ME450
Fall 2015 Semester

Team 10: Kazakhstan Solar-Powered Water Heater

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"We have fully abided by the University of Michigan College of Engineering Honor Code"

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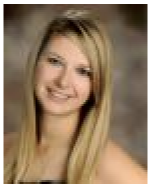
Authors



Alexandra Kolberg is currently a senior pursuing a degree in Mechanical Engineering, a minor in Multidisciplinary design, and is participating in the Program in Sustainable Engineering. She was a part of the General Motors Transmission Efficiency MDP project in 2014. These past two summers, Alexandra interned at General Motors and Hella Electronic Corporation, respectively, learning about the automotive industry from both the OEM and supplier sides. In May of 2016, she will complete her Bachelor's degree and would like find a career working as a design engineer in industry.

Nick Manzek is pursuing his Mechanical Engineering Degree at the University of Michigan. Nick has previously worked for Nordson Sealant Equipment as an intern supporting the mechanical engineering department. Currently, Nick is part of a Multidisciplinary Design Team sponsored by Proctor and Gamble to aid in the development of their paper printing process. Nick plans to complete his Bachelor's degree in April of 2016 and pursue a career designing for industry.

Siobhan McDermott is a senior pursuing a degree in Mechanical Engineering. Throughout her college career, she has been a part of BLUELab, specifically working with the people living in Hagley Gap, Jamaica to design sustainable solutions in order to improve their standard of living. This past summer, Siobhan interned at Guardian Electric Manufacturing, which is an automotive and aerospace supply company. Siobhan will earn her Bachelor's degree in April 2016 and is hoping to pursue a career as a design engineer.

Connor Thompson is presently a senior pursuing a degree in Mechanical Engineering at the University of Michigan. Connor has previously worked as a research assistant in the University of Michigan Marine Hydrodynamics Lab under Professor Michael Bernitsas to further research on the Vortex Induced Vibrations for Aquatic Clean Energy project, which aims to create a hydrokinetic energy source that relies on ocean and river currents without requiring the construction of dams. Upon completion of his degree, Connor plans to pursue a career in the energy industry.

Executive Summary

A fish farm in the Kazakh town of Shelek would like to add variety to its output by beginning to grow Tilapia. There is an artesian well on the property that produces water at 16°C year round. We were tasked with designing a solar-powered system to heat the water produced by the well to 26°C, allowing the farmers to raise warm water fish, including tilapia.

In order to determine a final design, each group member individually contributed 20 design concepts through functional decomposition to collate into a diverse group of ideas. The group combined what we perceived to be the most promising components into five complete designs. The most important design component to consider was the method by which the device heated water; as such, each design heated water in a different way using either completely passive solar heating, active solar with direct or indirect circulation, hybrid passive-active solar, or gas-powered heating. The group created a Pugh chart to rate the designs according to the following categories: ability to effectively heat water, cost sensitivity, ability to utilize solar energy, compatibility with water infrastructure currently existing on-site in Kazakhstan, and ability to contain excess water.

The design our group ultimately chose utilizes active solar energy and direct water circulation. Specifically, water taken into the system is circulated through pipes that feed through a chamber exposed to sunlight beneath a clear polycarbonate surface. With each pass through the system, the water is incrementally heated until it is hot enough for use in the fish tanks, at which point it can be transferred to an insulated storage tank from which it can be accessed by the fish farmers. It is important to note that the water in the system can be heated beyond 26°C, so that it can be mixed with the naturally-occurring 16°C water at the fish farm in order to maximize the control the farmers have over the temperature of the water.

While our design heats water entirely with solar power, it does not use solar energy to circulate water through the system. Instead, our design uses a pump to expedite the circulatory process. Our group does not anticipate this need to be a problem, as the fish farm currently has infrastructure in place that moves water from the site of the artesian well to the facility itself.

Our group has completed and tested a prototype of the design. The prototype is comprised of a scale model half the size of our recommended water heater, along with a pump and a water cooler to circulate a sample of water as a proof-of-concept test. The frame of the device itself was constructed from wood, and copper piping was used to circulate the water inside the device. A multiwall polycarbonate sheet was used to complete the prototype. The prototype itself has been tested successfully, heating water at a rate of approximately 10°C per hour.

Problem Description and Background

Our sponsor, REFRESCH, has acted as a contact between our group and Askhat Akmetov, the leader of the aquaculture branch of the fishery association in Shelek, Kazakhstan. Over-fishing of Kazakhstan's natural waterways has led to the need for fish farms in order to improve the Kazakh economy [1,2]. Akmetov is overseeing the restoration of a fish farm constructed by Soviet engineers during the cold war. The fish farm in question has several large open-air pools, one indoor facility containing six additional 15'x15'x6' tanks, and an artesian well providing a steady source of groundwater at 16°C. The fish farm (Figure 1) is currently equipped to use the groundwater to support its indoor facility; however, Akmetov and the rest of the workers there would like to be able to use the same facilities to raise Tilapia. Tilapia will not survive in water of temperatures below 26°C [3]. REFRESCH has asked our group on behalf of the fish farm workers to design a device to heat the water from the farm's artesian well to a temperature at which tilapia can comfortably survive. Specifically, our group's final product needs to use a passive solar mechanism to introduce energy into the system.

Figure 1: Indoor facility of the fish farm in Kazakhstan we are working with.

The most commonly thought of method for capturing solar energy is by using solar panels, as mentioned in patent US 4273100 A [4], however, solar panels can often be very costly. A less expensive option that would be better for the situation we are working with would be passive solar technology. Passive solar power is a proven concept that has been utilized in the past for heating buildings and water [5-10], and included in several patented designs [11-14]. Passive solar designs often circulate fluid in a system that contains an area exposed to direct sunlight [15]. Convection and pumps are typically used to circulate the fluid throughout the system [9,16]. One established patent, US 4246890 A, effectively incorporates gravity into its cycle of heat transfer fluid; fluid moves through the system by condensing and falling through one half and heating to rise and complete the cycle [15]. Patent US 4505262 A also proves the same concept of a cycle powered by gravity and convection, while taking up less space on the ground than the first design [16].

The fish farm at which our final design would be implemented is not guaranteed a constant amount of sunlight every day of the year due to cloud cover and pollution, so our design will also need to include a reserve tank to contain excess heated water to use on cloudy days. Such a reserve tank would also create a buffer against the system catastrophically overheating. The system our group will design must apply the proven concept of passive solar power to the specific situation of Akmetov's fish farm, taking into account weather constraints, the accessibility of building materials, quantity of available water resources, and the needs of the Tilapia species.

User Requirements and Engineering Specs

After conducting background research and talking to the representatives from REFRESCH, the team established seven important customer requirements and corresponding engineering specifications to help guide the direction of the project. The requirements and specifications can be seen in Table 1, below.

Solar-Powered Device Design to Heat Indoor Ponds of a Tilapia Fish Farm			
Customer Requirement	**Engineering Specification**	**Source**	**Priority (Rank)**
Heat the water from the artesian well	Shall sustain water temperatures in 6 (2.5m x 5m x 5m) tanks at 26℃-30℃	REFRESCH	1
Must be able to contain excess water heated by the system	Shall sustain the fish tank temperature during a sun drought for a minimum of 3 days	REFRESCH	2
Must be compatible with the water pumping system in place	System can accept water at a maximum rate of 19 L/s	REFRESCH	3
Must not heat water enough to create mineral deposits on pipes	Shall not allow the water to heat above 90℃	REFRESCH	4

Must use materials available in Kazakhstan	100% of materials used in the device must be available in a Kazakhstan store or from a supplier	REFRESCH	5
Must stay within budget	Scale model will be built with a maximum of $400	REFRESCH	6

Table 1: The customer requirements and corresponding engineering requirements for this project.

Increasing the temperature from 16°C to 26°C is an essential engineering specification as our entire project relies on meeting this specification. Our engineering specification fully describes the requirement for heating the water from the artesian well. Our sponsor, REFRESCH, provided us with an optimal temperature range of 26°C to 30°C that we must meet in order for the tilapia to grow at the optimal rate [17]. Heating the water to this temperature range and maintaining it through the differing seasons [18] is crucial to the success of the project.

In order to create the most efficient and sustainable mechanism possible, we need to design a part of our system that can hold excess heated water for periods of time considered to be in sun drought. The representatives from REFRESCH provided us with the information that led to the definition of a sun drought as less than maximum sun for a minimum of three days [19].

It is crucial that the mechanism we build is compatible with the water pumping system currently in place at the fish farm in Kazakhstan. In our problem statement, we given a maximum of 19 L/s of water flow to use at our discretion. If we were to require more than the flow rate we were given, our mechanism would not be able to function.

When water is heated too much, it increases the chances of scaling due to mineral deposits on the inside of the pipes. This can lead to long term issues with the mechanism that can be costly and potentially threatening to the tilapia in the fish farm. Our sponsors made it clear that avoiding this phenomenon is a priority, so we cannot heat the water above 90°C [20].

All of the materials must be able to be obtained in Kazakhstan to create the most sustainable system possible [21]. This engineering requirement is designed to ensure that the system can be built, maintained and repaired by the fish farm. This requirement describes the importance of sustainability in our project, as expressed to us by REFRESCH.

We were provided a budget of $400 by REFRESCH in order to make our scale prototype. This is an essential specification because the area in Kazakhstan we are designing for is an economically disadvatanged area. We must design a mechanism that will be cost effective in order to have successful implementation in Kazakhstan.

Concept Generation

Following the translation of our user requirements to engineering specifications, we began to generate solutions that would meet these specifications. We initially began by performing a functional decomposition of our task (Figure 2), which allowed us to break our overarching problem into smaller, more manageable tasks. Through the functional decomposition process, we were able to identify the main tasks that need to be addressed. These tasks included utilizing solar power and storage of the heated water. After identifying these tasks, we worked independently to generate as many solutions as possible. Following the independent concept generation, we gathered together to brainstorm ideas. As a result, we had many solutions for our various tasks. Our solutions ranged from the various ways to implement solar power to heat the water to methods of storing the water to ensuring fish safety.

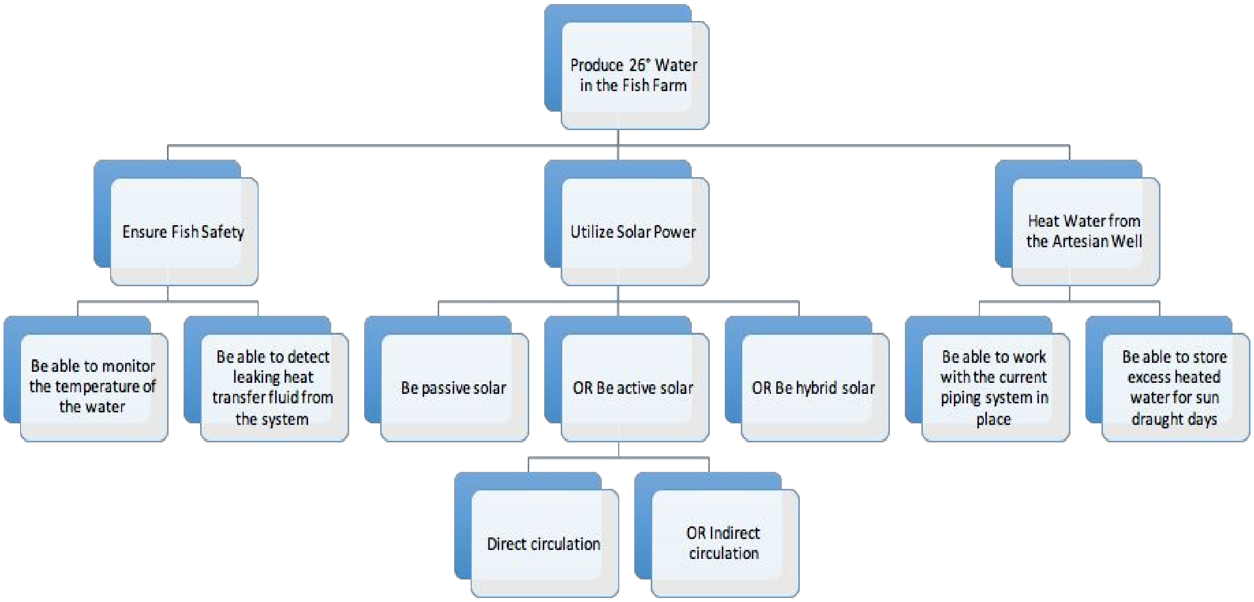


Figure 2: The functional decomposition of the project to determine the areas of interest in the scope.

Since our most important task was to raise the temperature of the water, our major challenge was to generate as many concepts as possible to utilize solar power. One of our concepts was to use passive solar power (Figure 3). Passive solar power is a very simple concept as it does not rely on any mechanical or electrical components. Instead, a passive solar heater relies on thermosyphoning in order to circulate heat. Thermosyphoning is a method of passive heat exchange that relies solely on natural convection to circulate water through a system. Water would then flow down into the solar collector through gravity. The water would be heated in the solar collector causing the heat to move to the hot water tank. From this tank, water could be distributed to the various fish tanks.

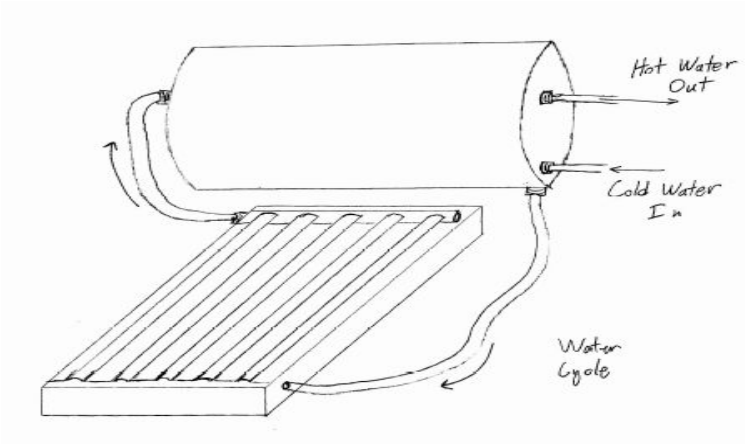


Figure 3: This is a schematic of a passive solar concept.

Another one of our concepts was to use active solar power with a direct circulation. Direct circulation works by circulating water through the system through the use of mechanical or electrical devices, typically a pump. This system also includes a storage tank that can maintain a supply of heated water for the use of the fish farm. We also considered the possibility of using indirect circulation solar power. Indirect circulation operates like a direct circulation system, but circulates a heat transfer fluid instead of water throughout the system.

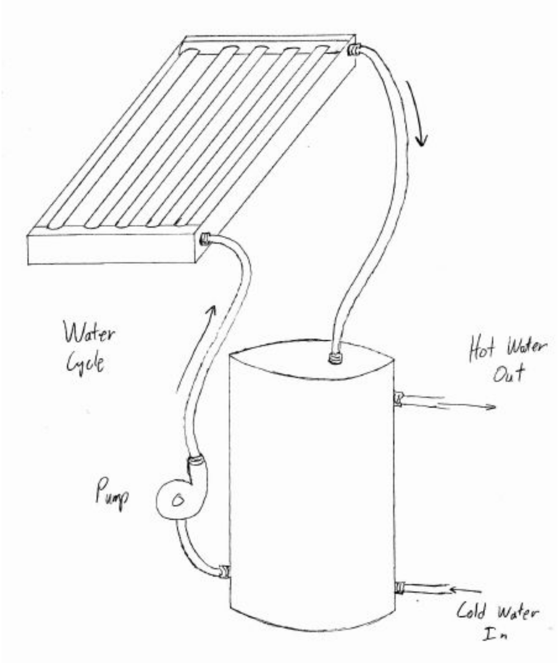


Figure 4: This is a schematic of an active solar concept using direct circulation.

We additionally created a concept based on hybrid solar power, a system similar to an active indirect circulation system. The heat transfer fluid is circulated through the system by a pump. The main aspect in which it differs from a indirect active system is the boiler added to the system. The boiler allows for water to be heated on days when there is limited sunlight.

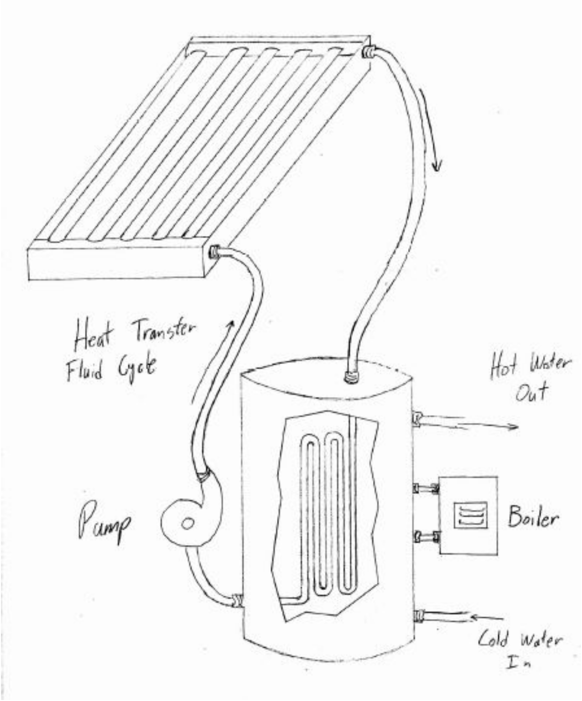


Figure 5: This is the schematic of a hybrid solar concept.

Concept Selection

We used a Pugh chart to document and score our concepts (Table 2). The criteria was weighted from highest to lowest priority in the following order: ability to heat water, cost sensitivity, solar energy utilization, compatibility with current water circulation system and ability to store excess heated water. Our top three concepts, in order, were the totally passive, hybrid, and direct circulation systems.

Criteria	Weight	Concept 1: Totally Passive	Concept 2: Active - Direct Circulation	Concept 3: Active - Indirect Circulation	Concept 4: Hybrid	Concept 5: Gas Heater - No Solar Energy Used
Heat the water from	0.55	4	4	3	5	5

the artesian well						
Cost Sensitivity	0.15	5	3	3	2	1
Utilize Solar Energy	0.12	5	5	5	3	1
Compatible with the water pumping system in place	0.1	4	3	2	3	3
Contain excess heated water from the system	0.08	3	4	4	4	5
Total	**1**	**4.19**	**3.87**	**3.22**	**4.03**	**3.72**

Table 2: The criteria and respective weights to aid with final concept selection. The scale is 1-5 with 1 being the worst and 5 being the best. The pugh chart shows that concept 1 is the best concept.

The hybrid system has the ability to provide heated water regardless of the sun's availability (Figure 5, pg 10). The hybrid system is a combination of an indirect circulation active system passive solar. Again, this advantage comes at the cost of lower efficiency as system complexity. A complicated system is more susceptible to malfunctions.

The totally passive system received the highest score (Figure 3, pg 9). Even though this system relies totally on the sun for energy, it has no other added equipment, such as pumps or a control system, making it very simple and less likely to break down. Since the system is easy to build and maintain, it can be made to suit the exact size of any fish farm. One passive solar water heating unit consists of one solar collector and one storage tank. Depending on the demand of heated water, one or a dozen units can be built. It also is much more feasible than any of the other designs. Designing a simple, totally passive solar system allows the fish farm to build as many units as they deem they need instead of feeling the burden of a more intensive direct circulation or hybrid system.

However, the totally passive system does not allow for the flow rate of the water through the system to be controlled. The direct circulation system utilizes a pump to move water through the solar collector, where it is heated. The water is subsequently returned to the storage tank until it is needed. This system has the ability to house the storage tank indoors, which provides better insulation (Figure 4, pg 9). Even with the small loss of efficiency due to the pump, we believe it is the best system for the fish farm.

Key Design Drivers

In order to generate a concept that will satisfy the customer, we needed to follow a number of design specifications. We must heat the water from the artesian well, be able to contain excess water heated by the system, create a system compatible with the current piping system, not heat the water too much, use materials found in Kazakhstan, and stay within a budget. We have identified the engineering fundamentals that need to be addressed in order to complete the design specifications. We performed a heat transfer analysis, another engineering analysis, and a cost-benefit analysis. The aspect of the design that was the most challenging was figuring out how to perform the heat transfer analysis and how to orient the mechanism for the most efficient way to heat the water using passive solar. The difficulty in accomplishing our goals for this project is a result of our limited knowledge of heat transfer and passive solar technology. However, in order to overcome our difficulties, the team has determined some design drivers to aid the design process. Table 3, below, shows the design drivers used in this project.

Driver ID	Description	Importance	Design Driver Analysis	Validation
Heat Transfer	The mechanism we create must be able to heat the water in the fish farm	If it does not heat the water in the indoor pools, the fish farm cannot start growing Tilapia	Analytical model of the heat transfer through the body of water to determine the most effective heat transfer source temperature	Run a timed heating test on a very basic scale-model for proof-of-concept prototype
Store excess water	Need to be able to store excess heated water for use in sun drought days	Without the storage of excess heated water, the mechanism cannot heat the water when little to no solar energy is available	Analytical model of the heat transfer from the water through different container materials	Run simulations of heat transfer through different materials and determine the different rates of heat loss

Compatibility	Need to be able to work with the current water piping system currently in place at the fish farm	If the mechanism is not compatible with the existing water piping system in place, the fish farm will have a difficult time implementing the new heating mechanism	Analytical model of the amount of pressure and water flow the mechanism can withstand	Run tests on a scale model of the amount of water flow and pressure the mechanism can withstand
Temperature sensor	Need to be able to detect when the source temperature is higher than 90°C due to material deposits and scaling in the pipes	If the mechanism does not have to capability to detect how hot the source temperature is, material deposited and scaling can occur in the pipes and cause long-term damage	Conduct experiment to determine if a temperature sensor can determine if the source temperature is about 90°C or not	Test of physical model
Cost sensitive	Need to be able to cost as little as possible	Kazakhstan is an economically disadvantaged country and if the mechanism is too expensive, it will not be feasible to implement	Conduct research to determine the best materials for the mechanism, taking into account durability and price	Conduct a cost-benefit analysis

Table 3: Design Drivers for the concept generation stage of the project.

The major problems we experienced were with the heat transfer analysis and the engineering analysis. The difficulty in the heat transfer analysis was that we had to perform a full analysis on the heat transfer into the water, and the team is still learning how to perform such an analysis. Additionally, we needed to decide whether the benefits outweigh the costs of implementing a control system in the water to determine if the water in the pipes are overheating to a temperature where mineral deposits can form on the pipes. These problems were addressed with extra time in the project plan schedule and more research to help the process go more smoothly.

Chosen Design

Our chosen concept is an active solar heating system using direct circulation of the water. It consists of three main parts: a solar collector, a storage tank, and a pump. The solar collector is a sealed box with a transparent top and a dark-colored inside for maximum heat absorption. The storage tank can be any insulated container capable of storing water. After cold water enters the storage tank, it is pumped to the solar collector, heated, then returned to the storage tank. This process repeats for as long as hot water is needed.

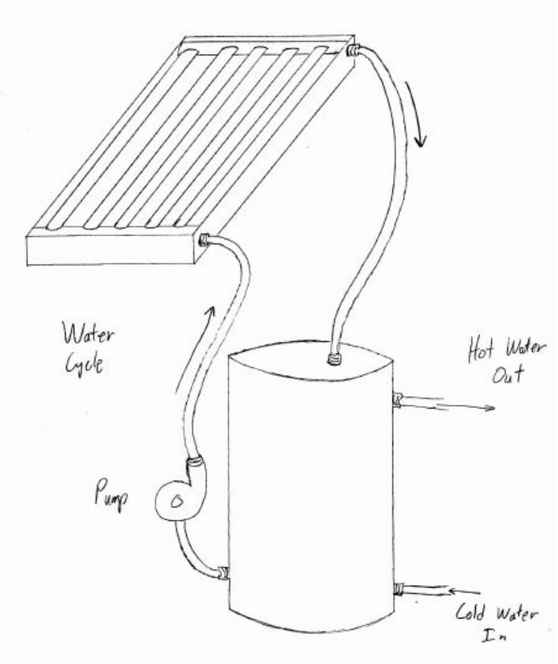


Figure 4 (repeated for convenience): This schematic depicts our chosen solution of a passive solar water system.

Concept Description

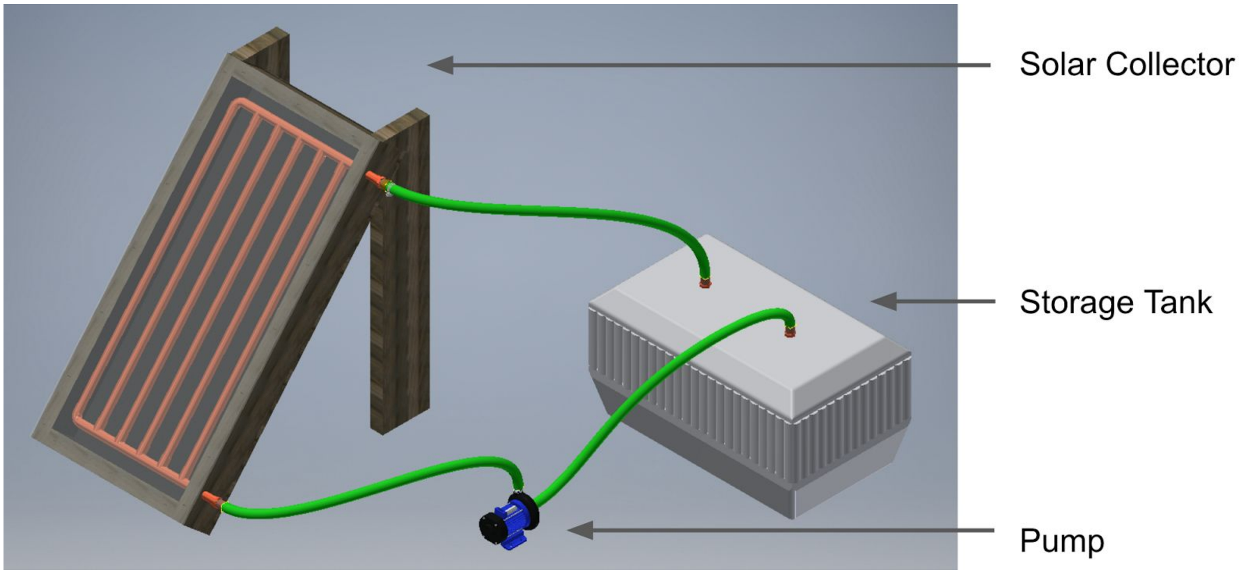


Figure 6: This schematic depicts our chosen design of an active system with direct water circulation.

Our active solar water heating system will consist of three parts, a pump, a solar collector, and a storage tank. The solar collector has a wooden frame consisting of wooden 2x4” beams for the box and 2x6” beams for the support legs. The top of the solar collector has a double layered plexiglass sheet. Our analysis showed that the double layer traps heat and would be a more efficient design. The bottom of the box is made from plywood. Within the box there is a system of copper pipes through which the water will travel. The inside of the box is also painted black to expedite heat absorption.

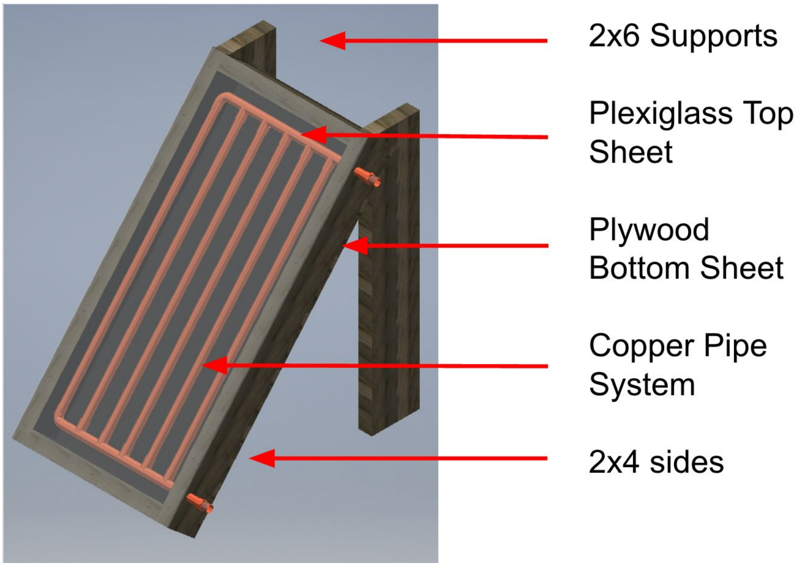


Figure 7: This schematic depicts the solar collector and its parts.

The network of copper pipes consists of elbow fitting and tee fittings as well as ¾ inch copper tubing. All copper components are soldered together to prevent leaks. On the inlet and outlet of the pipe network there are male screw connections that brass female adapters can screw on to for our water lines.

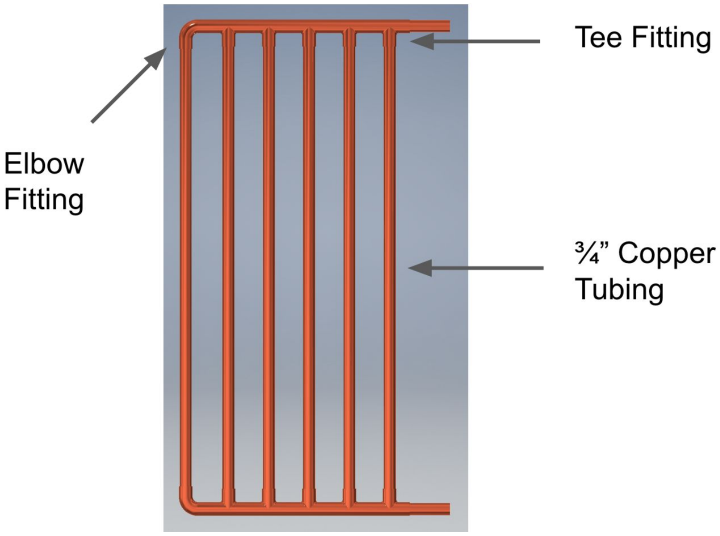


Figure 8: This schematic depicts the copper pipe network.

The storage tank is a simple styrofoam cooler. For our prototype, this allows us to replicate the insulation abilities of a full scale tank while staying within our budget. The top of the cooler has the same male copper connections found on the copper pipe network so that the same hoses and fittings can be used.

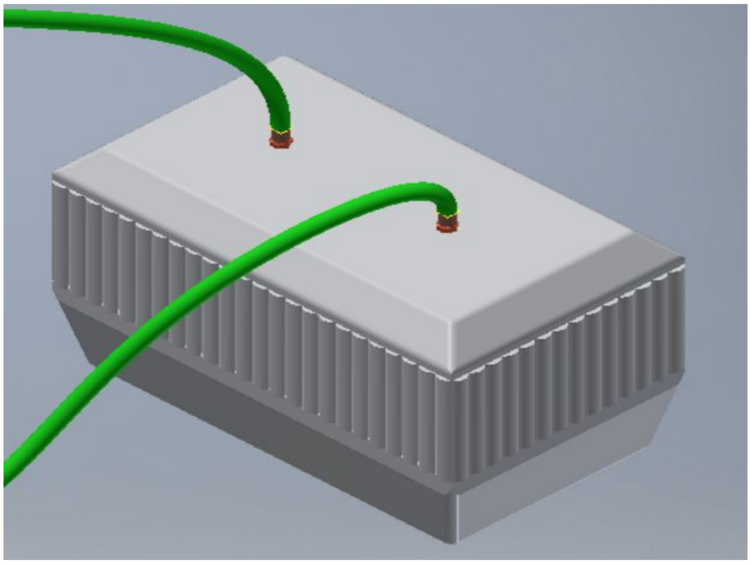


Figure 9: This schematic depicts the styrofoam cooler and hose network.

The pump will have a power output of ½ HP and be able to cycle about 1500 gallons per hour. The pump will have ¾ inch screw fittings at the inlet and outlet to allow it to easily connect to our system.

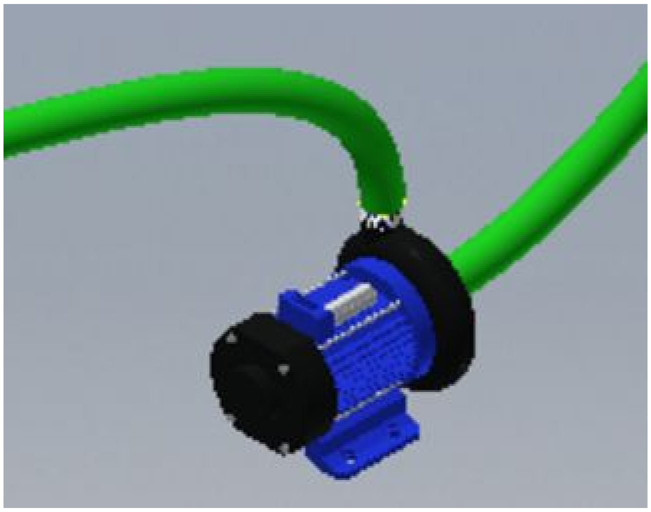


Figure 10: This schematic depicts the styrofoam cooler and hose network.

Engineering Analysis

Theoretical Modeling:

One of our major design drivers is to ensure that the solar collectors work effectively to raise the water to at least 26°C. To determine the final temperature of the water and water flow rate through our system, we needed to perform a heat transfer analysis on the solar collector. We began our analysis by drawing a schematic of the solar collector and its different layers. We then wrote down what type of heat transfer occurred at each layer. Since we had noted some concern about the heat transfer analysis we met with two different heat transfer professors to talk through our approach to the problem to ensure that we were on the right track.

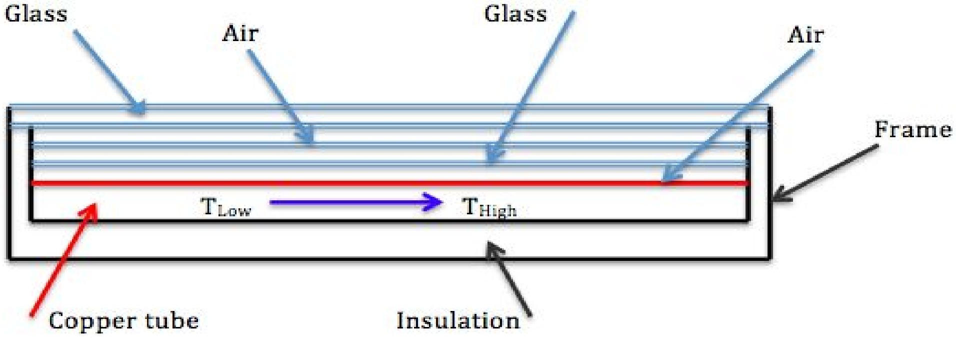


Figure 11: This schematic shows the various layers associated with our solar collector.

Meeting with the professors proved to be very useful as they clarified any remaining questions we had about our system. Following these meetings, we began to perform the heat transfer analysis. For the layers leading up to the copper tube, we used the following equation to determine the thermal resistance through the various layers and the effect it would have on the temperature of the tube.

$$\sum R = R_{cond,glass\ 1} + R_{conv,air\ 1} + R_{cond,glass\ 2} + R_{conv,air\ 2} + R_{conv,cu} + R_{cond,cu}$$

Once we had that term, we set up a control volume in the copper tube to analyze how the temperature of the water changed with a small distance.

$$\dot{E}_{cv} = \dot{q}_{in} - \dot{q}_{out} + q_{sun} - \dot{q}_{TC} = 0$$

The control system allowed us to take the general energy balance equation and substitute terms to come up with a new energy balance equation. We set this new equation to zero because we are considering the steady state case.

$$\dot{E}_{cv} = \dot{m}C_pT_m(x) - \dot{m}C_pT_m(x+dx) + q''_{sun}P_m dx - \frac{T_s - T_\infty}{\sum R}$$

Using this equation, we were able to generate a spreadsheet that would compute the temperature of the water at any given mass flow rate up to 14 kg/s. Given the difference in sizing from our model to their actual collector. It was beneficial to be able to change parameters to reflect accurately the final water temperature for any desired mass flow rate. Our theoretical model indicates that our solar collector can heat water to 30°C at a flow rate of 7 kg/s. To increase efficiency, we decided to add fins to our system as well as add a layer of aluminum to reflect additional light to our pipes.

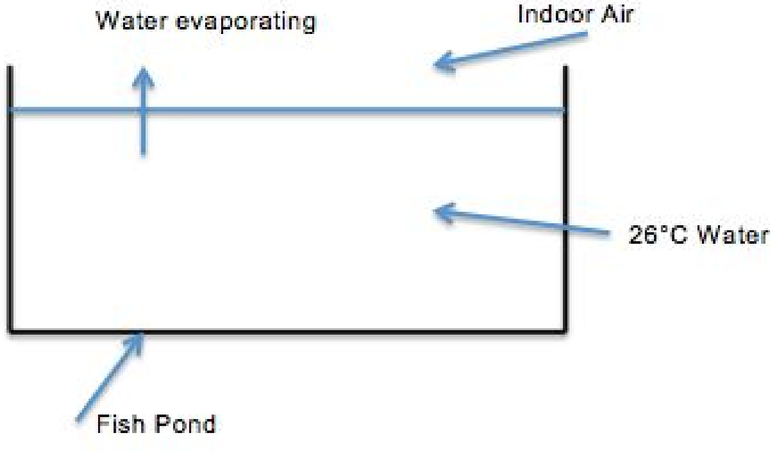


Figure 12: This is a visual representation of a fish pond.

We additionally analyzed the amount of water evaporating from the 26°C fish tanks to the indoor atmosphere in order to determine the amount of fresh water that would need to be supplied to maintain the required water temperature. The amount of water that would be evaporated depends on several factors such as temperature of the water and air as well as the humidity of the air and the velocity of the air. The humidity in Kazakhstan can range from 25% relative humidity to 95% relative humidity.

Using the following equation, we were able to create a spreadsheet to determine the heat loss due to evaporation of the heated water into the air depending on the humidity in the air.

$$g_s = \frac{(25 + 19v)A(x_s - x)}{3600}$$

This equation calculate the amount of evaporated water per second, where v is the velocity of the air, A is the water surface area, x_s is the humidity ratio in saturated air at the same temperature as the water and x is the humidity ratio in the air.

$$q = g_s h_{we}$$

We used this value to calculate the required heat supply to a single fish pool. The term, q, refers to the heat needed to maintain the water temperature at 26°C and the term h_{we} refers to the evaporation heat of water which is a constant 2270 kJ/kg.

After doing the following calculations, we determined that for days of high humidity, we would only need to supply 13.1 kg/s whereas on days of low humidity, we would need to supply 98 kg/s of 26°C.

Mockup Construction:

For our mockup we wanted to build the three main components of our system to visualize how they will all fit together. The solar collector was made from cardboard and tape. Our full scale prototype is made of wood and plexiglass, but by building the mockup we were able to see that we do not need to have tight tolerance to get the components to fit together in an acceptable manner. The storage tank was modelled with a plastic container and duct tape to represent insulation. To get the desired heat retention in our prototype, we switched to a styrofoam cooler to hold the water. The pump was made out of foam to be a visual representation in our system. All three components were connected with pipe cleaners to represent the hoses with red pipe cleaners demonstrated heated water and blue pipe cleaners showing colder water flow.

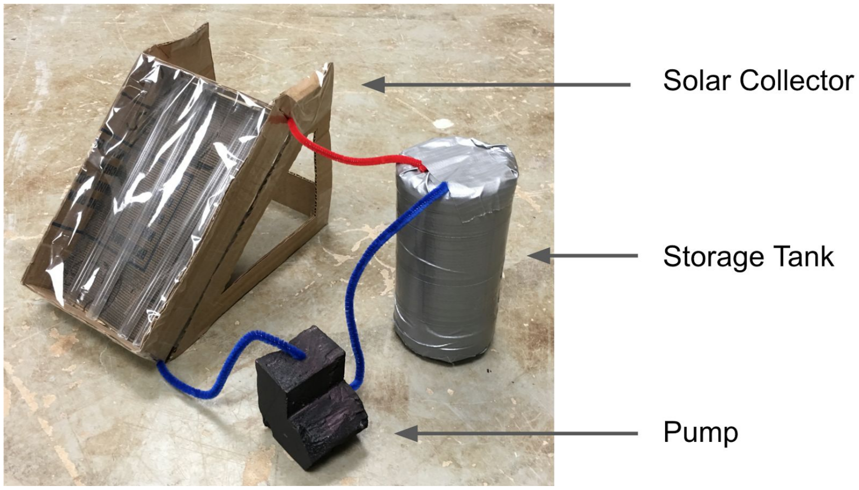


Figure 13: System mockup with solar collector, storage tank and pump.

We believe that our mode of analysis was appropriate because it focused on the part of most importance to our system: the solar collector. The pump and storage tank are not as important because they are useless unless we can prove that we can heat water using the sun's energy. We chose a level of detail that was enough for us to find out what temperature we could heat water to as it was moving through our system at a rate of 150 gallons per minute. After our analysis, we realized that the copper tubes that carry water through the solar collector must be about half an inch from the plexiglass top of the solar collector. This allows for maximum heat absorption. Our design seems functional and as it stands, we believe it will heat the water to some degree, however, we are not totally confident in the temperature we received from our analysis. We believe that the temperature that resulted from our analysis is much higher than the temperature that can be achieved at the rate water is flowing through the solar collector. We plan to carefully go over our calculations as well as collect data from our prototype to compare the results with our theory.

FMEA/ Risk Analysis

In order to have the best understanding of our design, we have performed a formalized FMEA and Risk Analysis. The FMEA and Risk Analysis are shown, respectively, in Tables 4 and 5, below.

Item	Function	Potential Failure Mode	Potential Effects of Failure	Severity of Effect	Potential Causes of Failure	Probability of Occurrence	Current Design Controls	Detection	RPN	Recommended Action

Temperature sensor control system	Detects when the water in the fish tank is not within the normal range	Temperature sensor does not detect when fish pool overheats	Fish die due to overheating	10	Device not attached properly	3	Test and validate method	4	120	Incorporate an alert to notify workers if the temperature is not working
					Sensor stopped working due to component failure	4		5	200	Choose a robust temperature sensor
		Temperature sensor does not detect when fish pool is too cool	Fish die due to being too cold	10	Device not attached properly	3		4	120	Incorporate an alert to notify workers if the temperature is not working
					Sensor stopped working due to component failure	4		5	200	Choose a robust temperature sensor
Pipes	Delivers the water from the artesian well to the solar collector	The water in the pipes can freeze in the winter	The water can not make it to the solar collector to heat up and will not heat the fish tanks	8	The pipes are not properly insulated	8	Test and ensure the pipes are well insulated	2	128	Choose a reliable type of pipe insulation
		The pipes burst	The water will not be as effective warming up the fish tanks with a lower flow rate	7	Pressure build-up in the pipes	2	Test and ensure the pressure is one the pipes can tolerate	2	28	Incorporate a pressure monitoring device the pipes

			This could cause damage to the piping system	4				4	32	Research pressures that can be tolerated by the pipes in the facility
	Delivers the water from the solar collector to the holding tank	The water in the pipes can freeze in the winter	The water can not make it to the holding tank and will not heat the fish tanks	8	The pipes are not properly insulated	8	Test and ensure the pipes are well insulated	2	128	Choose a reliable type of pipe insulation
		The pipes burst	The water will not be as effective warming up the fish tanks with a lower flow rate	7	Pressure build-up in the pipes	2	Test and ensure the pressure is one the pipes can tolerate	2	28	Incorporate a pressure monitoring device the pipes
			This could cause damamge to the piping system	4				4	32	Research pressures that can be tolerated by the pipes in the facility
	Delivers the water from the holding tank to the fish tanks	The pipes burst	The water will not be as effective warming up the fish tanks with a lower flow rate	7	Pressure build-up in the pipes	2	Test and ensure the pressure is one the pipes can tolerate	2	28	Incorporate a pressure monitoring device the pipes
			This could cause damam	4				4	32	Research pressures that

			ge to the piping system							can be tolerated by the pipes in the facility
Heating Tank	Hold the water that has come from the well and that has been heated before it is pumped to the holding tank	The tank can fall off the top of the solar collector	The water can not be moved to the fish tanks now	8	Bracket that holds the tank on top may fail	1	Test and validate method	1	8	Choose a robust bracket
			The tank could land on a worker during maintenance	10				1	10	Develop strict maintenance manual
Solar Collector	Heats the water from the well using solar energy	The solar collector may not heat the water	The fish will not receive any hot water and potentially freeze to death	9	The solar collector may not be positioned right	5	Test and validate angles	7	315	Research the optimal angle to position the solar collector
					The solar collector may be receiving too much water too quickly	3	Test and validate water pumping method	2	54	Determine the optimal flow rate that the solar collector can take
Holding Tank	Holds the water heated from the solar collector to use at a time when solar energy is not available	The tank may not hold the heat in the water	The tank can not transfer hot water to the fish tanks in a sun drought	7	The tank is not well insulated	3	Test and ensure the tank is well insulated	5	105	Choose a reliable type of tank insulation

Table 4: The formalized FMEA for the solar-powered water heater. The aspect of the design with the highest risk is the positioning of the solar collector. The red boxes show that failure is almost certain to occur. The yellow boxes show that failure is likely to occur. The green boxes show that failure is less likely to occur.

Hazard	Hazardous Situations	Likelihood	Impact	Level	Schedule	Cost	Action to minimize hazard
Fish tank overheating	When heating the fish tank, the fish could be harmed or die due to the water overheating.	Unlikely	Catastrophic	Medium	Minimal or no impact	Little to no cost	Add another pipe directly from the well to the fish tanks to feed in cooler water.
Water through pipes overheating	When heating the fish tank, the water through the pipes could exceed the maximum temperature limit and deposit minerals on the pipes.	Unlikely	Moderate	Low	Minimal to no impact	Unit cost increase by the amount of a sensor	Add a temperature sensor in the storage tank to monitor the temperature of the heated water. Once the water gets to a certain temperature, stop the heated water flow into the tank.
Electrical shock	When the water temperature is monitored, anything coming into contact with the water could be harmed by shock if the control system is not properly insulated.	Remote	Serious	Low	Minimal to no impact	Unit cost increase by the amount of the insulation	Add extra insulation around the control system elements implemented in the fish tanks.
Pipe bursts	When the pressure in the pipes is too great, the workers could be injured by scalding water due to the burst pipes.	Remote	Catastrophic	Low	A halt in production due to the possibility of having to order a speciality hot water tank	Unit cost increase by the amount of a hot water tank	Implement a pressure sensor with an emergency release valve.
Heating tank falls	It is possible that after prolonged use the mechanism securing the heating tank in place may fail due to fatigue and cause the tank to fall and damage the equipment or harm workers.	Remote	Moderate	Negligible	Little to no impact	Little to no cost	Establish a routine maintenance protocol.
Pipes freeze	It is possible that during the winter, the water in the	Likely	Serious	High	Minimal to no impact	Unit cost increase by the	Add extra insulation around the

	exposed pipes may freeze due to lack of insulation and result in no hot water reaching the fish tanks which causes the fish to die.					amount of the insulation	outdoor, exposed piping system.

Table 5: The Risk Analysis for the solar-powered water heater.

The aspect of the design with the highest risk is the solar collector, which heats the water from the artesian well using solar energy. This aspect has the most risk because the solar collector needs to be placed in the most optimum position so that it can be most effective all day. If this component of the design fails, the fish tanks will not receive warm water and the fish will likely die from the water being too cold. Currently, there are no controls in place to determine the optimal solar collector position other than to test and validate different angles. In order to reduce the risk associated with this aspect of the design, we researched the optimal angle to place the solar collector and how to orient it with the fish farm building already standing. After determining that the optimum orientation for the solar collector is south-facing with a 36.23° tilt, the risk associated with this aspect of the design is greatly reduced. Overall, the risk is now at an acceptable level.

Manufacturing Plan

A detailed list of all manufacturing plans and a bill of materials can be found in Appendix B. For our prototype we decided to stick with a manufacturing process that was simple and easily replicable in Kazakhstan. Because we have access to a machine shop some steps call for a drill press but a hand drill is perfectly acceptable for those parts. All screw holes have been required to be pre drilled to guarantee proper screw placement as well as reduce the chance of the wood splitting. The methods we chose for manufacturing are not very precise. It is hard to create an angled cut to the exact degree using a circular saw. Luckily high precision is not necessary for our design. The most important aspect of the solar collector is having a sealed space that allows for the heating of the copper tubing within. This can be achieved with relatively low tolerances. The production cost of the solar collector and hose connections are relatively low compared to the cost of the pump.

Final Design

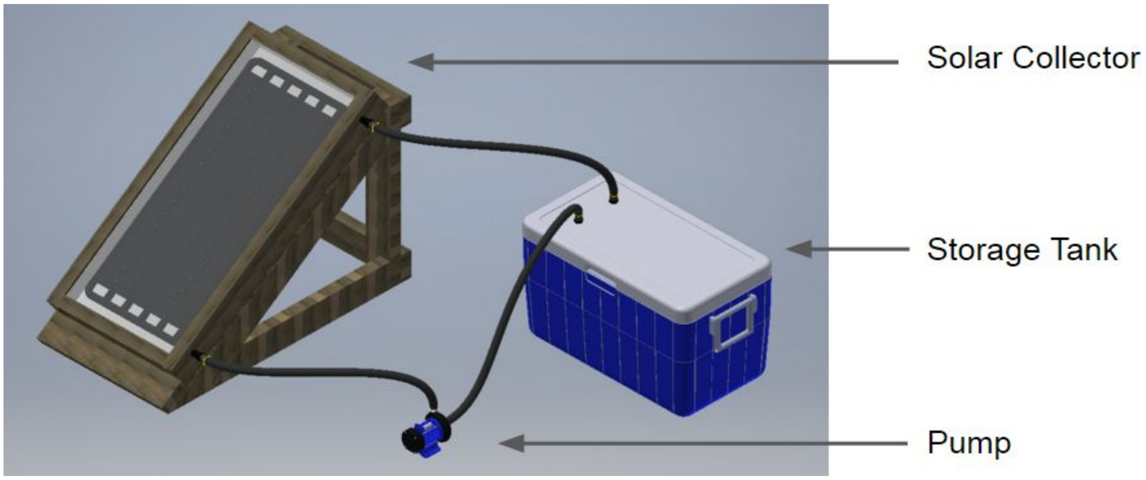


Figure 14: This schematic depicts our final design of an active system with direct water circulation.

Our final design consists of three parts, a pump, a solar collector, and a storage tank. The solar collector has a wooden frame consisting of wooden 2x4” beams. The top of the solar collector is a double layered polycarbonate sheet. Our analysis showed that the double layer traps heat and would be a more efficient design. The bottom of the box is made from plywood. Within the box there is a system of copper pipes through which the water will travel. There are ⅛” thick aluminum fins soldered in between the copper pipes as well as a matte black coating to increase heat absorption. Below the copper pipes as well as on the inner sides of the box there is a layer of aluminum foil to reflect heat back to the pipe network. Below the aluminum foil there is a layer of foam to keep the heat within the cavity the pipes are located in.

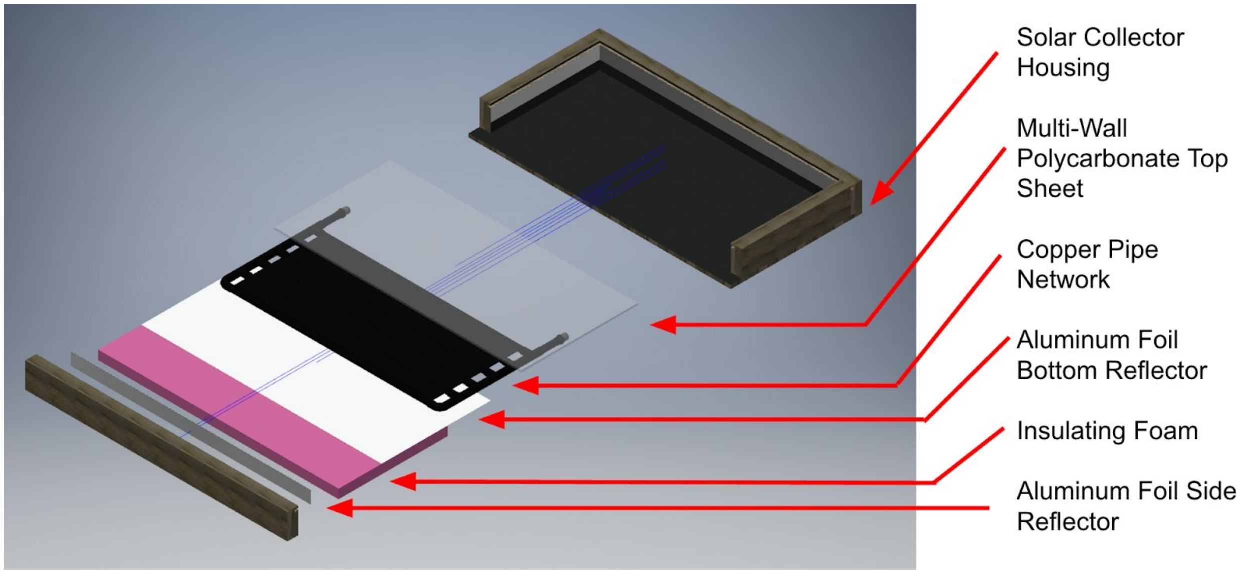


Figure 15: This schematic depicts the solar collector and its parts.

The network of copper pipes consists of elbow fittings and tee fittings as well as ¾” diameter copper tubing. All copper components are soldered together to prevent leaks. On the inlet and outlet of the pipe network there are copper male screw fittings with NPT (national pipe thread) threads. To accommodate the female GHT (garden hose thread) threads of the transfer hoses, a brass fitting with NPT female threads and GHT male threads is attached to the copper male screw fitting.

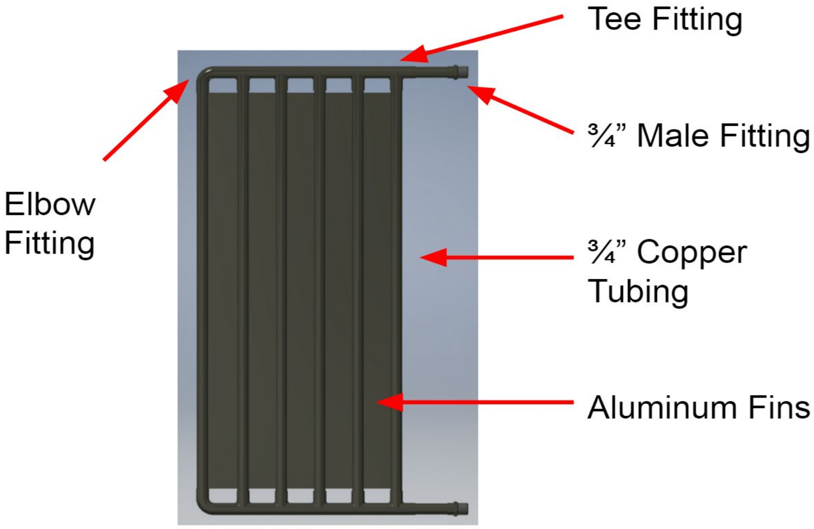


Figure 16: This schematic depicts the copper pipe network.

The solar collector stand is a simple wooden structure that supports the solar collector. For our prototype, this allows us to rest the solar collector at the optimum angle of 36 degrees. The solar collector rests on top of the stand and is removable so that the system is easy to move to different locations.

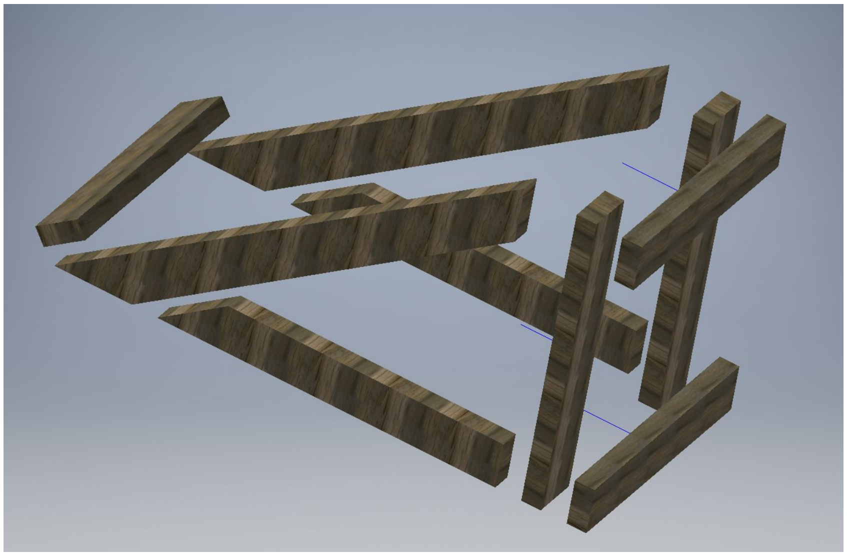


Figure 17: This schematic depicts the wooden stand that holds the solar collector.

The storage tank is a simple plastic cooler which is able to hold 75 qts. For our prototype, this allows us to replicate the insulation abilities of a full scale tank while staying within our budget. The top of the cooler has the same male copper connections found on the copper pipe network so that the same hoses and fittings can be used.

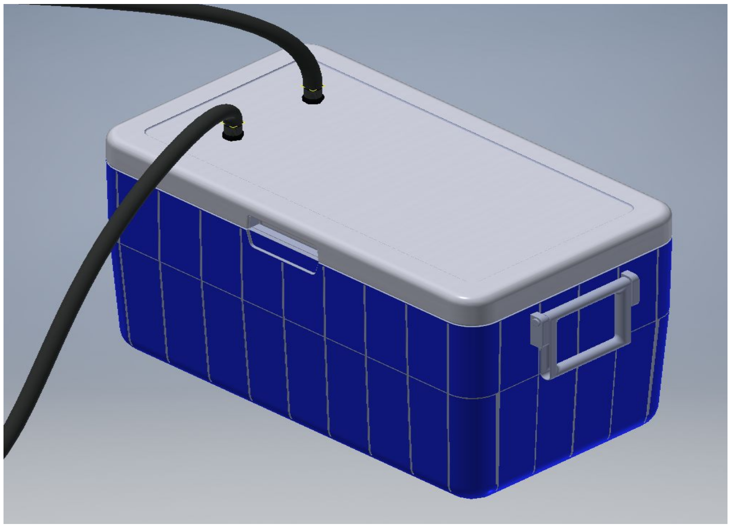


Figure 16: This schematic depicts the plastic cooler and hose network.

The pump will have a power output of ½ HP and be able to cycle about 300 gallons per minute. The pump will have ¾ inch hose screw fittings at the inlet and outlet to allow it to easily connect to our system.

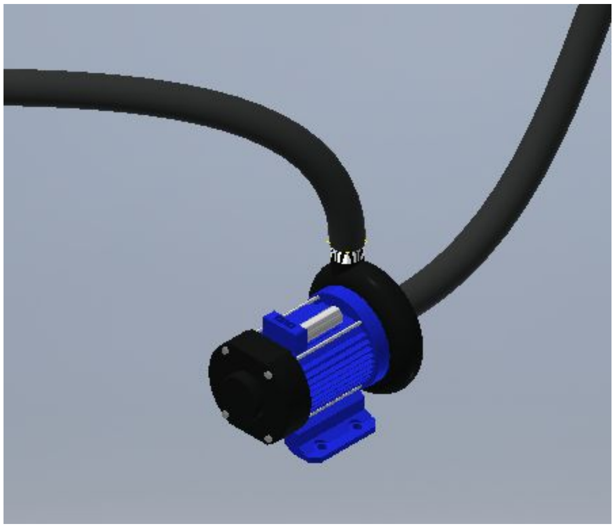


Figure 17: This schematic depicts the styrofoam cooler and hose network.

Challenges/ Recommendations

Currently, the main challenges in the project are the the utilization of the maximum supply of water we are given, the accuracy of our heat transfer analysis, and the material selection process. Our design is difficult because we need to find a way to heat water that is provided at 150 gal/min. Because the amount of flow is so high, we will most likely have to restrict the flow of the water somehow so that we can use less at a time. Additionally, we are working with a very ideal situation and with approximations for most values given to us from the facility is Kazakhstan. As of now, exact values of dimensions at the fish farm and other values that are critical for analysis are being approximated, which makes for a chance of error in the calculations. With the calculations being made on a heavily ideal situation, the results of the analysis may not be as accurate compared to what would happen in actuality. Finally, as we move forward, we anticipate the validation testing to be challenging. We are planning on testing our system to validate our analysis. We need to have the prototype completely finished before we can begin testing. In order to overcome these problems, we plan to research more options for flow restriction and material selection, along with talking to REFRESH for assistance with these issues.

Proof-of-Concept Validation Plan

Our major requirement was to heat water from 16℃ to 26℃. We conducted a test with the system in direct sunlight, and an ambient temperature of 3℃, to determine if water can be heated using the sun's energy. The only equipment used in the experiment was a thermocouple and multimeter. Figure 18 shows the system set-up during testing.

Figure 18: This is the testing set-up including the thermocouple used to determine the reserve tank temperature.

We submerged a thermocouple in the water within the insulated tank to measure the increase of temperature in the water being recirculated through the system. We ran this test for 90 minutes and recorded the temperature of the water in the insulated tank every 15 minutes. Within 90 minutes, the temperature of the water increased from 19℃ to 31℃.

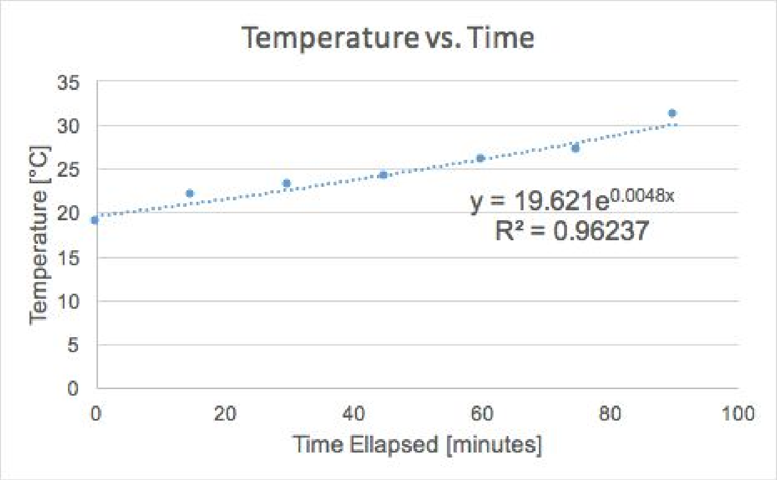


Figure 19: The exponential trend resulting from the data collected during testing.

Data from the validation testing suggests an initial temperature jump followed by a steady increase in small increments. This could be due to the continuous mixing of hot and cold water in the insulated storing tank. We can estimate an increase of 10℃ in the span of an hour. Better results could have been obtained in testing if the testing location was completely open with no near-by buildings.

Ultimately, the solar collector can perform to the capacity that it was intended to and will need to be scaled up for actual implementation within the fish farm. As an end result, we are able to heat the water from 16°C to 26°C within one hour.

Project Plan

Our project plan consists of a Gantt chart that gives a timeline of the tasks we needed to complete by Design Review 4. Table 6, below, shows the Gantt chart for the team's progress leading up to Design Review 2. The team hit all the deadlines we set for ourselves, except for completing the team profiles and the in-depth patent research. Additionally, we started many aspects of the project later than we had originally anticipated. This shows that the team needed to work harder to start the tasks earlier to ensure enough time for completion.

Table 6: The team's Gantt chart shows the tasks that have been completed up until Design Review 2. The blue lines indicate the anticipated time line, while the green lines show that the task was completed on time and the red line show that the task was completed late.

After Design Review 2, the Gantt charts shows the team's progress leading up to Design Review 3. The team hit all the deadlines we set for ourselves, except for the internal deadlines for the heat transfer analysis and other engineering analysis. Additionally, we started many aspects of the project later than we had originally anticipated, but finished many aspects early, as well. This shows that the team needs to work harder to start the most tasks earlier to ensure enough time for completion. This Gantt Chart can be seen in Table 7, below.

Table 7: The team's Gantt chart shows the tasks that have been completed up until Design Review 3. The blue lines indicate the anticipated time line, while the green lines show that the task was completed on time and the red line show that the task was completed late.

After Design Review 3, the Gantt charts shows the team's progress leading up to Design Review 4. The team hit all the deadlines we set for ourselves and finished most activities in a shorter time frame than allotted. Additionally, we started many aspects of the project later than we had originally anticipated, but finished some aspects early, as well. This Gantt Chart can be seen in Table 8, below.

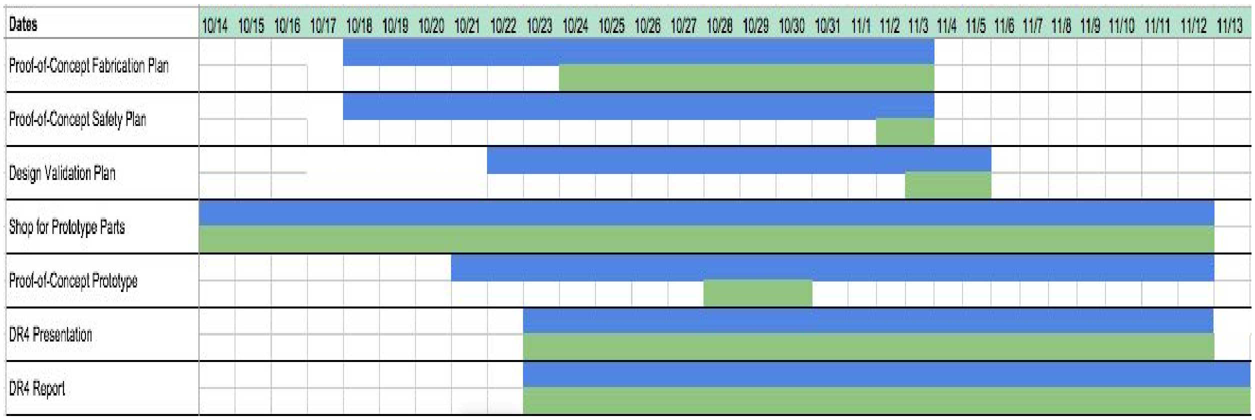


Table 8: The team's Gantt chart shows the tasks that have been completed up until Design Review 4. The blue lines indicate the anticipated time line, while the green lines show that the task was completed on time and the red line show that the task was completed late.

After Design Review 4, the Gantt charts shows the team's progress leading up to Design Review 5. The team hit most of the deadlines we set for ourselves, but they manufacturing took longer than anticipated which pushed back the majority of the validation. This Gantt Chart can be seen in Table 8, below.

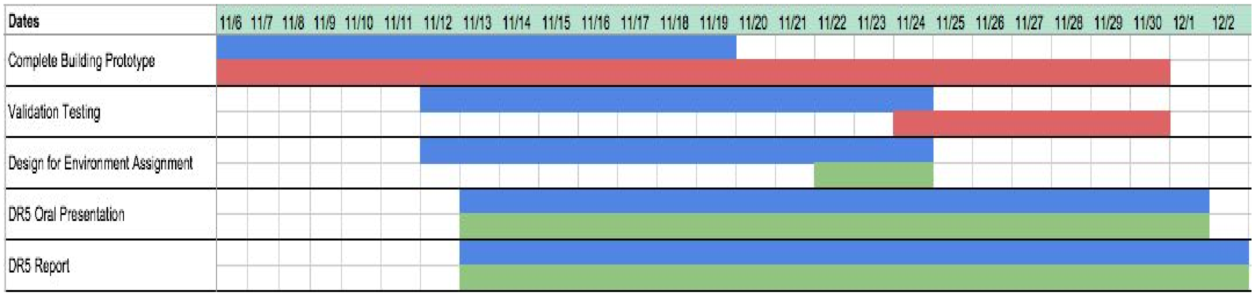


Table 9: The team's Gantt chart shows the tasks that have been completed up until Design Review 5. The blue lines indicate the anticipated time line, while the green lines show that the task was completed on time and the red line show that the task was completed late.

After Design Review 5, the Gantt charts shows a projected timeline for task completion leading up to the Design Expo. According to the Gantt Chart, we are trying to maximize the time that we spend on final components of the project in preparation for Design Expo. This Gantt Chart can be seen in Table 10, below.

After Design Review 5, the Gantt charts shows the team's progress leading up to Design Expo. The team hit most of the deadlines we set for ourselves, but the proof-of-concept validation took longer than expected because the validation testing was delayed due to weather. This Gantt Chart can be seen in Table 8, below.

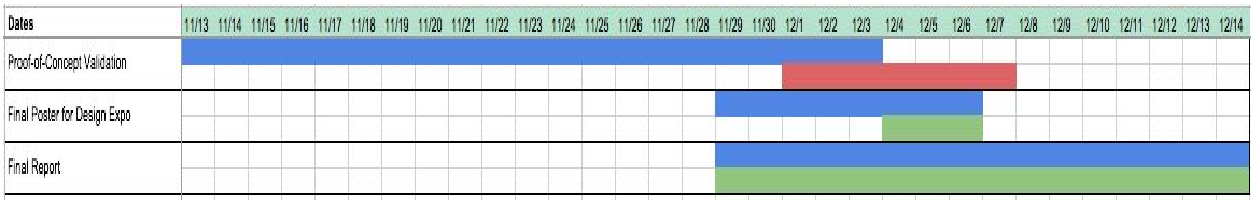


Table 10: The team's Gantt chart shows the tasks that have been completed to the end of the project. The blue lines indicate the anticipated time line, while the green lines show that the task was completed on time and the red line show that the task was completed late.

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Appendix A: Complete List of Initial Concepts Generated

Systems
- Totally Passive
- Active systems
  - indirect circulation of heat transfer fluid
  - direct circulation of water
- Hybrid - indirect circulation with added gas boiler
- Solar panels power electric hot water heater

Storage tanks
- plastic with insulation
- metal with insulation
- placed above solar collector (outside)
  - on roof
  - on ground level
- placed in the building with fish tanks (inside)
- mechanical device inside tank to shut off system when the tank is at capacity

Solar Collector housing
- glass or plastic for top sheet
- wood
- carbon fiber
- metal
- adjustable base and frame to optimize for angle of sun

Internal fluid tube materials in solar collector
- copper
- iron
- plastic
- rubber
- acrylic

Solar Collector Locations
- ground
- platform few feet off ground

- roof
- on top of solar collector
- build into south wall

Monitoring water temperature

- sensors
    - in storage tank
    - in fish tanks
    - before fish tanks
- Recycling option if temperature is not hot enough
- pressure release valves

Ways to circulate water through system

- thermosyphoning
- electric pump
- gravity
- water pressure from artesian well
- Fish Safety

Appendix B: Bill of Materials and Manufacturing Plans

Bill of Materials					
Material	**Manufacturer**	**Part No.**	**Cost**	**Quantity**	**Total Cost**
1/4" plywood	home depot		$24.98	1	$24.98
1/4" multiwall polycarbonate	home depot		$96.00	1	$96.00
7ft. wood 2x4	home depot		$1.78	5	$8.90
1" wood screws (bag)	home depot		$3.60	1	$3.60
silicon caulk	home depot		$5.92	1	$5.92
caulk gun	HDX		$2.77	1	$2.77
.75" dia. copper pipe (10ft.)	Cerro	3/4 M 10	$12.51	2	$25.02
.75" dia. copper 90-degree	NIBCO	C607	$0.80	2	$1.60
.75" dia. copper tee	NIBCO	CP611HD34	$2.12	10	$21.20
.75" dia. male adapter	NIBCO	C604HD34	$1.98	2	$3.96
cooler 75qt.	Coleman		$39.97	1	$39.97

Water Pump (donated)			$0.00	1	$0.00
5/8" dia. hose	Teknor	8876	$7.47	3	$22.41
5/8" hose insulation			$10.50	1	$10.50
1" hose (3ft)			$7.50	1	$7.50
hose clamps			$0.94	6	$5.64
hose splicer			$4.00	2	$8.00
				TOTAL	$287.97

Whole System					
Team Name: ME450 Team 10					
Manufacturing Plans for individual parts follows					
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
Copper Pipe Network					
1	Solder copper fittings together according to manufacturing drawing			propane torch, solder, pliers	
Hoses					
1	cut hoses to desired lengths			knife	
2	for each hose slide one end on to a brass female screw connection and use a clamp to sure the connection in place			screwdriver	
3	repeat for the other end of the hose				
Solar Collector					
1	Use 3" wood screws to attach the long and short wood 2x4s together to form a rectagle of approx 1.5x3 ft. with the black spray pained sides facing in			screwdriver	

2	Use 1" wood screws to attach 2x4 rectangle assembly to the plywoods base, with the black spray painted side facing the 2x4s			screwdriver	
3	Slide the copper pipe assebly into the box and seal the inlet and outlet holes silicon				
4	Use 1" wood screw to attach both plexiglass sheets to the top of the solar collector			screwdriver	
5	use 3" wood screws to attach the 2x6 wooden supports to the solar collector fram			screwdriver	
6	solder 3/4" males copper screw fittings to the inlet and outlet of the copper pipe network			propane torch, solder, plyers	
7	attach one side of a hose to the outlet of the pump and one side to the input fitting of the solar collector			wrench	
8	attach one side of a hose from the output of the solar collector to the input of the storage tank			wrench	
Storage Tank					
1	Fit 3/4" male copper screw fitting into the holes on the top of the styrofoam cooler				
2	seal the fittings in place with silicon				
3	attach a hose from the solar collector			wrench	
4	attach a hose that goes to the inlet of the pump			wrench	

Part Name: Solar Collector Top					
Team Name: ME450 Team 10					
Raw Material Stock: 1/4" Multiwall Polycarbonate Sheet					
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed***

					(RPM)
1	Use table saw to cut piece to 18x36"	Table Saw	C-clamp		

Part Name: Solar Collector Bottom Base					
Team Name: ME450 Team 10					
Raw Material Stock: 1/4" Plywood Sheet					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (RPM)**
1	Use table saw to cut piece to 18x36"	Band Saw	C-clamp		
2	Drill through holes according to pattern on manufacturing drawing	Drill Press	vise	.25" inch drill bit, collet	840
3	Spray Paint Black			spray paint	

Part Name: Solar Collector Long Side					
Team Name: ME450 Team 10					
Raw Material Stock: Wood 2x4					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (RPM)**
1	Cut wooden 2x4 to 36" in length		vise	circular saw	
2	Drill .125" dimater holes to 1" depth according to pattern on manufacturing drawing	Drill Pres	vise	.125" inch drill bit, collet	840
3	cut .25" thick slot according to manufacturing drawing	table saw			
4	Spray paint black			spray paint	

Part Name: Solar Collector Long Side with holes					
Team Name: ME450 Team 10					

Raw Material Stock: Wood 2x4					
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut wooden 2x4 to 36" in length		vise	circular saw	
2	Drill .125" dimater holes to 1" depth according to pattern on manufacturing drawing	Drill Pres	vise	.125" inch drill bit, collet	840
3	Cut .25" thick slot according to manufacturing drawing	table saw			
4	Drill .75" diameter through holes on the sides of the 2x4 according to pattern on manufactruing drawing		vise	.75" inch drill bit, hand drill	840
5	Spray paint black			spray paint	

Part Name: Solar Collector Short Side					
Team Name: ME450 Team 10					
Raw Material Stock: Wood 2x4					
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut wooden 2x4 to 18" in length		vise	circular saw	
2	Drill .125" dimater holes to 1" depth according to pattern on manufacturing drawing	Drill Pres	vise	.125" inch drill bit, collet	840
3	Cut .25" thick slot according to manufacturing drawing	table saw			
4	Spray paint black			spray paint	

Part Name: Water Circulation Hose					
Team Name: ME450 Team 10					
Raw Material Stock: .75" diamter hose					

Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (RPM)**
1	Cut hose to 2.5 ft. in length			band saw	
2	Remove excess burs			knife	

Part Name: Solar Collector Internal Piping					
Team Name: ME450 Team 10					
Raw Material Stock: .75" diameter copper pipe					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (RPM)**
1	Cut pipe to 16" in length			band saw	
2	Remove excess burs			file	

Part Name: Solar Collector Horizontal Frame Component					
Team Name: ME450 Team 10					
Raw Material Stock: Wood 2x4					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (RPM)**
1	Cut wooden 2x4 to 26" in length		vise	circular saw	
2	Make 36 degree angle cut along short end of the wooden 2x4		vise	circular saw	

Part Name: Solar Collector Vertical Frame Component					
Team Name: ME450 Team 10					
Raw Material Stock: Wood 2x4					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (RPM)**
1	Cut wooden 2x4 to 23.22" in length		vise	circular saw	

Part Name: Solar Collector Diagonal Frame Component					
Team Name: ME450 Team 10					
Raw Material Stock: Wood 2x4					
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut wooden 2x4 to 39.5" in length		vise	circular saw	
2	Make 36 degree angle cut along bottom short end of the wooden 2x4 and a 54 degree angle along the top short end		vise	circular saw	

Part Name: Solar Collector Frame Stop					
Team Name: ME450 Team 10					
Raw Material Stock: Wood 2x4					
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut wooden 2x4 to 18" in length		vise	circular saw	

Part Name: Water Storage Tank					
Team Name: ME450 Team 10					
Raw Material Stock: Styro Foam Cooler (24x14x15")					
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut .75" diameter holes in the top according to pattern on manufacturing drawing		vise	.75" drill bit, hand drill	

Part Name: Solar Collector Aluminum Fins					
Team Name: ME450 Team 10					

Raw Material Stock: 1/8" Aluminum Plate					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (RPM)**
1	Use band saw to cut piece to 1.9x27.2"		vise	band saw	

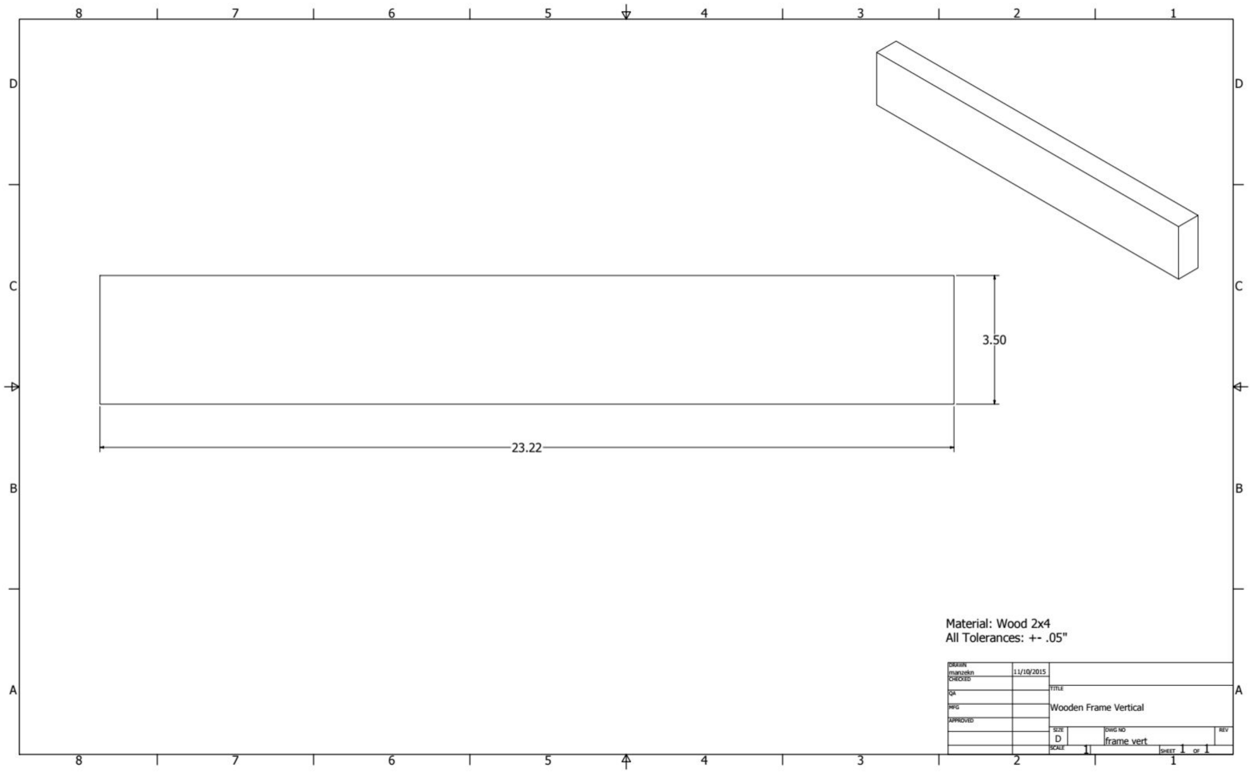
Part Name: Solar Collector Foam Insulation					
Team Name: ME450 Team 10					
Raw Material Stock: 1.25" Foam Sheet					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (RPM)**
1	Use knife to cut foam to 15x33"			knife	

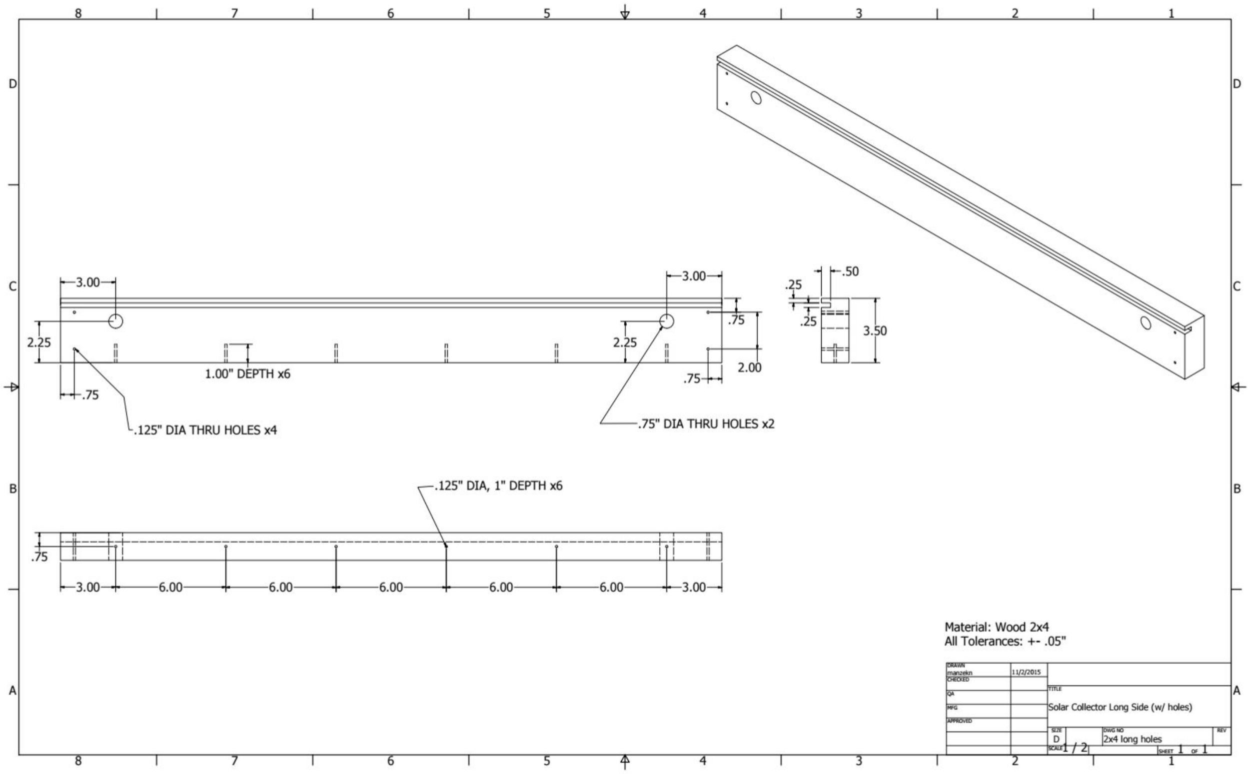
Part Name: Foil Long Side					
Team Name: ME450 Team 10					
Raw Material Stock: Aluminum Foil					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (RPM)**
1	Use scissors to cut aluminum foil to 1.75x33"			scissors	

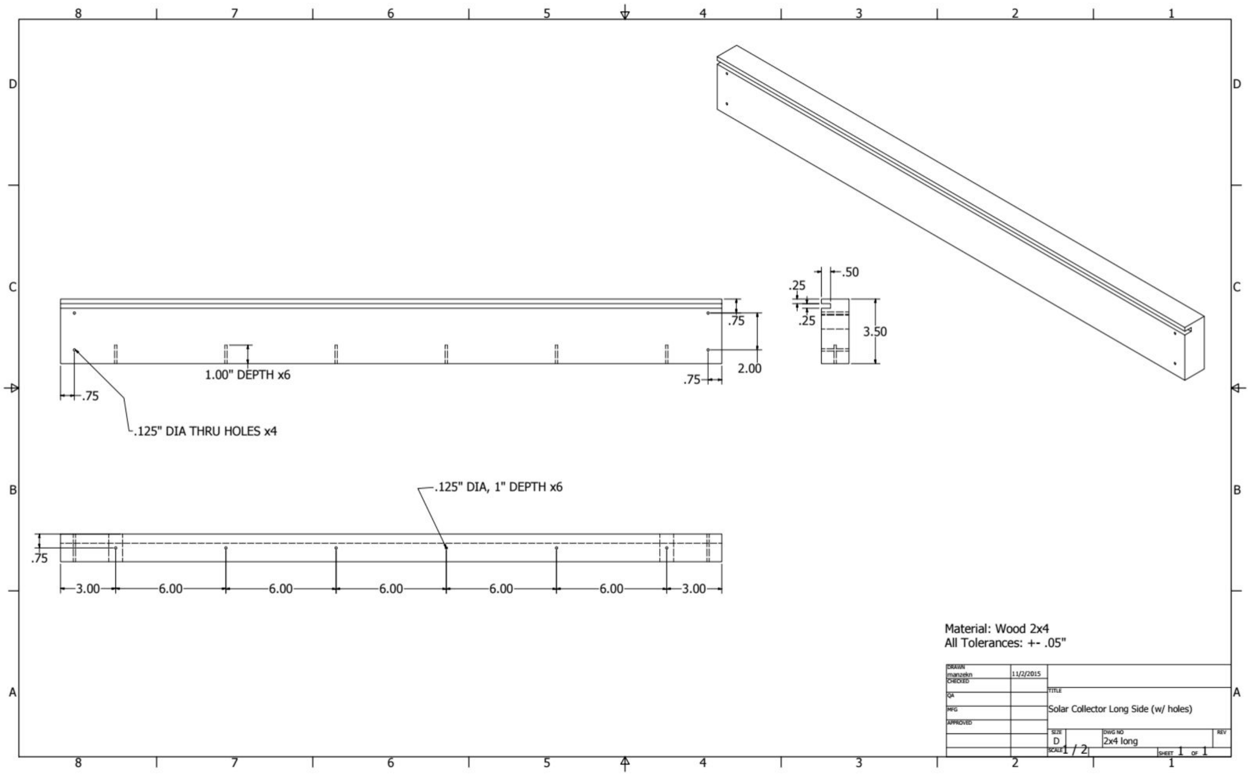
Part Name: Foil Short Side					
Team Name: ME450 Team 10					
Raw Material Stock: Aluminum Foil					
Step #	**Process Description**	**Machine**	**Fixtures**	**Tool(s)**	**Speed (RPM)**
1	Use scissors to cut aluminum foil to 1.75x15"			scissors	

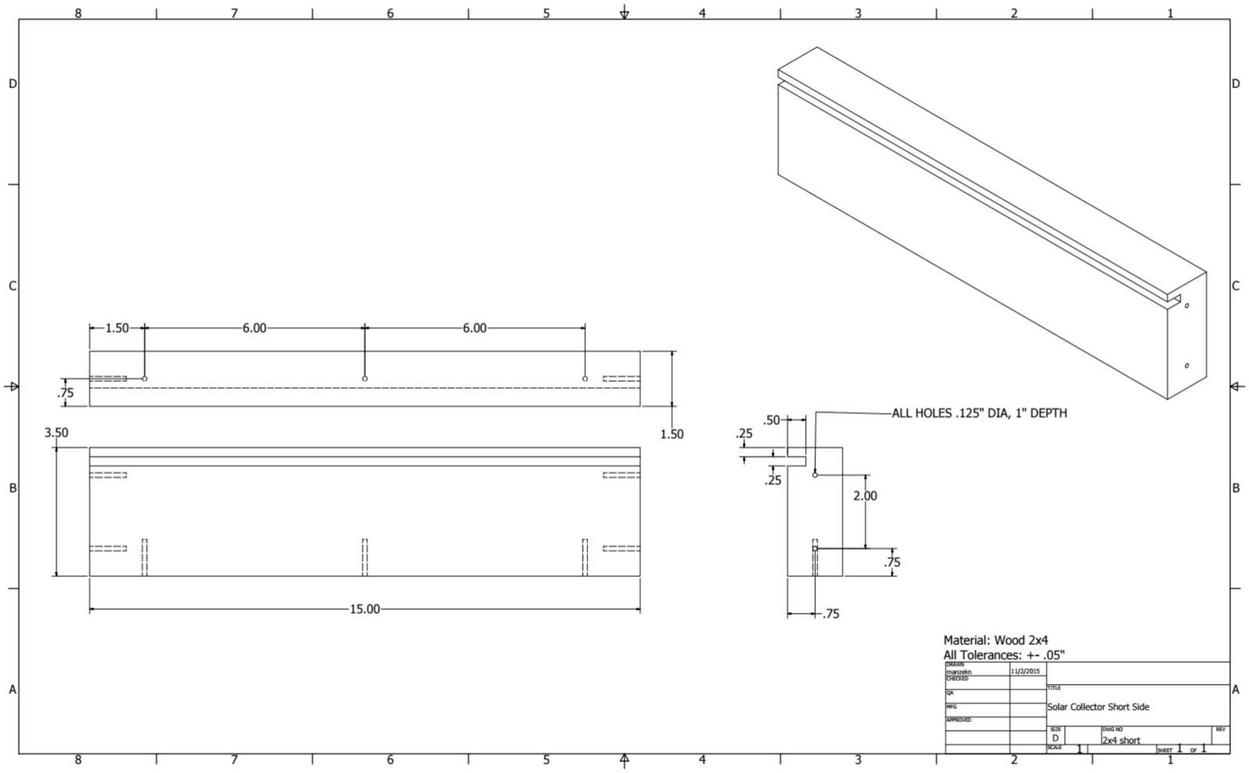
Part Name: Foil Base					
Team Name: ME450 Team 10					
Raw Material Stock: Aluminum Foil					
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Use scissors to cut aluminum foil to 15x33"			scissors	

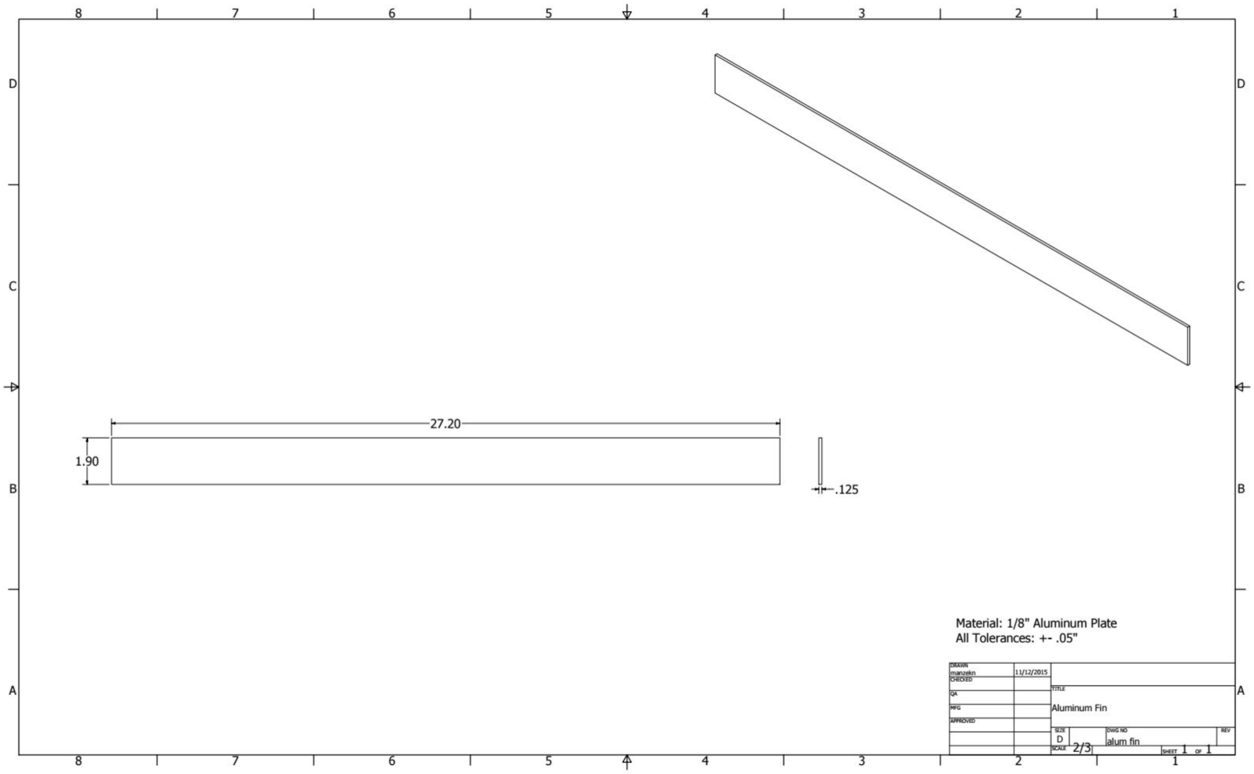
Appendix C: Final Design Engineering Drawings

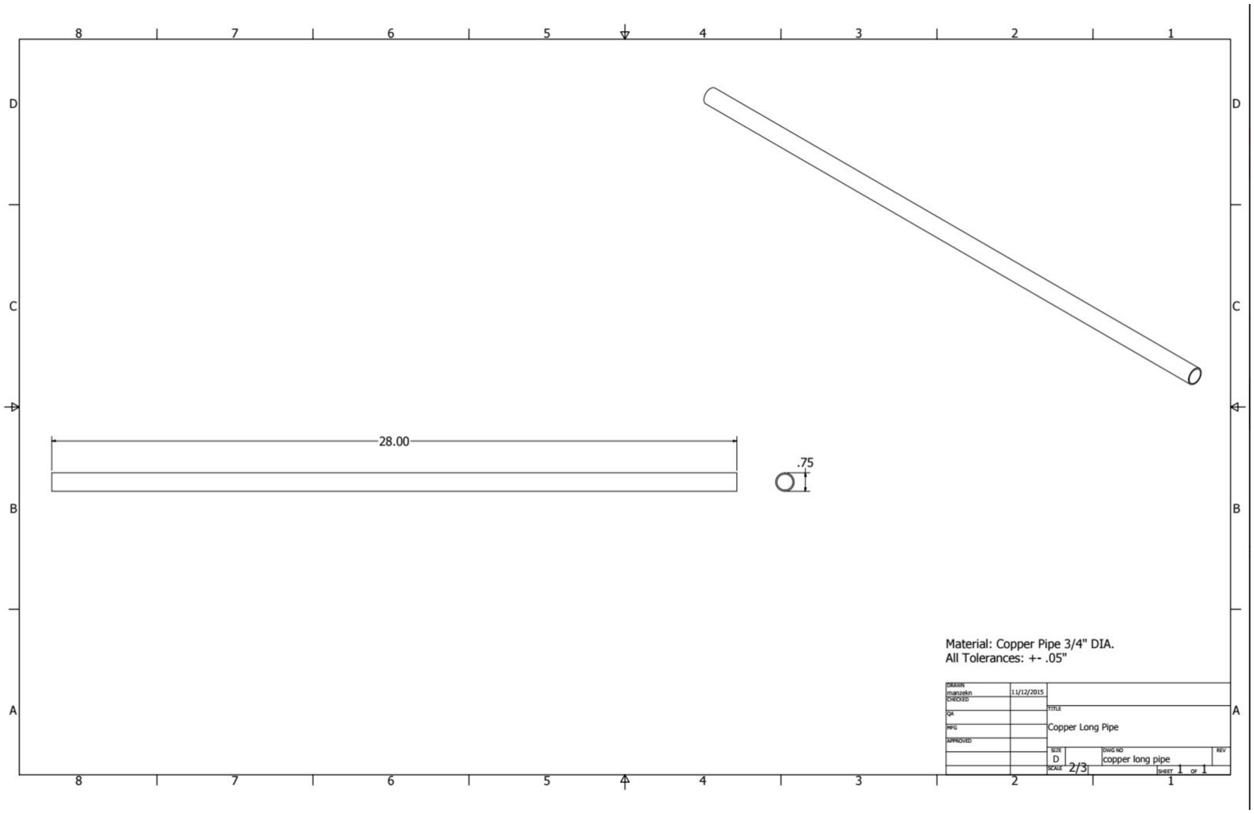



3.00
3.00
.25
.50
.25
3.50
.75
2.25
2.25
2.00
1.00" DEPTH x6
.75
.75
.125" DIA THRU HOLES x4
.75" DIA THRU HOLES x2
.125" DIA, 1" DEPTH x6
.75
3.00
6.00
6.00
6.00
6.00
6.00
3.00
Material: Wood 2x4
All Tolerances: +- .05"
DRAWN
manzekn
11/2/2015
CHECKED
QA
MFG
APPROVED
TITLE
Solar Collector Long Side (w/ holes)
SIZE
D
DWG NO
2x4 long holes
REV
SCALE 1 / 2
SHEET 1 OF 1


.25
.50
.25
3.50
.75
2.00
1.00" DEPTH x6
.75
.75
.125" DIA THRU HOLES x4
.125" DIA, 1" DEPTH x6
.75
3.00
6.00
6.00
6.00
6.00
6.00
3.00
Material: Wood 2x4
All Tolerances: +- .05"
DRAWN
manzekn
11/2/2015
CHECKED
QA
MFG
APPROVED
TITLE
Solar Collector Long Side (w/ holes)
SIZE
D
DWG NO
2x4 long
REV
SCALE 1 / 2
SHEET 1 OF 1

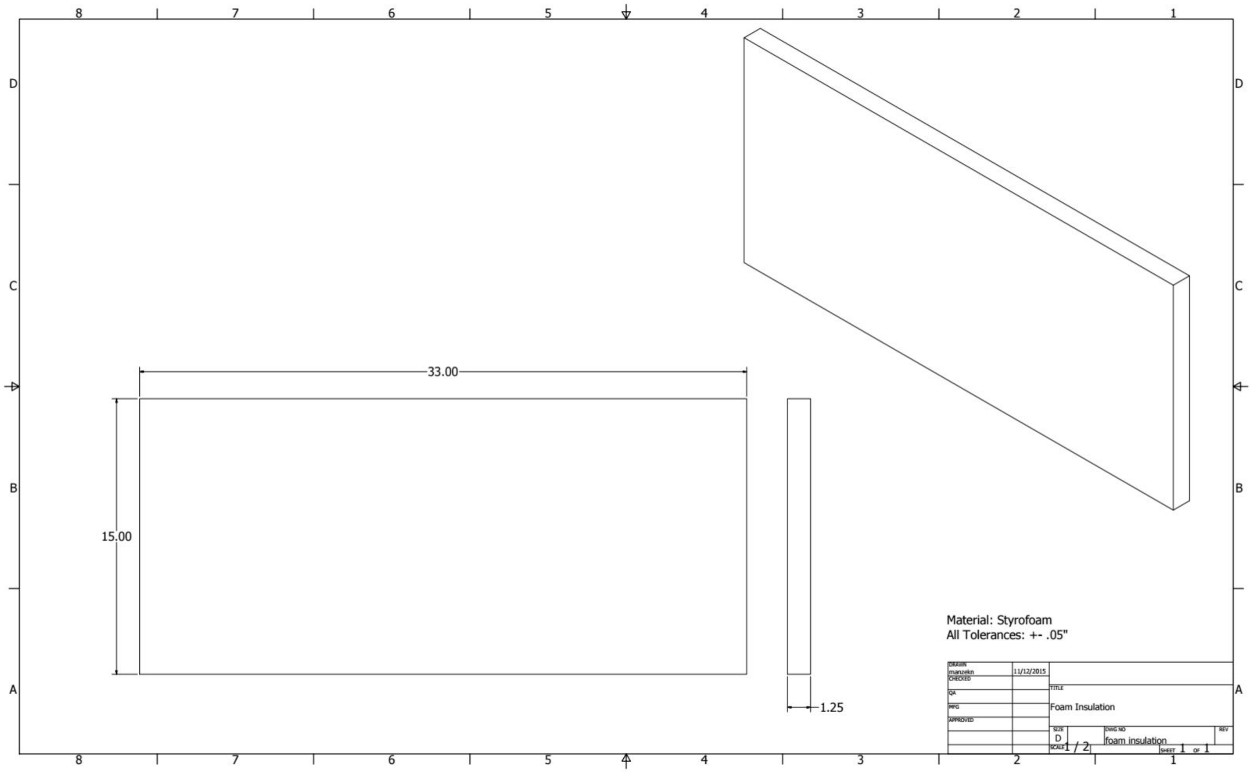

1.50
6.00
6.00
.75
3.50
1.50
15.00
.50
.25
.25
ALL HOLES .125" DIA, 1" DEPTH
2.00
.75
.75
Material: Wood 2x4
All Tolerances: +- .05"
DRAWN
manzekn
11/2/2015
CHECKED
QA
MFG
APPROVED
TITLE
Solar Collector Short Side
SIZE
D
DWG NO
2x4 short
REV
SCALE
1
SHEET 1 OF 1


27.20
1.90
.125
Material: 1/8" Aluminum Plate
All Tolerances: +- .05"
DRAWN
manzekn
11/12/2015
CHECKED
QA
MFG
APPROVED
TITLE
Aluminum Fin
SIZE
D
DWG NO
alum fin
REV
SCALE
2/3
SHEET 1 OF 1



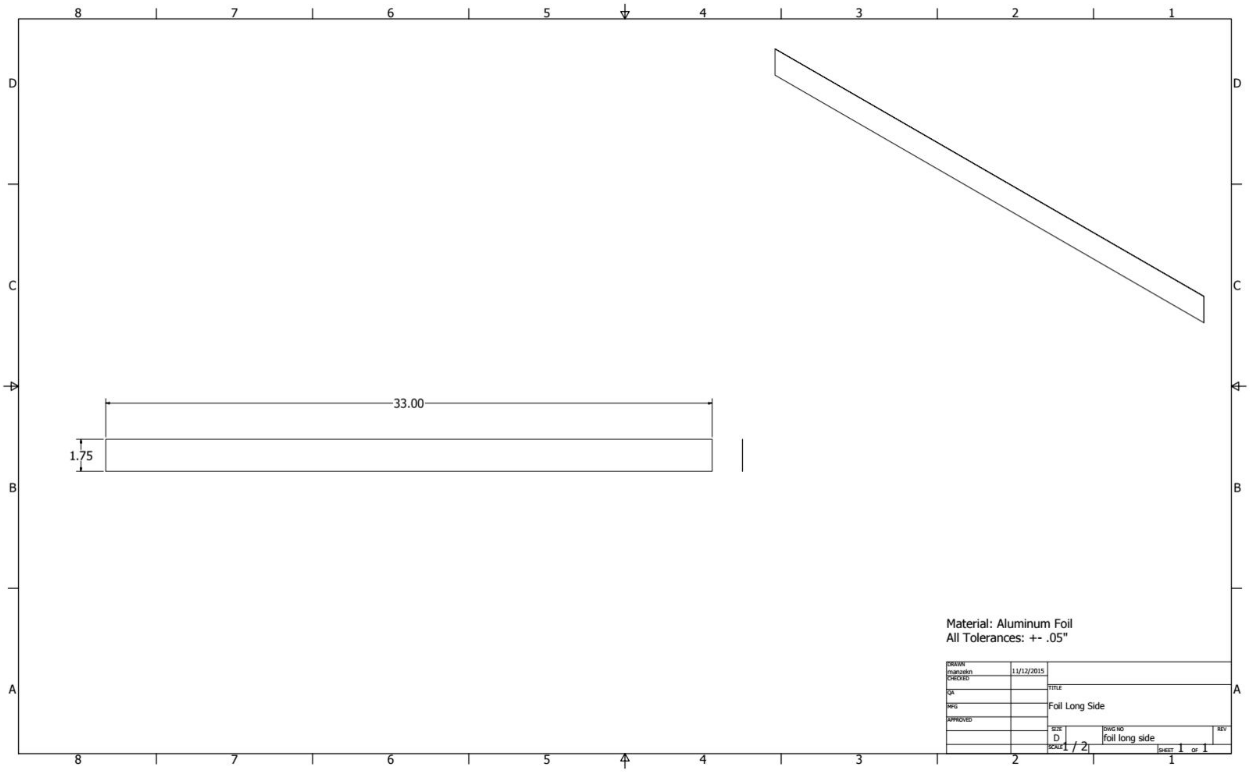
Material: Copper Pipe 3/4" DIA.
All Tolerances: +- .05"

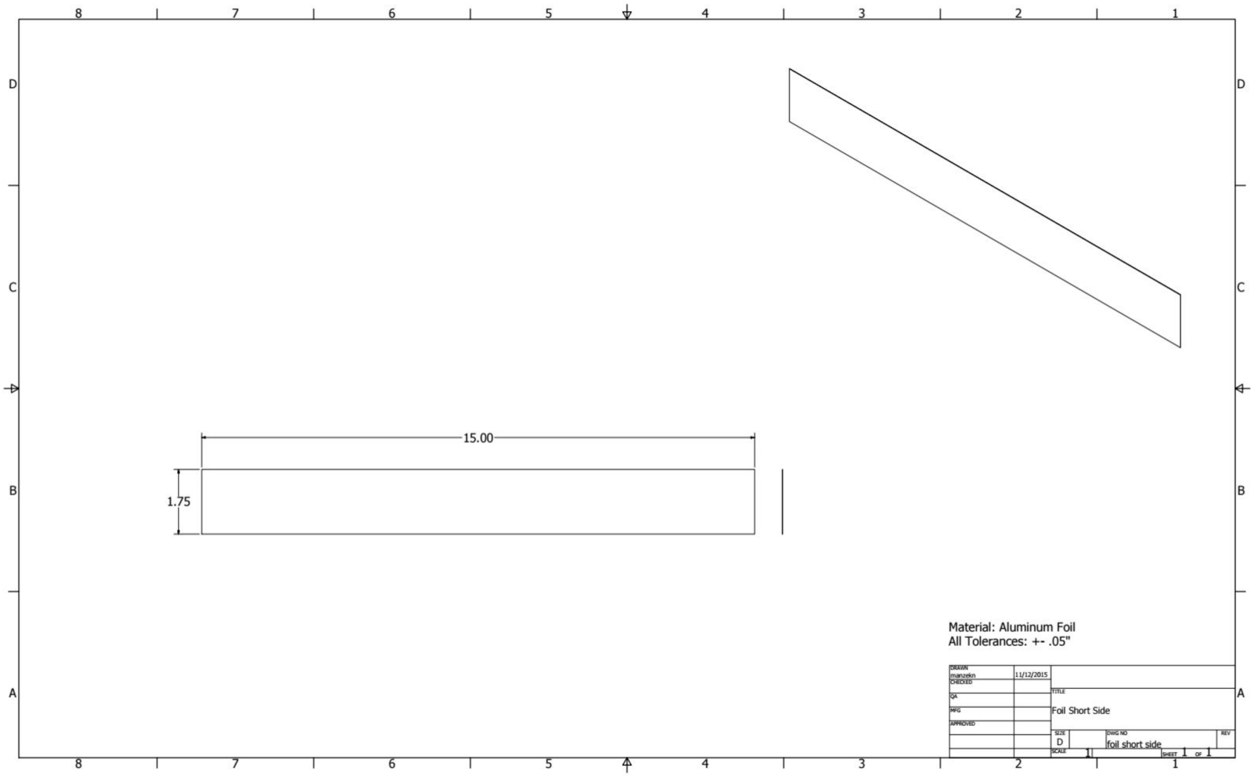
DRAWN manzekn 11/12/2015
CHECKED
QA
MFG
APPROVED
TITLE Copper Long Pipe
SIZE D
DWG NO copper long pipe
REV
SCALE 2/3
SHEET 1 OF 1

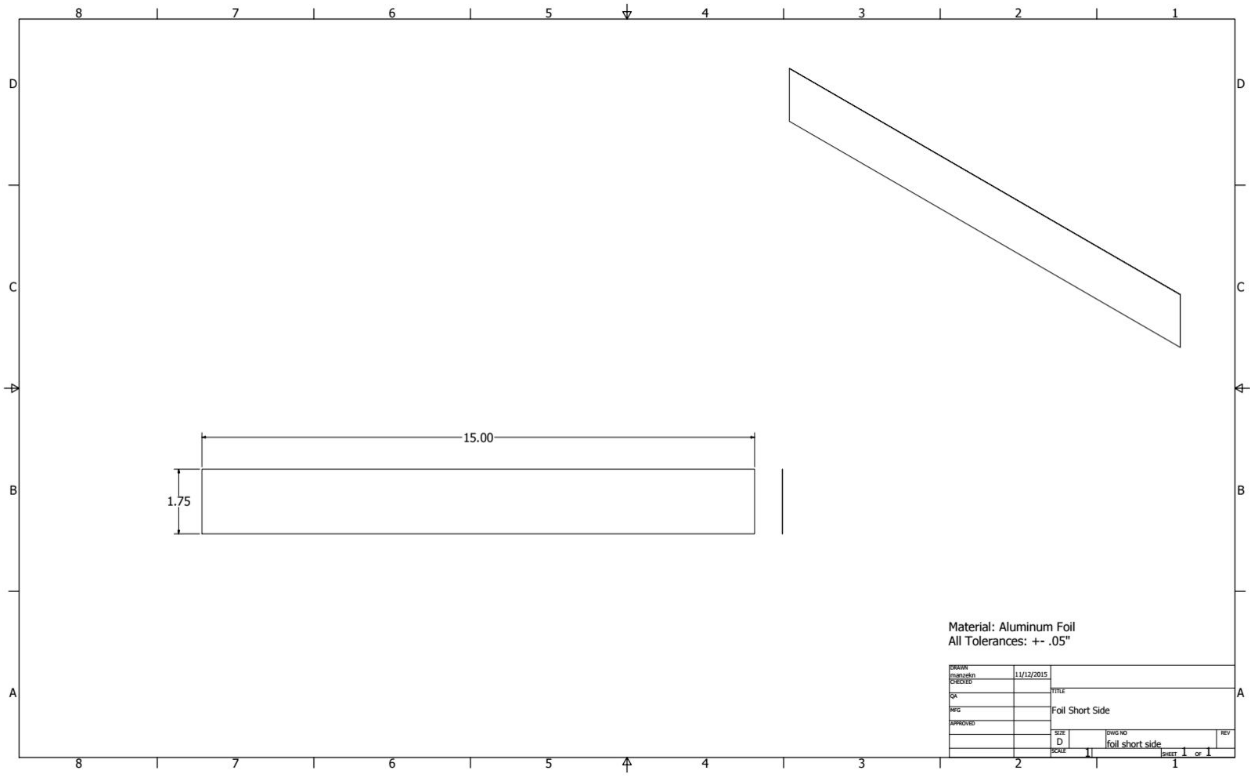


Material: Styrofoam
All Tolerances: +- .05"

DRAWN manzekn 11/12/2015
CHECKED
QA
MFG
APPROVED
TITLE Foam Insulation
SIZE D
DWG NO foam insulation
REV
SCALE 1 / 2
SHEET 1 OF 1

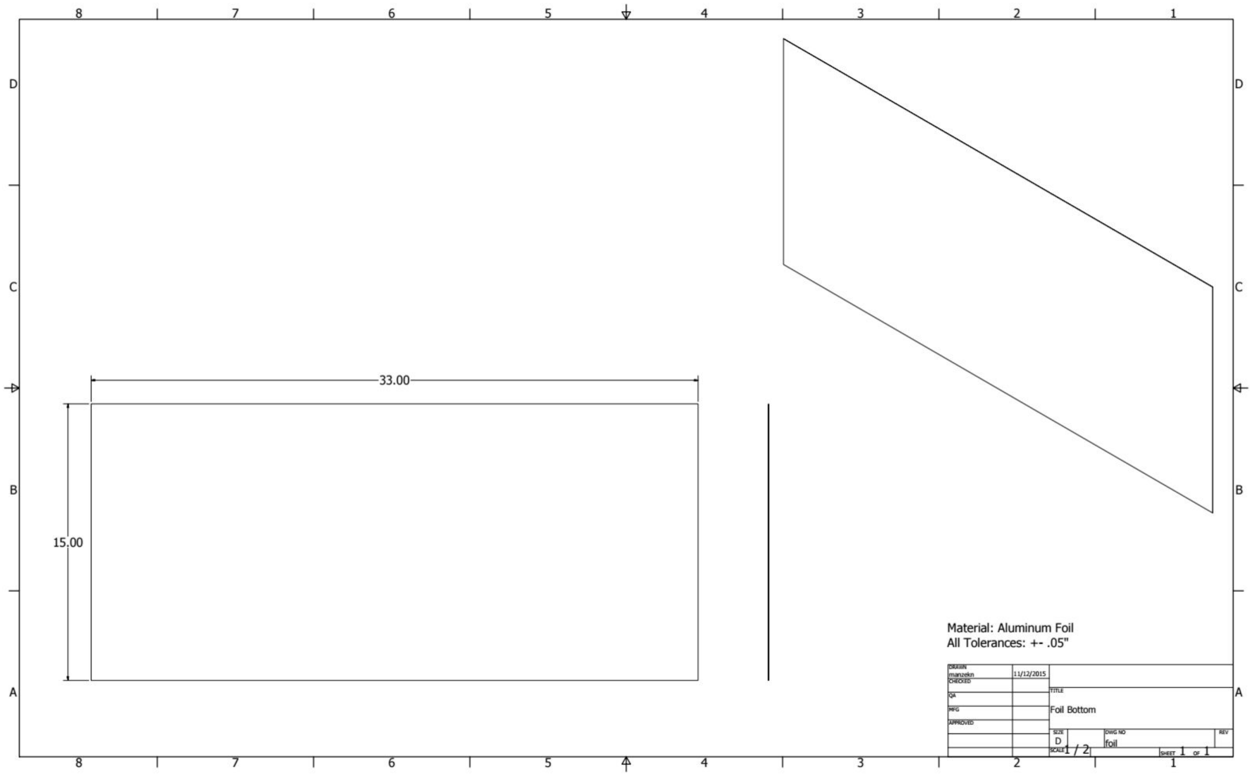

33.00
1.75
Material: Aluminum Foil
All Tolerances: +- .05"
DRAWN
manzekn
11/12/2015
CHECKED
QA
MFG
APPROVED
TITLE
Foil Long Side
SIZE
D
DWG NO
foil long side
REV
SCALE 1 / 2
SHEET 1 OF 1


15.00
1.75
Material: Aluminum Foil
All Tolerances: +- .05"
DRAWN
manzekn
11/12/2015
CHECKED
QA
MFG
APPROVED
TITLE
Foil Short Side
SIZE
D
DWG NO
foil short side
REV
SCALE 1
SHEET 1 OF 1



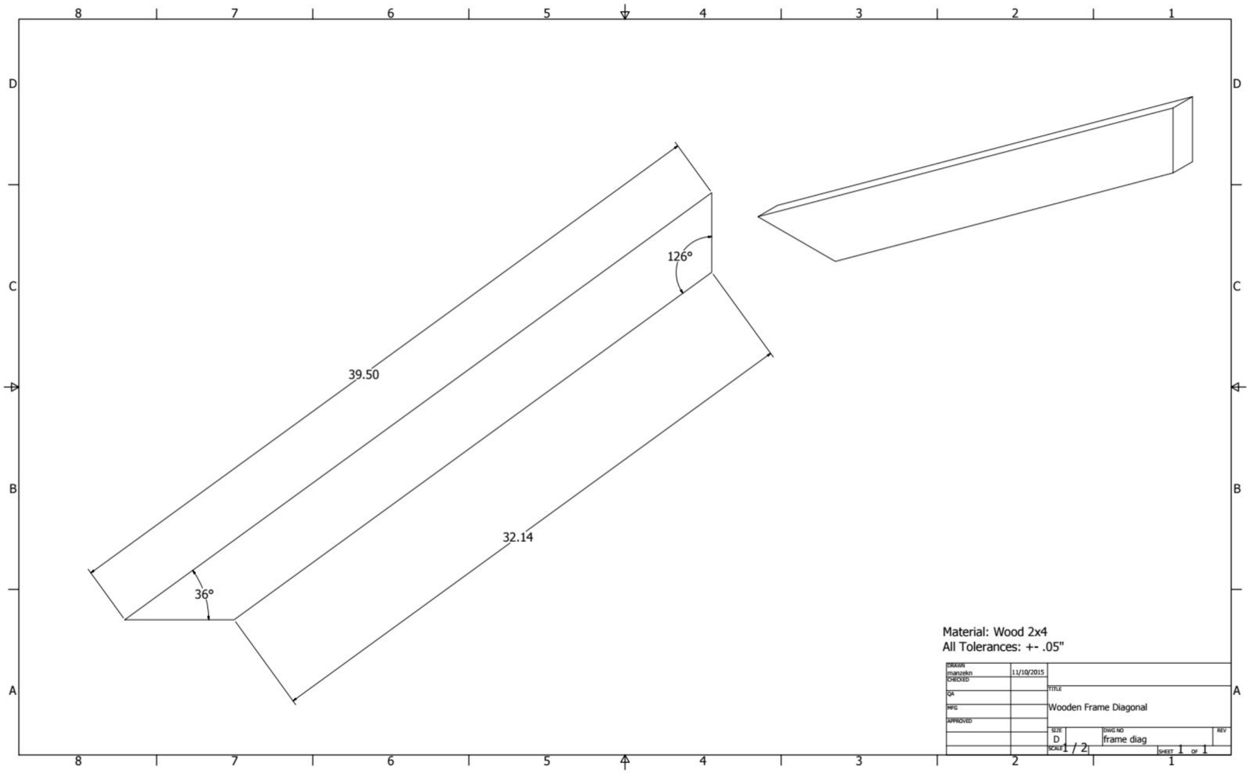
Material: Aluminum Foil
All Tolerances: +- .05"

DRAWN manzekn 11/12/2015
CHECKED
QA
MFG
APPROVED
TITLE Foil Short Side
SIZE D
DWG NO foil short side
REV
SCALE 1
SHEET 1 OF 1



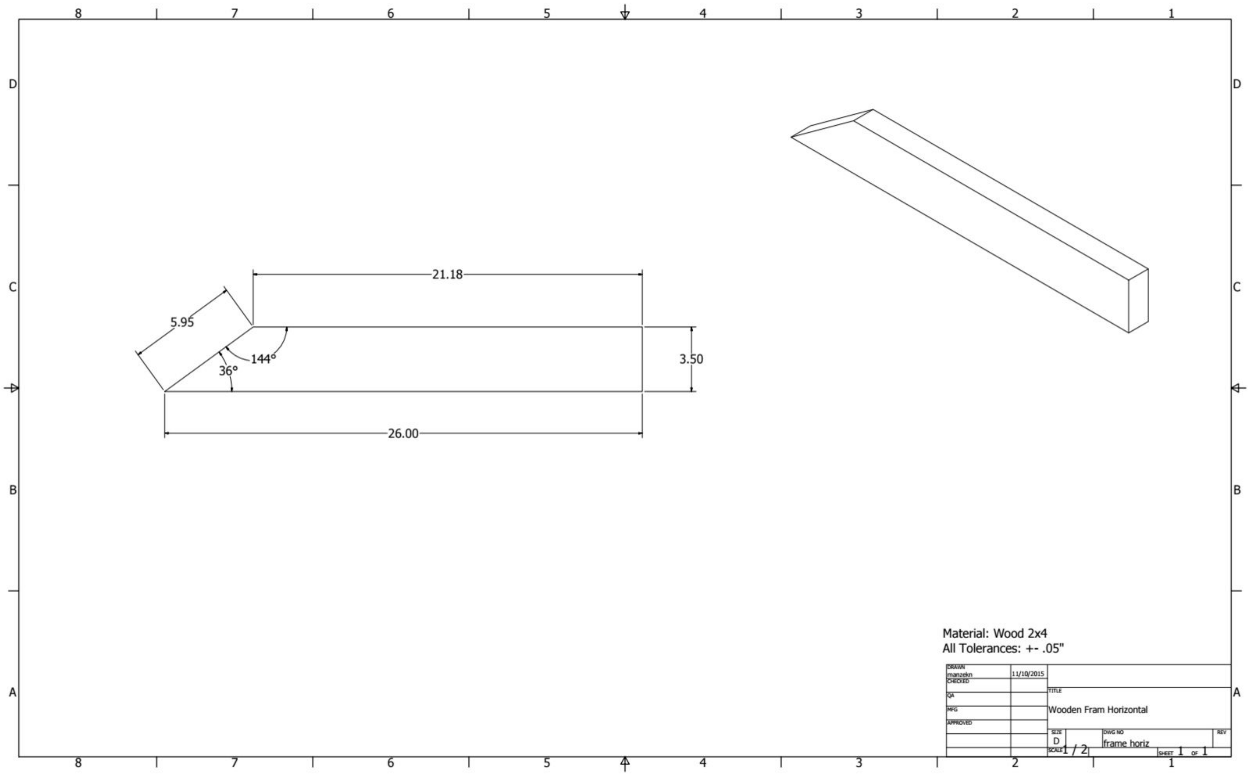
Material: Aluminum Foil
All Tolerances: +- .05"

DRAWN manzekn 11/12/2015
CHECKED
QA
MFG
APPROVED
TITLE Foil Bottom
SIZE D
DWG NO foil
REV
SCALE 1 / 2
SHEET 1 OF 1



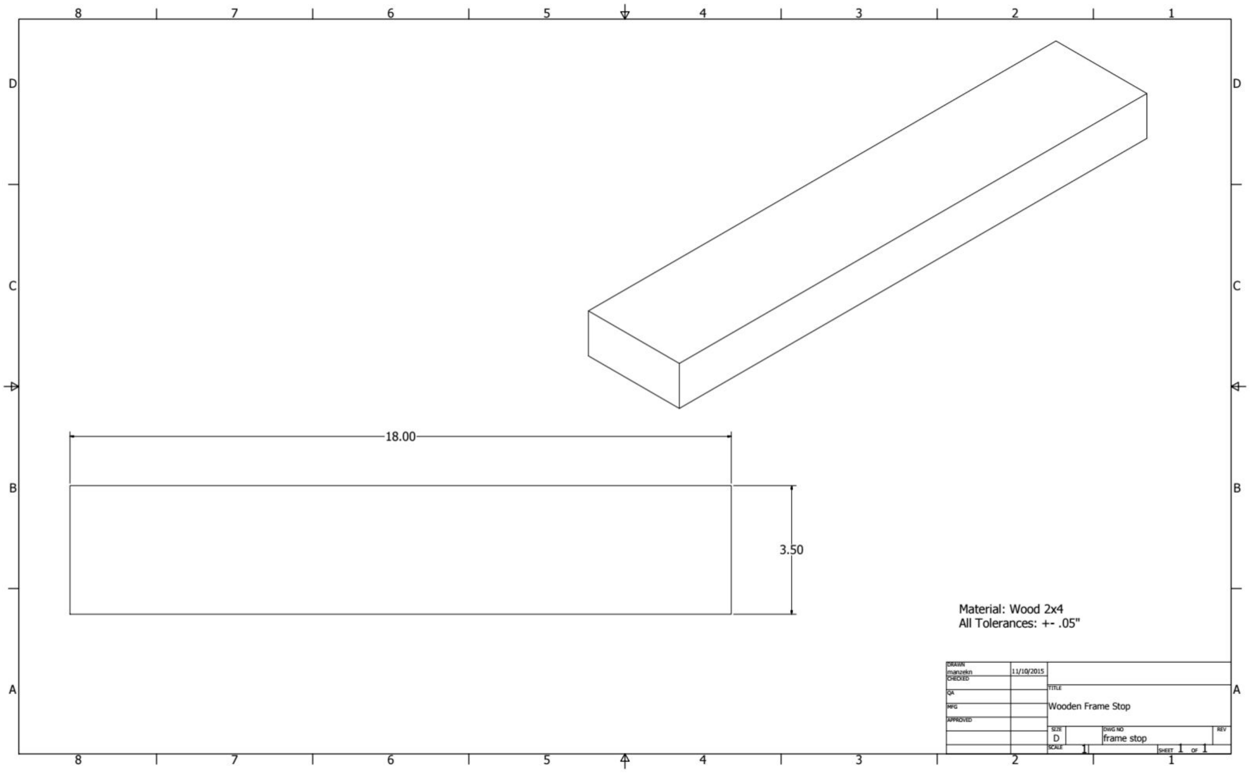
Material: Wood 2x4
All Tolerances: +- .05"

DRAWN manzekn 11/10/2015
CHECKED
QA
MFG
APPROVED
TITLE Wooden Frame Diagonal
SIZE D
DWG NO frame diag
REV
SCALE 1 / 2
SHEET 1 OF 1



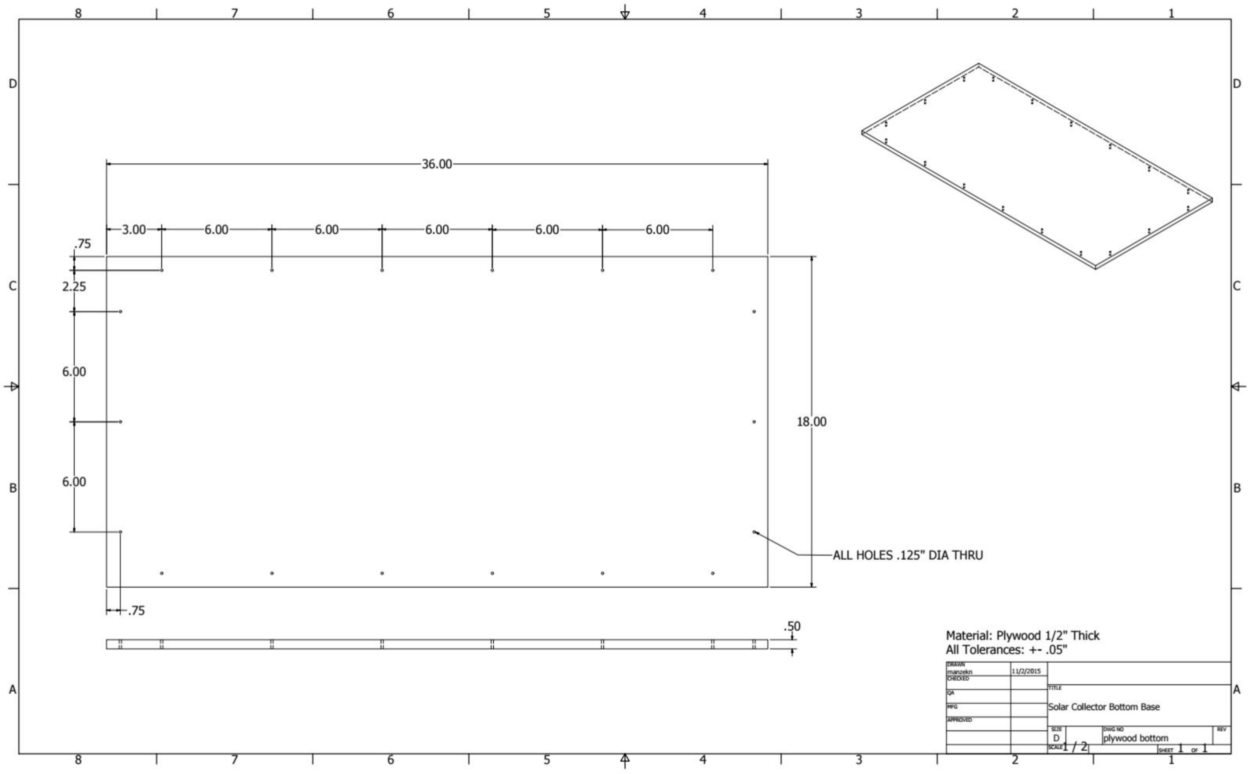
Material: Wood 2x4
All Tolerances: +- .05"

DRAWN manzekn 11/10/2015
CHECKED
QA
MFG
APPROVED
TITLE Wooden Fram Horizontal
SIZE D
DWG NO frame horiz
REV
SCALE 1 / 2
SHEET 1 OF 1

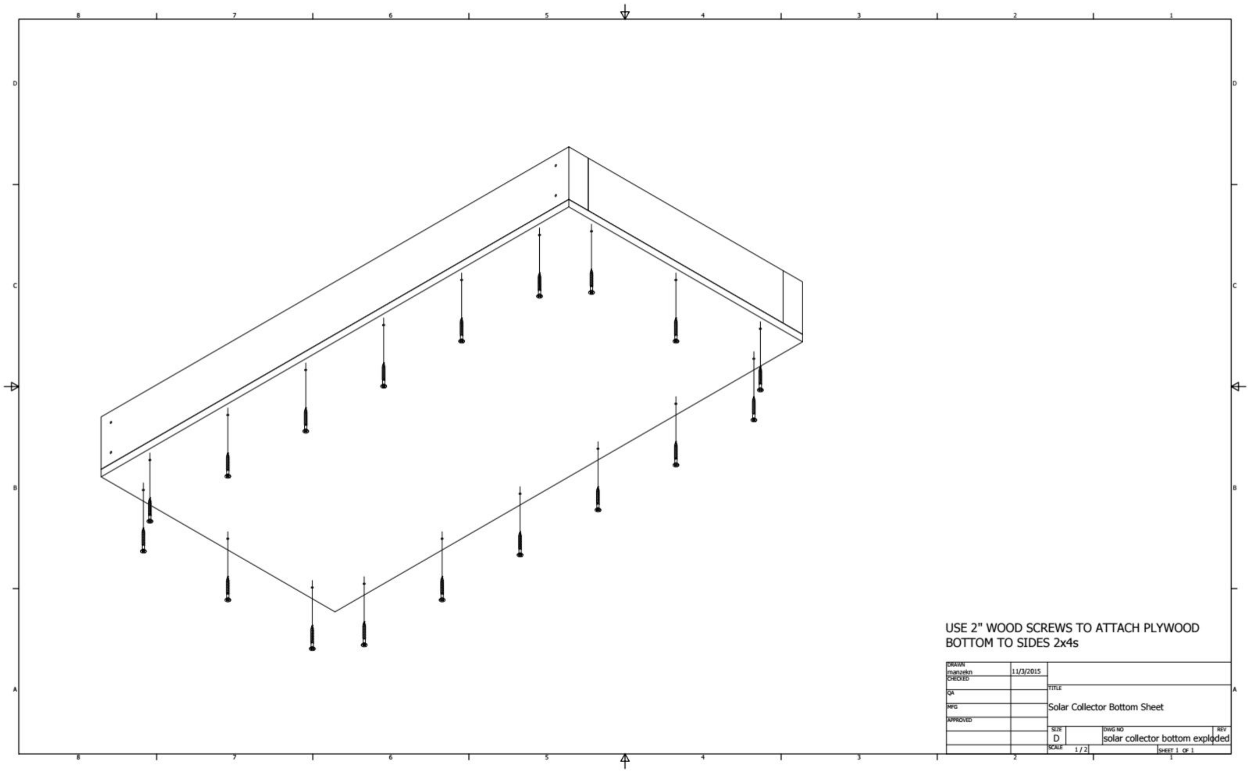


Material: Wood 2x4
All Tolerances: +- .05"

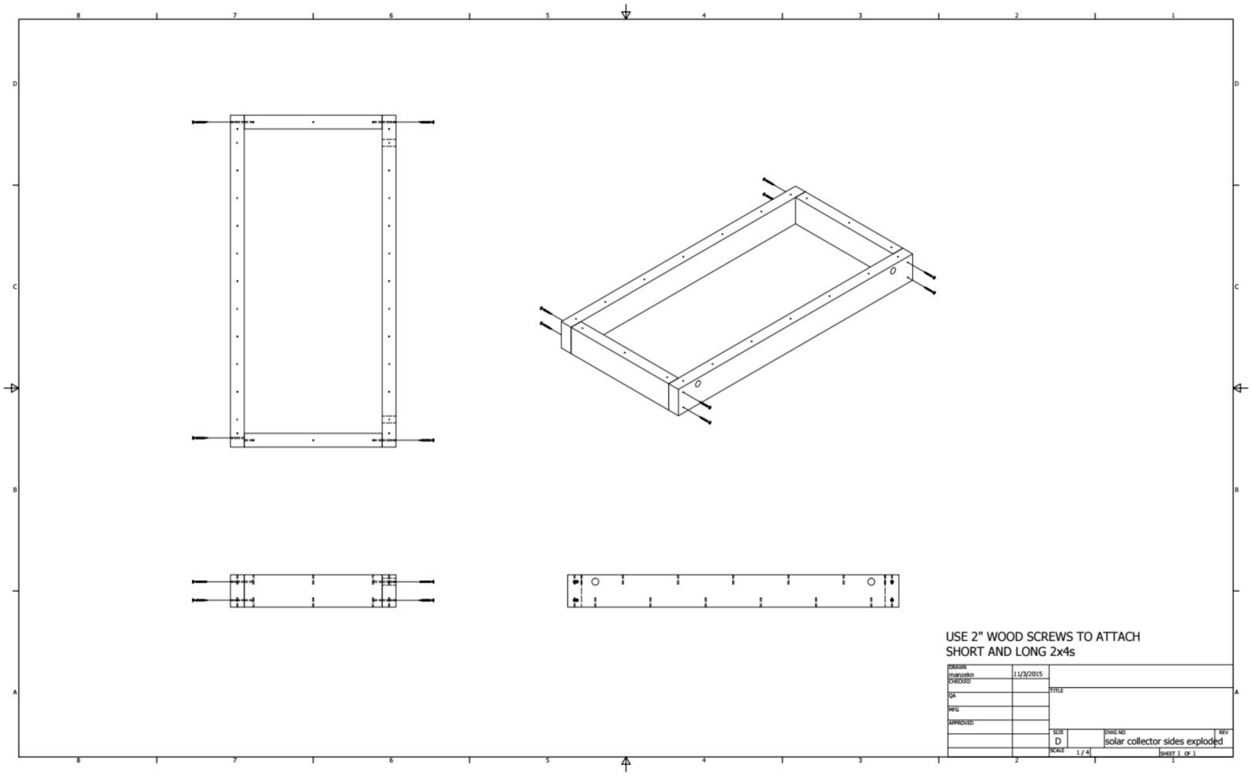
DRAWN manzekn	11/10/2015	
CHECKED		TITLE Wooden Frame Stop
QA		
MFG		
APPROVED		SIZE D · DWG NO frame stop · REV
		SCALE 1 · SHEET 1 OF 1



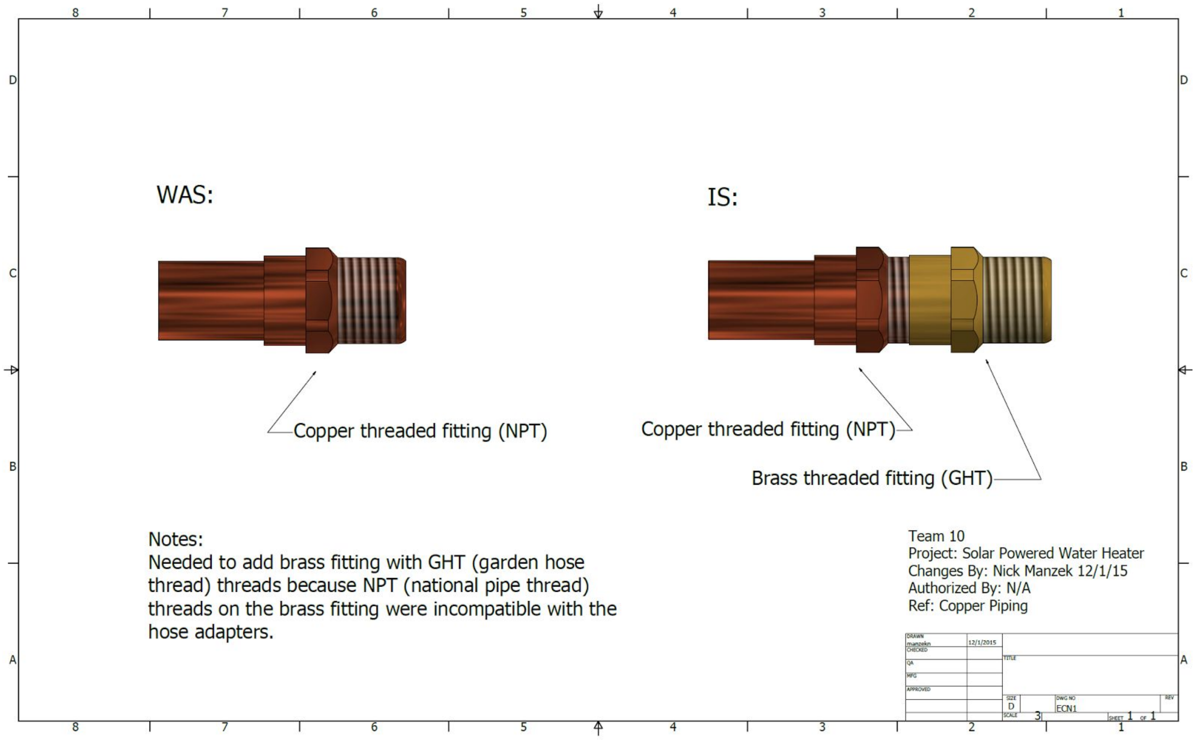
Material: Plywood 1/2" Thick
All Tolerances: +- .05"



USE 2" WOOD SCREWS TO ATTACH PLYWOOD BOTTOM TO SIDES 2x4s


USE 2" WOOD SCREWS TO ATTACH
SHORT AND LONG 2x4s

Appendix D: Engineering Change Notices



Notes:
Needed to add brass fitting with GHT (garden hose thread) threads because NPT (national pipe thread) threads on the brass fitting were incompatible with the hose adapters.

Team 10
Project: Solar Powered Water Heater
Changes By: Nick Manzek 12/1/15
Authorized By: N/A
Ref: Copper Piping

Appendix E: Validation Protocol

To ensure the success of our project, it was essential to verify that our prototype met each of our engineering specifications. Since one of our major requirements was to heat water from 26℃-30℃, we placed thermocouples at the inlet and outlet of the solar collector to measure the change in temperature of the heated water. We ran this test continuously until we had 26℃ water. This data gave us concrete proof that our prototype can heat the water to the necessary mark.

Another important requirements was to maintain the fish tank temperature during prolonged periods of little to no sunlight. We measured the initial temperature of water going into storage tank using a thermocouple. We then measured the temperature of water after several hours. This test showed whether or not our system can maintain a water temperature above 26℃.

Our prototype needs to compatible with the fish farm's system in Kazakhstan. Our system needs to manage a maximum flow rate of 19 L/s or 300 gal/min. We proved this by testing our prototype with a pump that moves water at 300 gal/min.

To ensure the temperature does not go over 90℃, we monitored the temperature of the water leaving the solar collector as well as the temperature of the water in the storage tank.

Some of our validation can be done by inspection. To meet the comparable material requirement, we bought all of our supplies from the Home Depot or similar stores. To build our prototype with a $400 budget, we maintained a ledger of all of our purchases.

Appendix F: Ethical Design Statements

Alexandra Kolberg

When designing our system, we considered safety at every step. Whether that be the safety of the user, the fish, or the environment, safety always was a top priority. In my opinion, safety and ethics go hand in hand because if an engineer acts ethically, the risk associated with the design often decreases. The system we are designing directly affects the fish being raised in the fish farm. We followed the Fundamental Canon, Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties." In our design process, we conducted a risk analysis and an FMEA to aid us in determining where the most risk lies in our design. We took into account the affects that our system may have on the fish and the habitat they lived in. For example, if the water were to overheat from the solar collector and continue to be fed into the pools of fish, the water could become too hot and the fish could die.

Finally, we followed the Fundamental Canon, “Engineers shall perform services only in the areas of their competence.” Our project required basic heat transfer analysis to be performed. Only students who had prior exposure to heat transfer performed the analysis in order to eliminate additional error resulting from a learning curve. In addition, we met with heat transfer professors in order to ensure that our analysis was as accurate as possible. This corresponds with the Fundamental Canon, “Engineers shall associate only with reputable persons or organizations.” It is important to gain knowledge from sources that are reliable and dependable with their information.

Nick Manzek

Of all the principles in engineering ethics, the most important one to the success of our project was safety. Our project is directly linked to a food source of the people of Kazakhstan. Because of this special considerations were made to ensure the safety of the fish to survive the growing process but also to ensure the safety of the people that will eventually eat the fish. One design concept we considered relied on pumping an anti-freeze fluid through piping that came in contact with the water the fish were housed in. Should that piping have sprung an unnoticeable leak, the fish would have been exposed to the anti-freeze fluid during their growth cycle. Even if the fish did not die from the leak, these chemicals would be infused into the fish and then ingested by the final consumer.

We also made sure that we were not designing a system that we could not conduct a thorough engineering analysis on. Our design depends heavily on heat transfer from the copper piping to the water. With two of the people in our group being in a heat transfer class as well as the professors available to us at the University of Michigan, we were confident would could provide adequate analyses.

Finally, when it came time to building the prototype, our team made sure to share the work so everyone was able to gain hands on experience. When one person in the group knew how to do a step, they would reach out to the others in the group to ask them if they wanted to learn instead of just doing the work and moving on. I think this added great value to the project because everybody was able to learn a new skill they did not know before.

Siobhan McDermott

Throughout this project, we continuously strived to apply the fundamental canons of the Code of Ethics. One of the most important canons expressed the importance of ensuring the public’s safety, health, and welfare. Since our project interacts with people, meeting this standard became our highest priority. To make certain that we designed a solution with the safety of the public in mind, we performed several safety assessments including a risk assessment and FMEA. The result of these assessments lead to further discussion about how to better improve our product.

We made several design decisions based on potential risks involved. For example, we chose a direct circulation system over an indirect circulation system. This choice allowed us to remove the potential for a heat transfer fluid to leak into the heated water heading for the fish. By circulating water instead, we ensured that our product would not introduce any chemicals that could potentially harm the fish or the people who consume the fish.

To design and build the best solution, we assigned tasks based on an individual's strength and proficiency in various areas. Those best qualified for certain tasks such as the heat transfer analysis took lead to make certain that the best quality of work was being produced. Additionally, we consulted professors and the machine shop experts to ensure that our design was analytically and physically secure.

Connor Thompson

The most important priority our group had throughout the process of designing and building our prototype was the safety of its users. This includes the environmental impact of our design's manufacture and use, the physical safety of its operators, and the well-being of the fish that will be sustained by the water the prototype has been designed to heat. In order to fulfill those goals, our group conducted an FMEA risk assessment. This allowed us to determine the best possible solution for any safety issue.

This process of risk assessment led us to make several key design choices, including the removal of heat transfer fluid from the design, which would be potentially harmful to the fish at the fish farm if allowed to leak from the system. Our prototype was also designed to be built with the most basic tools and materials possible, to reduce the risk of worker injury.

Finally, our group also tailored its own individual assignments to meet the abilities of the group members in addition to the needs of the prototype. Each individual task was evaluated by the group in order to determine which member of the group was best suited to complete it, upon which that member was assigned the task. This allowed our group to maximize the overall quality of our final product.