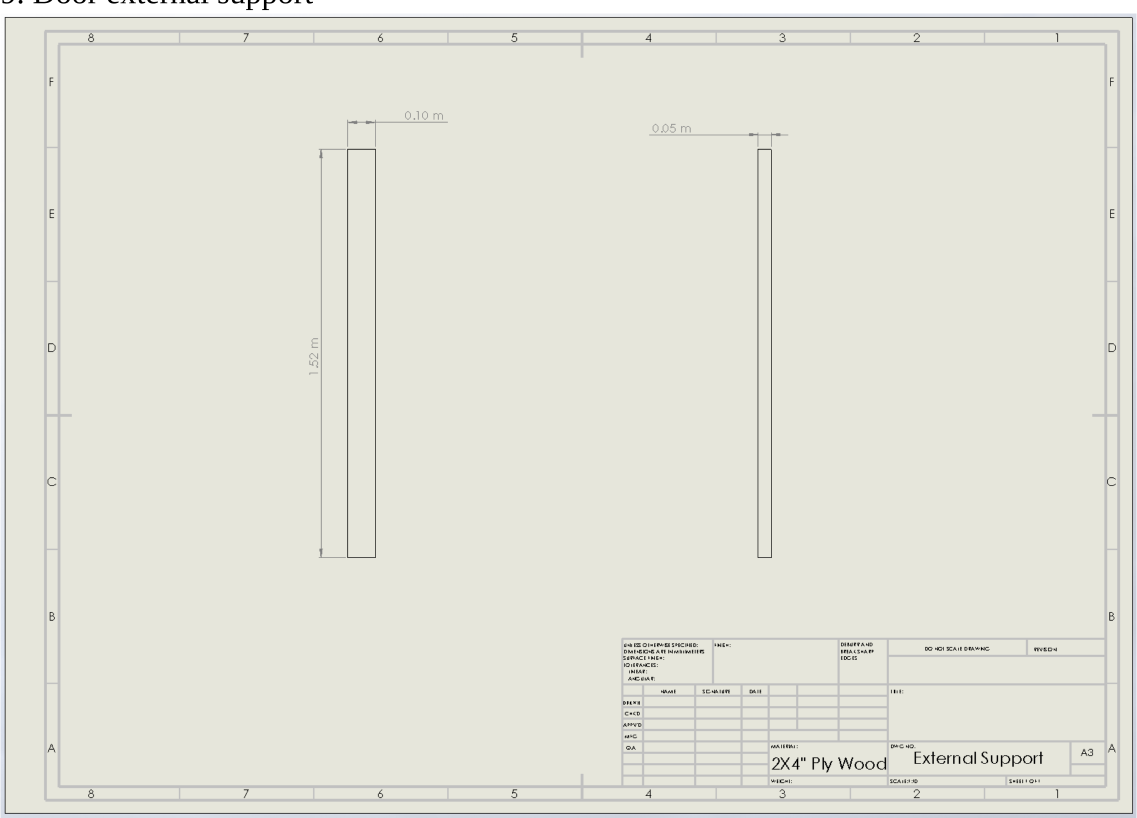
7. Door support



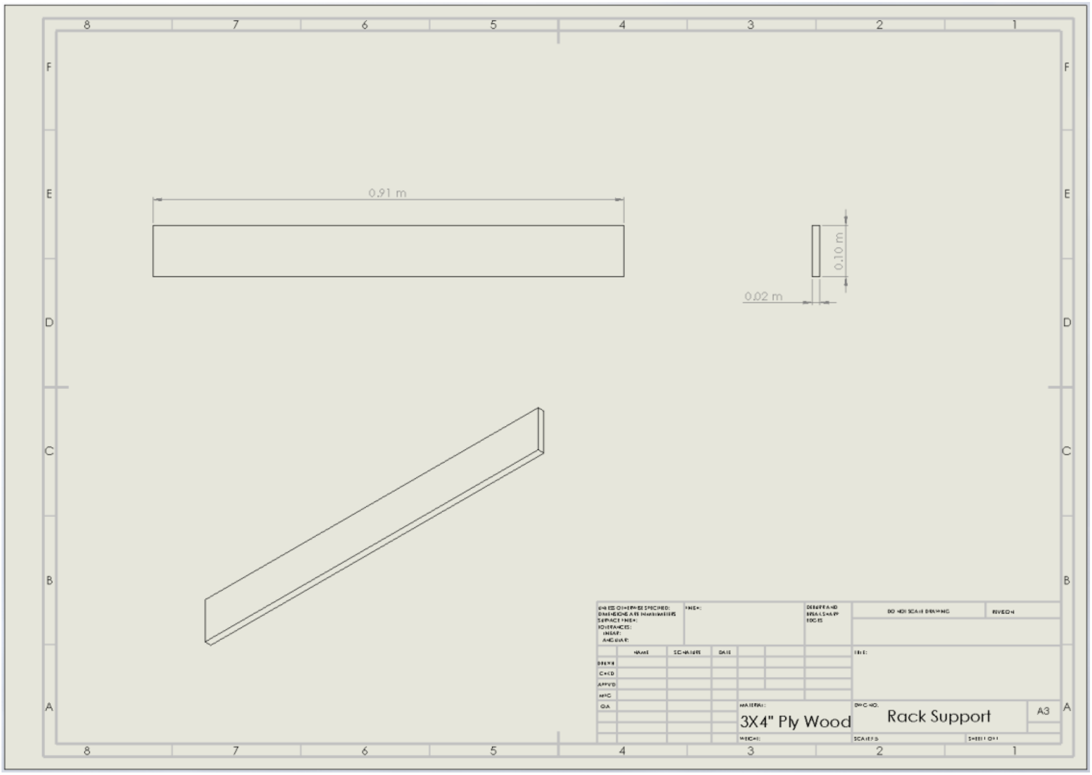
8. Door



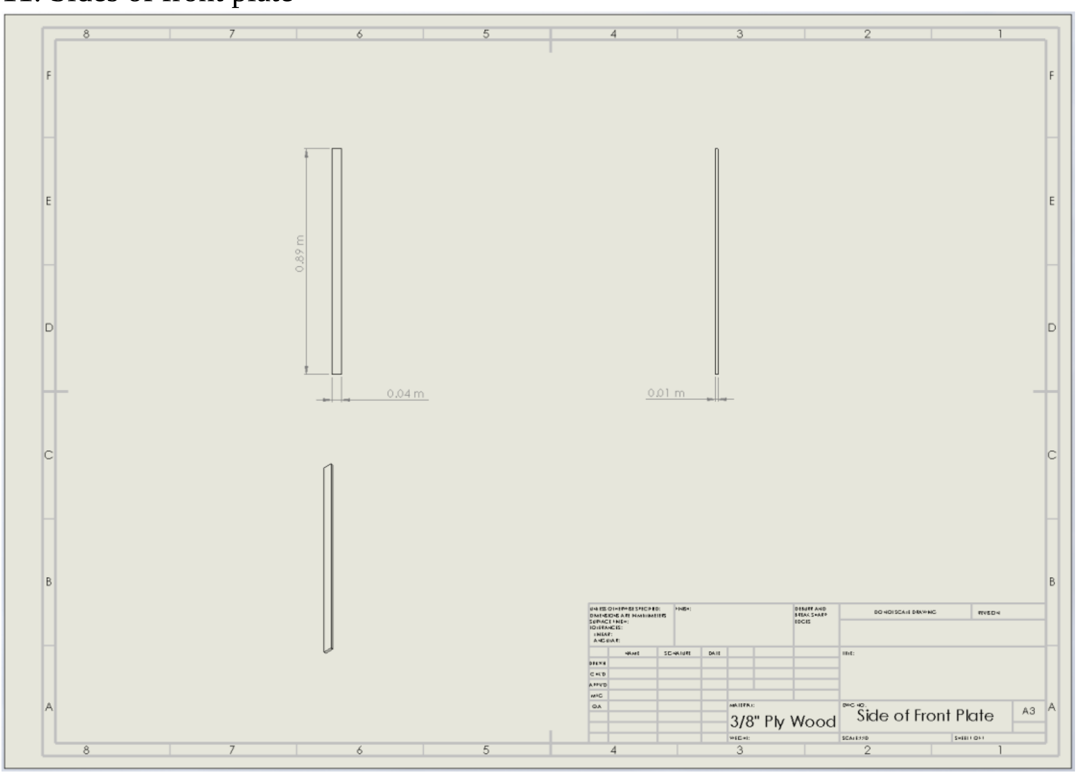
9. Door external support



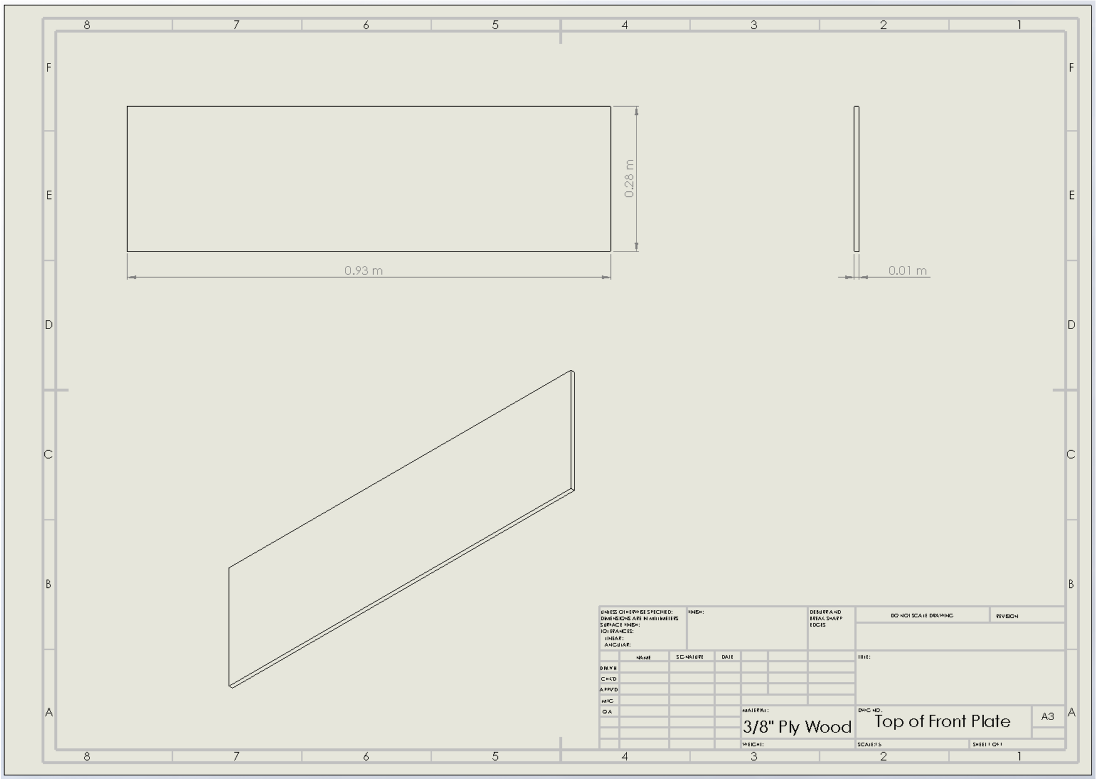
10. Rack support



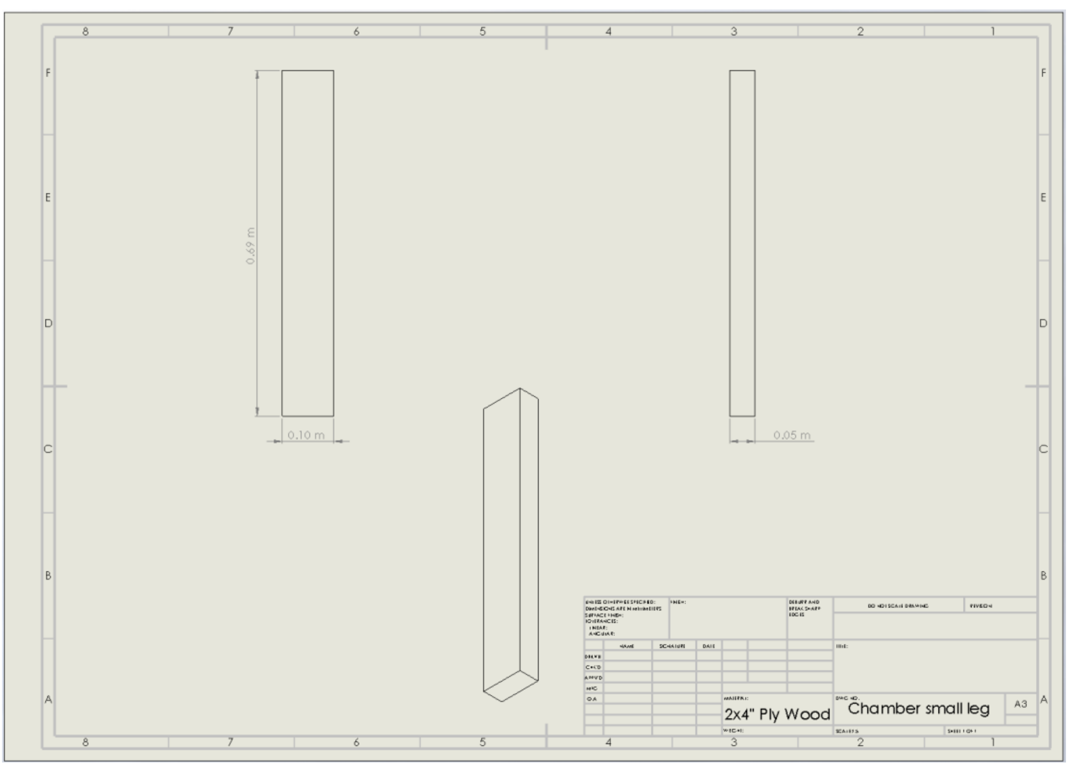
11. Sides of front plate



12. Top of front plate

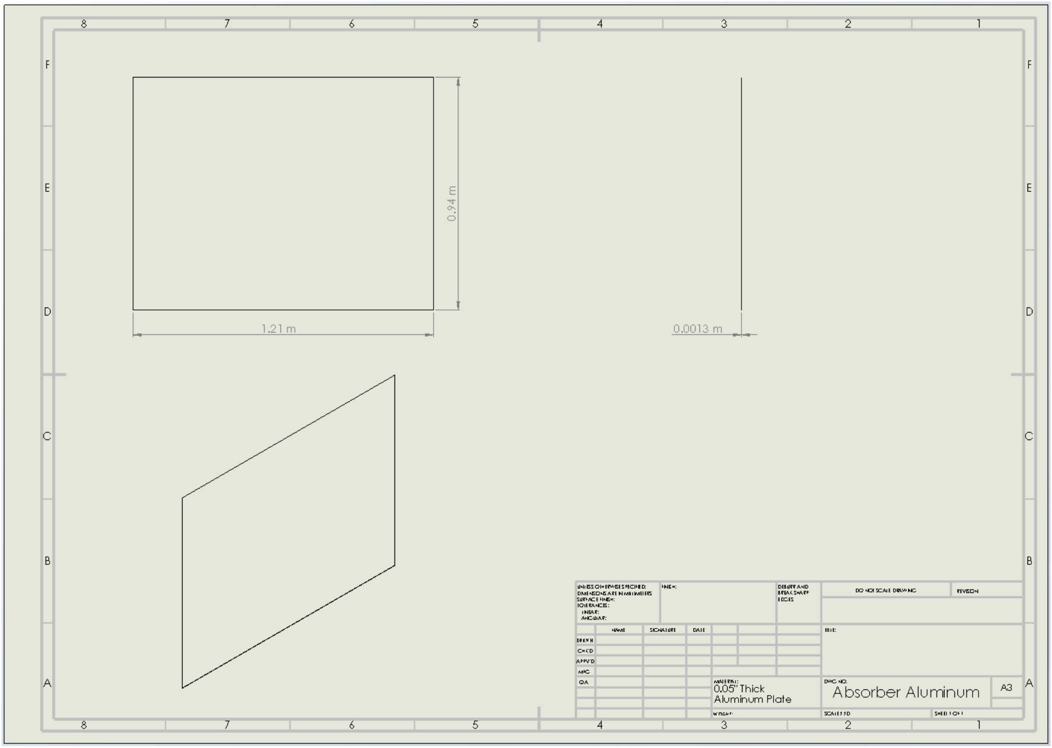


13. Chamber small leg

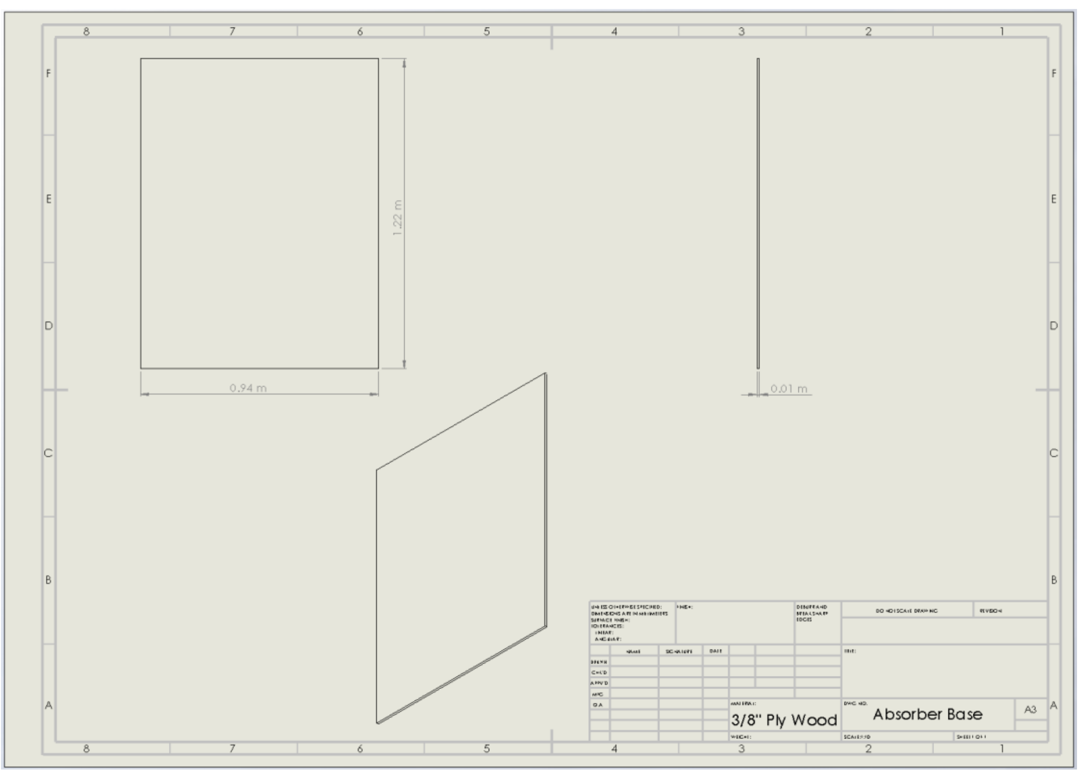


Absorber

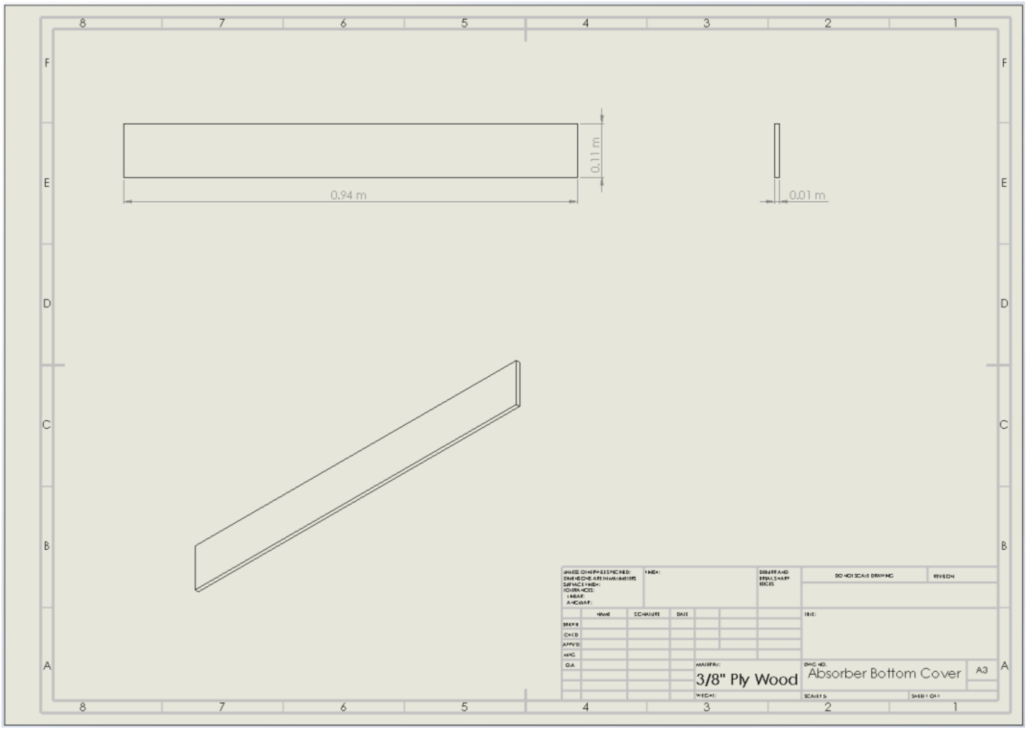
1. Absorber aluminum



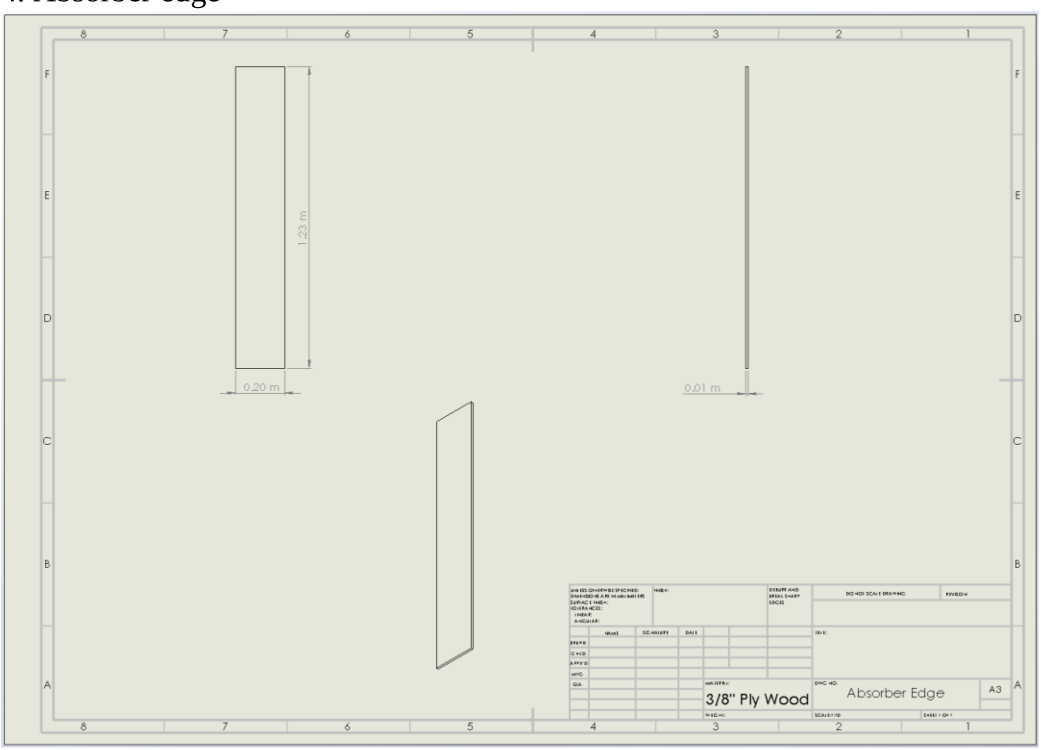
2. Absorber base



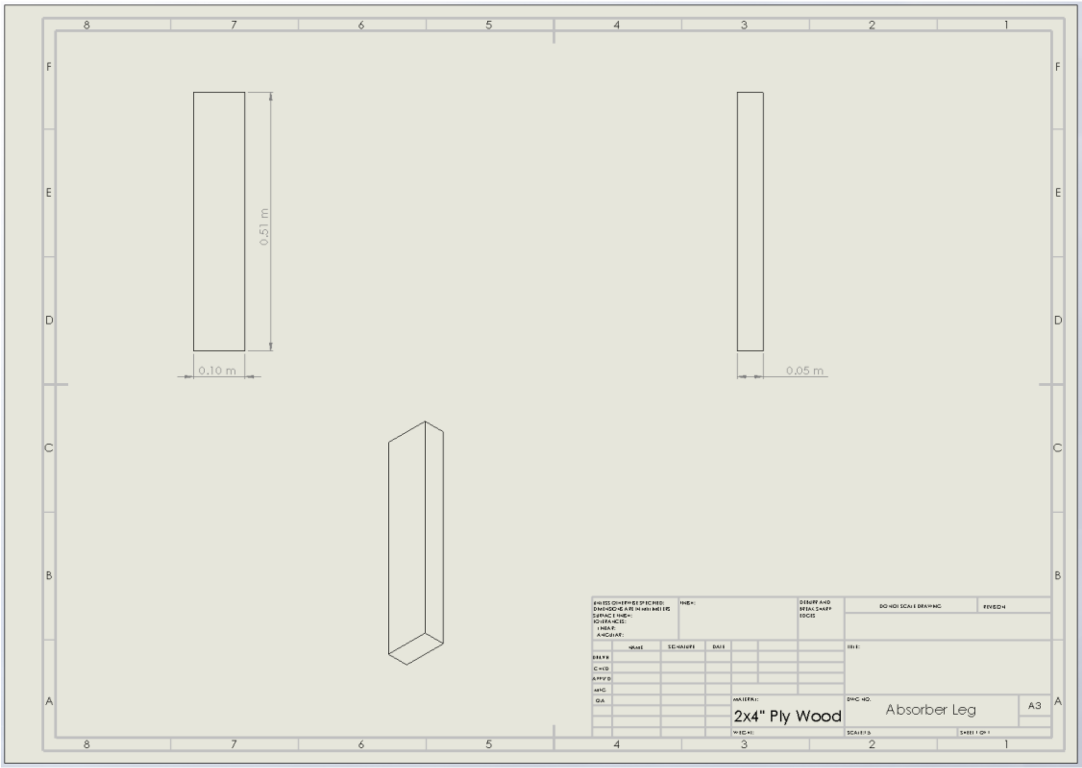
3. Absorber bottom cover



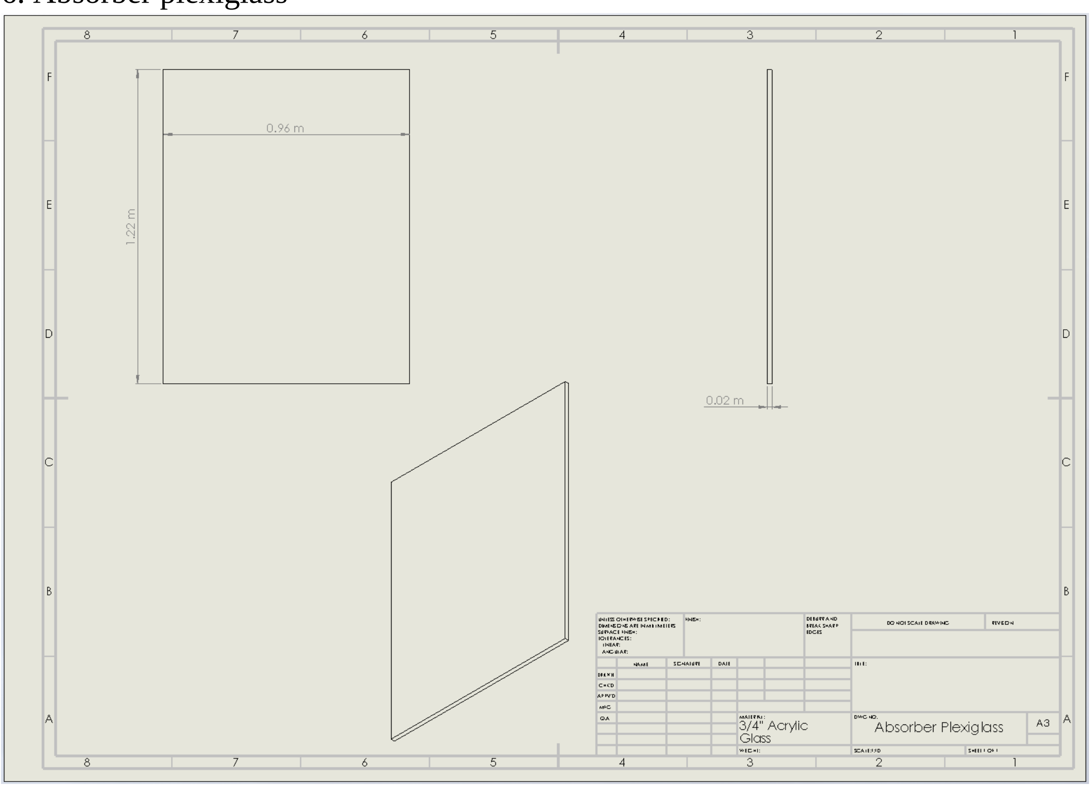
4. Absorber edge



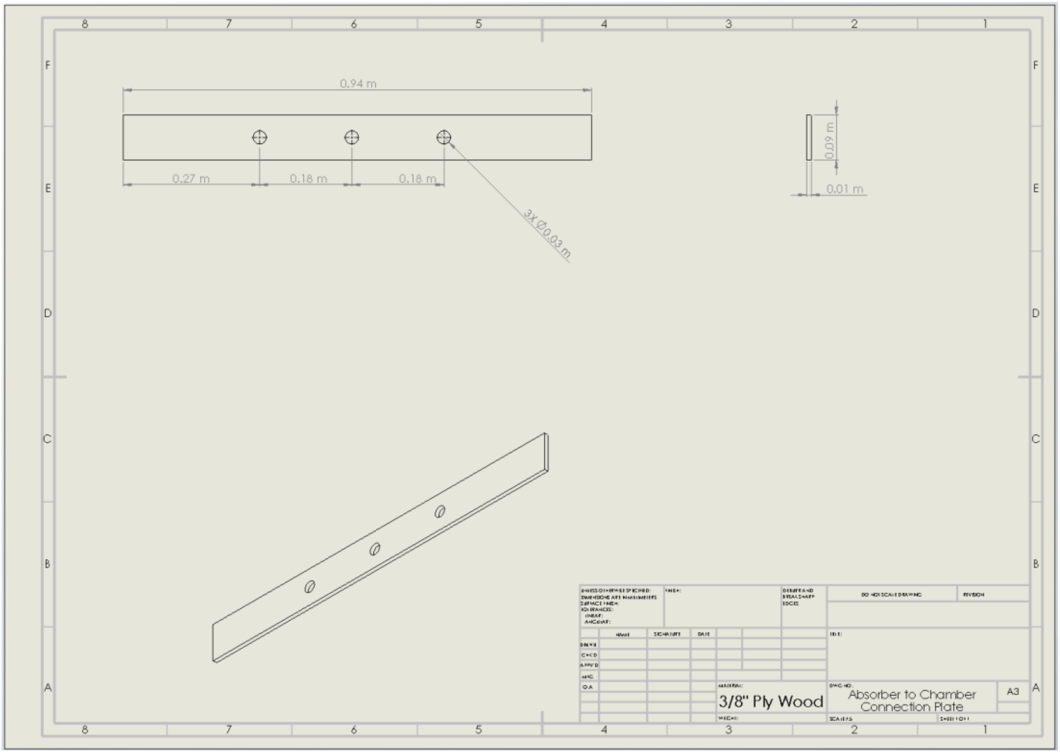
5. Absorber leg



6. Absorber plexiglass



7. Absorber to chamber connection plate



APPENDIX G: Preliminary Verification and Validation Plans
G.1 Verification Testing for Engineering Analysis
Testing in controlled environment.
Instrumentation:
· 200W Induction Lamp
· Three thermocouples with digital readouts
· Anemometer
· Possible fan to replicate wind?
· Computer with Labview Software. Additionally, results for when temperature reaches above 60 degrees, and fluctuations of temperature can be monitored.

Procedure:
1. Record ambient room temperature from thermostat.
2. Place induction lamp 18-24 inches from solar absorber to replicate the sun’s rays
3. Turn on induction light
4. Slice fruit for testing and place on racks of absorber
5. Place thermocouples in correct locations
   - one thermocouple inside solar absorber between acrylic and aluminum sheet
   - one thermocouple inside drying chamber with readout visible outside of chamber
   - one thermocouple at ventilation outlet
6. Place anemometer outside of ventilation holes to record air speed
7. Set up Labview Program to record readings from all three thermocouple callouts and anemometer.

Analysis: questions that we can investigate
- How long does it take fruit to dry? Is it successful?
- Does drying chamber reach temperature of over 60C?
- Measure weight fruit periodically throughout process. Every 30 min for 3 hours, 5 fruit dryer samples from each rack.
- Adjust ventilation by covering/opening more holes. Does this affect drying time?
- If fruit doesn’t dry within 14 hours, things to consider:
    - Is the light supplying enough power that would be equivalent to solar radiation?
    - Is there just too much fruit? Dry again with 1/2, ¼, the amount of total fruit started? Or should we gradually be adding fruit in?

G.2 Validation: Testing for User Operability/user needs
- Siemen’s Jack model. Import finalized CAD design into program and check sizing/dimensions (optional)
- Ensure that rack height/weight is comfortable for each of our group members. Bring in a group of friends (only petite women) to operate the drying chamber. Create a survey of comfort/ease of operation that they will fill out afterwards. This survey was not conducted in the scope of this project but can be continued with BlueLab.

Anonymous Validation Survey:

Please fill out the following information:

Weight: __________ Height: ______________ Age: _______________

For each question, please circle one of the responses to the right. If you selected neutral or have a comment about the attribute in question, please write in the space below the question.

1.	I was able to slide the door open/close easily.	Agree	Disagree	Neutral
2.	The door of the dryer was too heavy.	Agree	Disagree	Neutral
3.	The highest rack was too tall for me to reach.	Agree	Disagree	Neutral
4.	The highest rack was uncomfortable to reach.	Agree	Disagree	Neutral
5.	I can hold the weight of a fully loaded rack.	Agree	Disagree	Neutral
6.	The size of the rack was too large to carry.	Agree	Disagree	Neutral
7.	The rack was uncomfortable to carry.	Agree	Disagree	Neutral
8.	The racks were easy to slide into the chamber.	Agree	Disagree	Neutral