Red Feather 20F02 Capstone Final Presentation

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Background

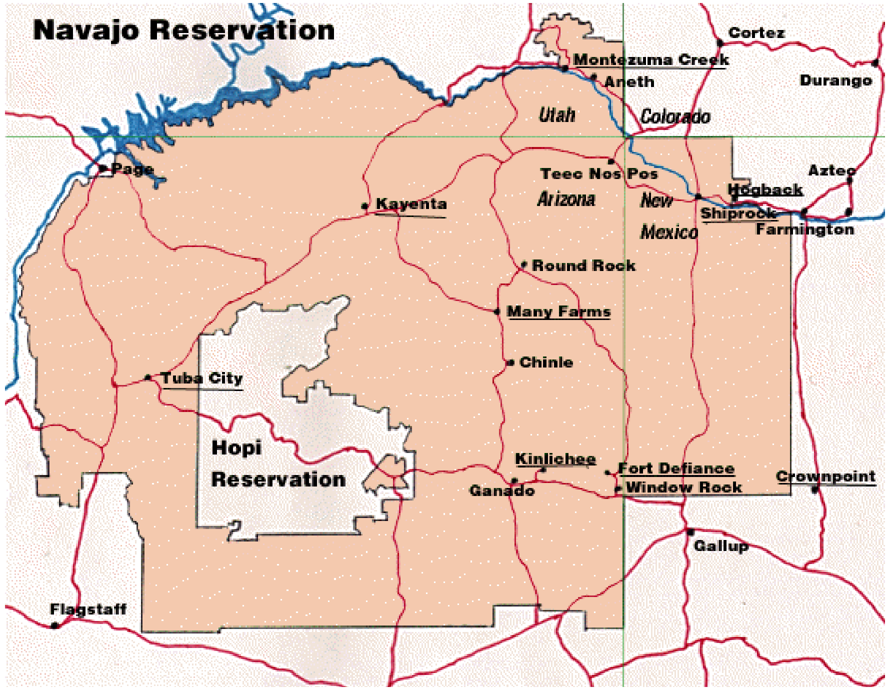


Figure 1: Map of Hopi Reservation and Navajo Nation [1]

- Red Feather does work primarily on the Hopi Reservation and in Navajo Nation
- Many homes on the Navajo nation and Hopi Reservation don't have adequate sources of heat during the evening, many rely on coal or wood-fired stoves
- They have started implementing solar furnaces, but that doesn't provide heat at night

Project Description

- The project is to create a thermal storage device that can store enough heat to warm a house at night.
- Team focused on developing a design and creating a proof of concept
- All the materials used must be locally sourced, easy to install and within the budget set by Red Feather
- The design for the thermal storage device needs to be straight forward and not too large
- It needs to be reliable and durable in the environment it is in

System CAD Drawing

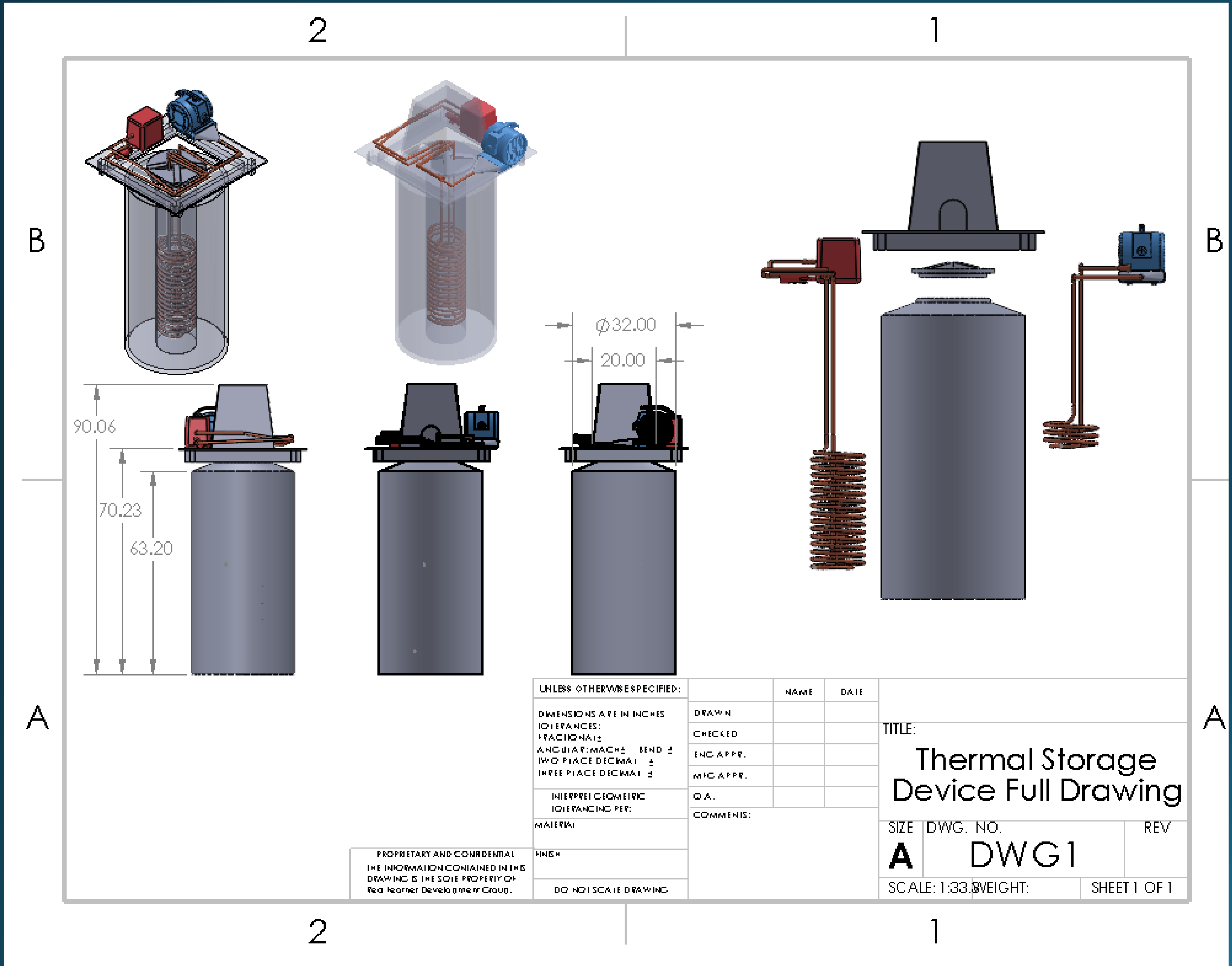


Figure 2: CAD Drawing

CAD Assembly

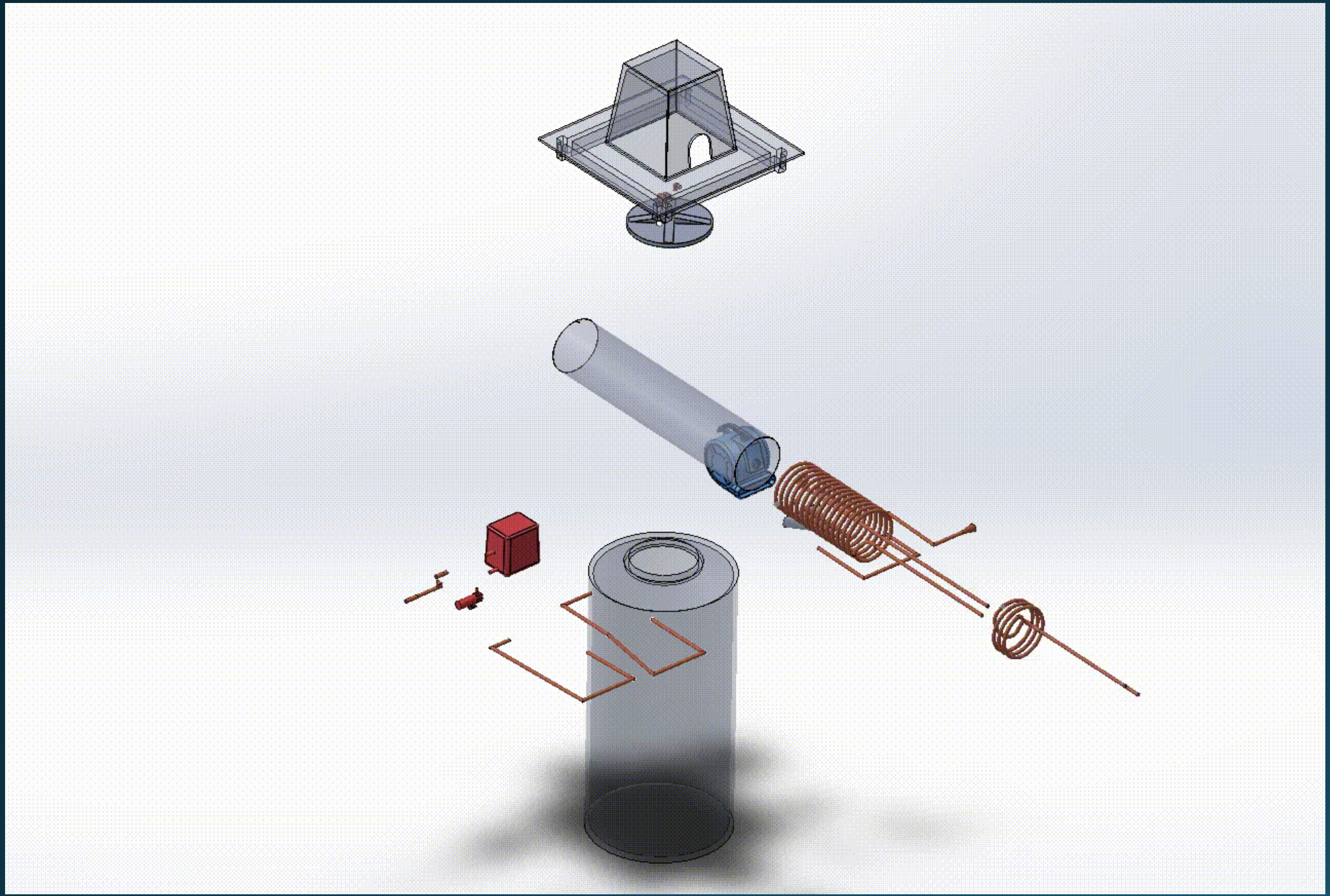


Figure 3: CAD Assembly GIF

Leak Tests

- No leaks in the liquid-to-liquid heat exchanger
- One leak in the liquid-to-air heat exchanger at the bottom. This area was resoldered and tested again. The leak persisted. After one more soldering job, there were no leaks

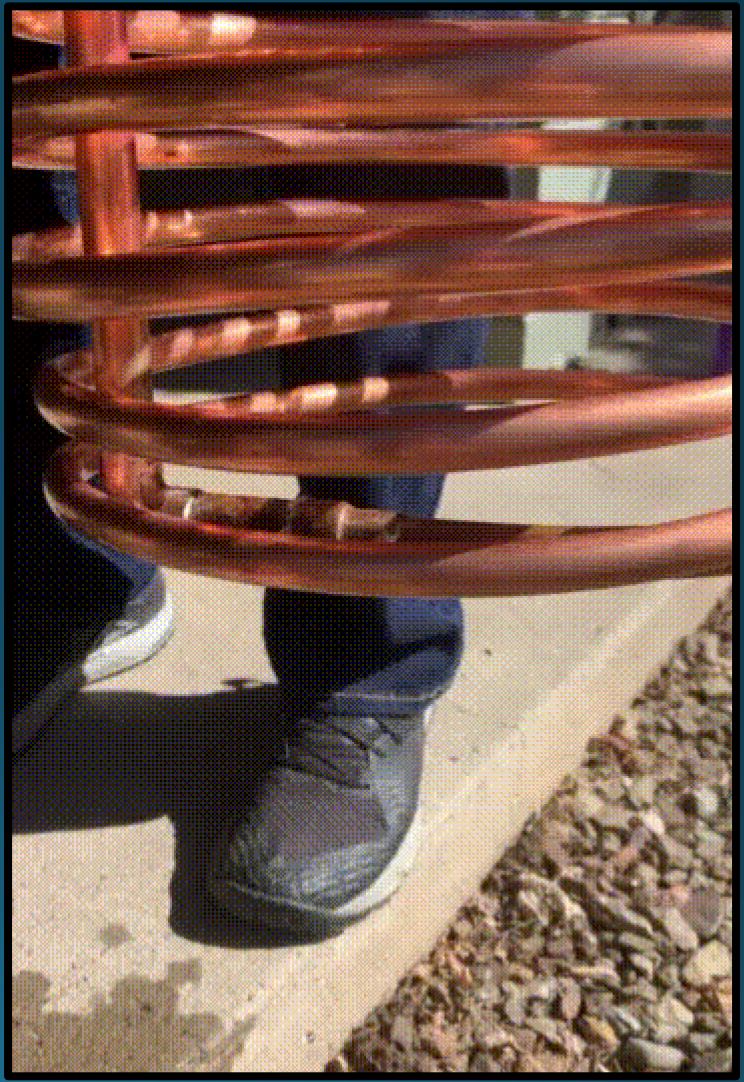


Figure 4: Heat Exchanger Leak Test

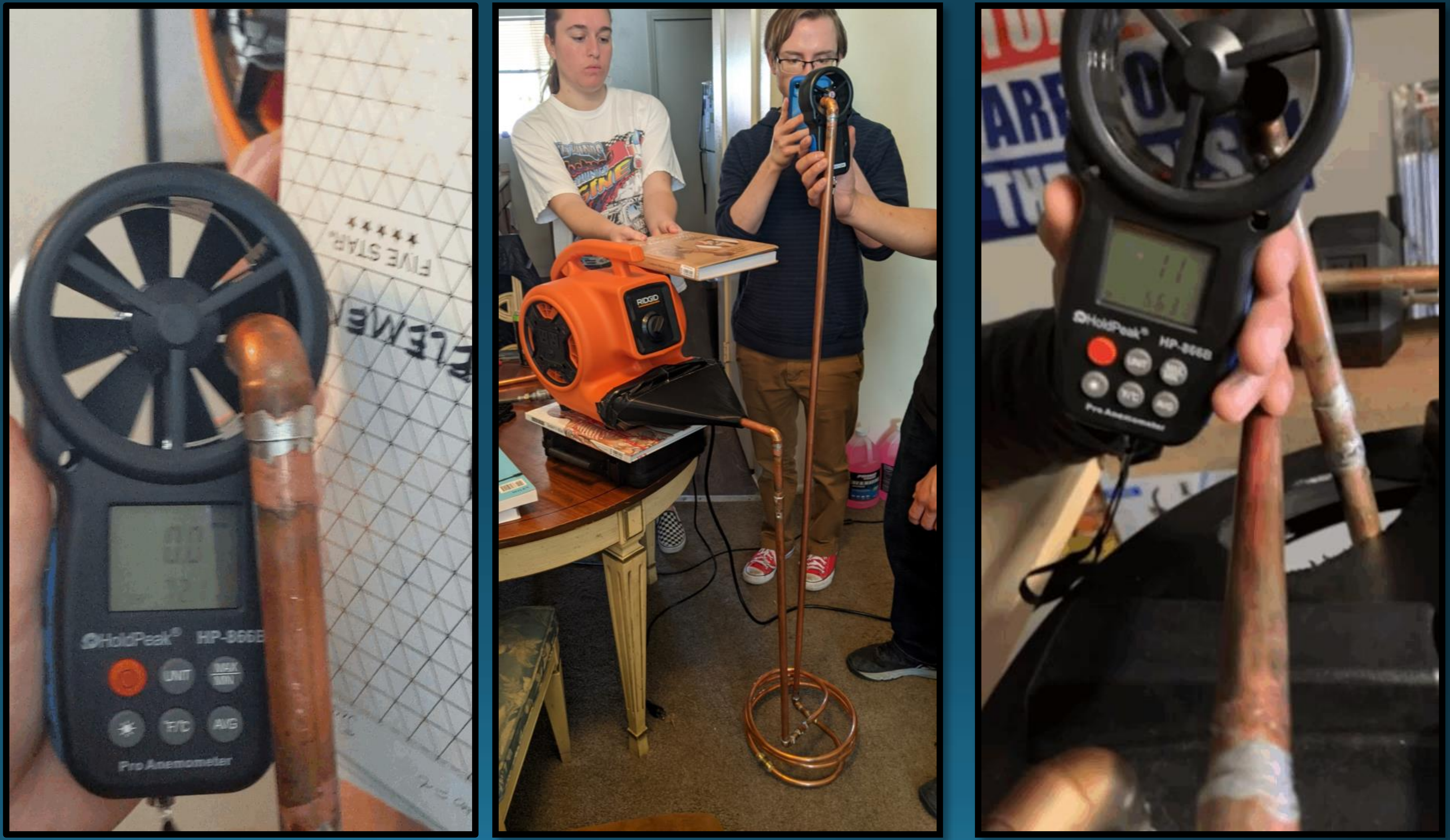
Air Velocity Test

- After the failed 1st test, the liquid-to-air heat exchanger was cut down in its length (19 turns) to its final form (3 turns), as seen in the 2nd test.
- The 2nd test was a success with 1.1-1.2 m/s
- The 3rd test was a success, with the whole system in the water-filled tank, and a velocity of 1.1 m/s

1st test: 0.1 m/s

2nd test: 1.1-1.2 m/s

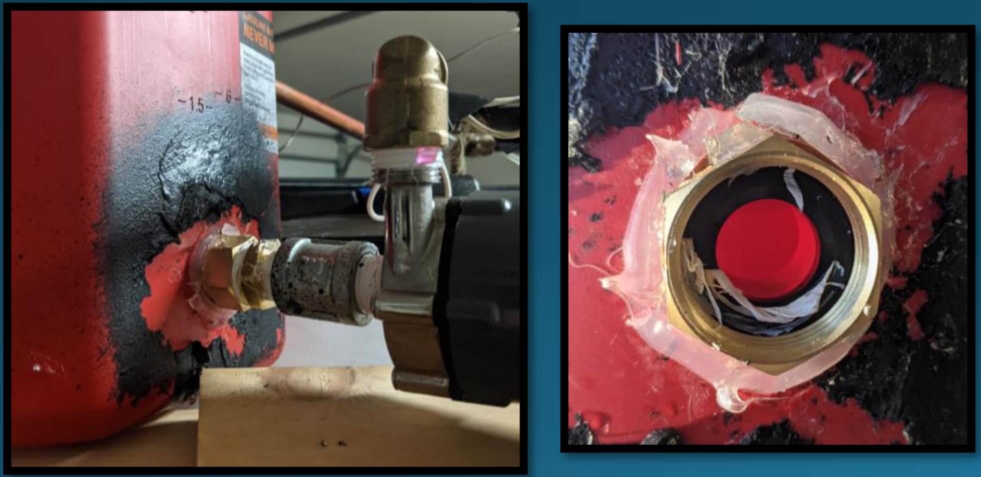
3rd test: 1.1 m/s



Figures 5a, b, and c: Air Velocity Tests 1, 2, and 3

Liquid Flow Test

- The liquid loop worked completely with the whole liquid loop together:
  - Heating tape
  - Heat exchangers
  - Reservoir
  - Pump
- The pump never runs dry, and there is very little loss of liquid from the reservoir. No piping leaks, there was only one leak at the reservoir's hole to the pump.
- The reservoir needed a better seal on the pump-to-reservoir hole. This seal has since been improved and fixed, so there are no leaks.



Figures 6a and b: Improved reservoir seal

Figure 7: Liquid Flow Test

Liquid Heating Test

- The temperature started at 65 degrees Fahrenheit and steadily increased over time.
- Test was stopped at 100 degrees Fahrenheit after 110 minutes.

Data Results:

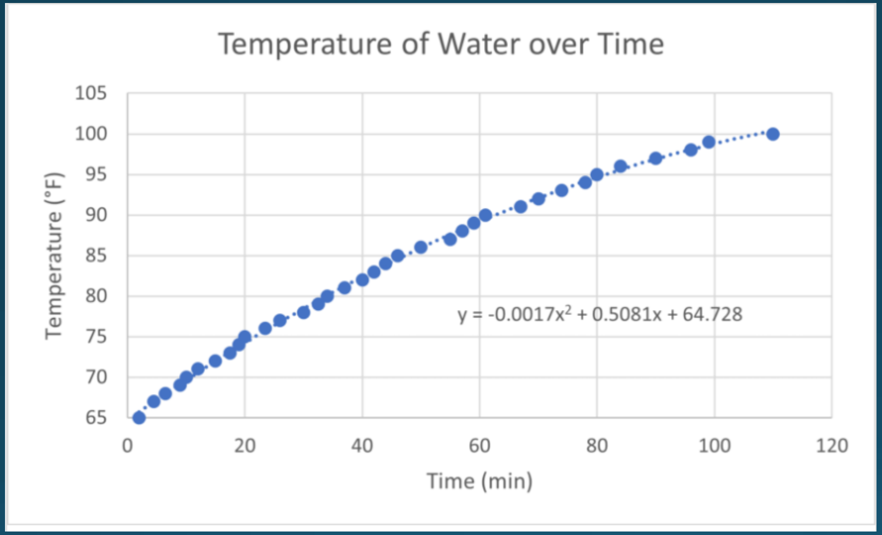


Figure 8: Temperature of Water over Time data results

Figure 9: Liquid Heating Test

8-hour Heating Test

- This test was meant to see the change in temperature of the liquid in the reservoir and liquid heating loop, and the change in the temperature of the air in the air heating loop.
- The test emulates a full-day's 8-hour heating/charging cycle before discharging heat at night.
- The tank was filled to approximately 150 gallons of water, and the liquid heat exchanger and reservoir was filled with 2 gallons of propylene glycol.
- The pump was run with the heating tape for 8 hours, from 9:00am to 5:00pm. The air was tested after being run from 4:30 to 5:00pm.
- The heating tape was at 69F after 5 minutes, and then reached a maximum temperature of 168F at 6.5 hours
- The propylene glycol's temperature started at 52.25F and ended at 59.45F
- The air temperature was tested after the 8 hours

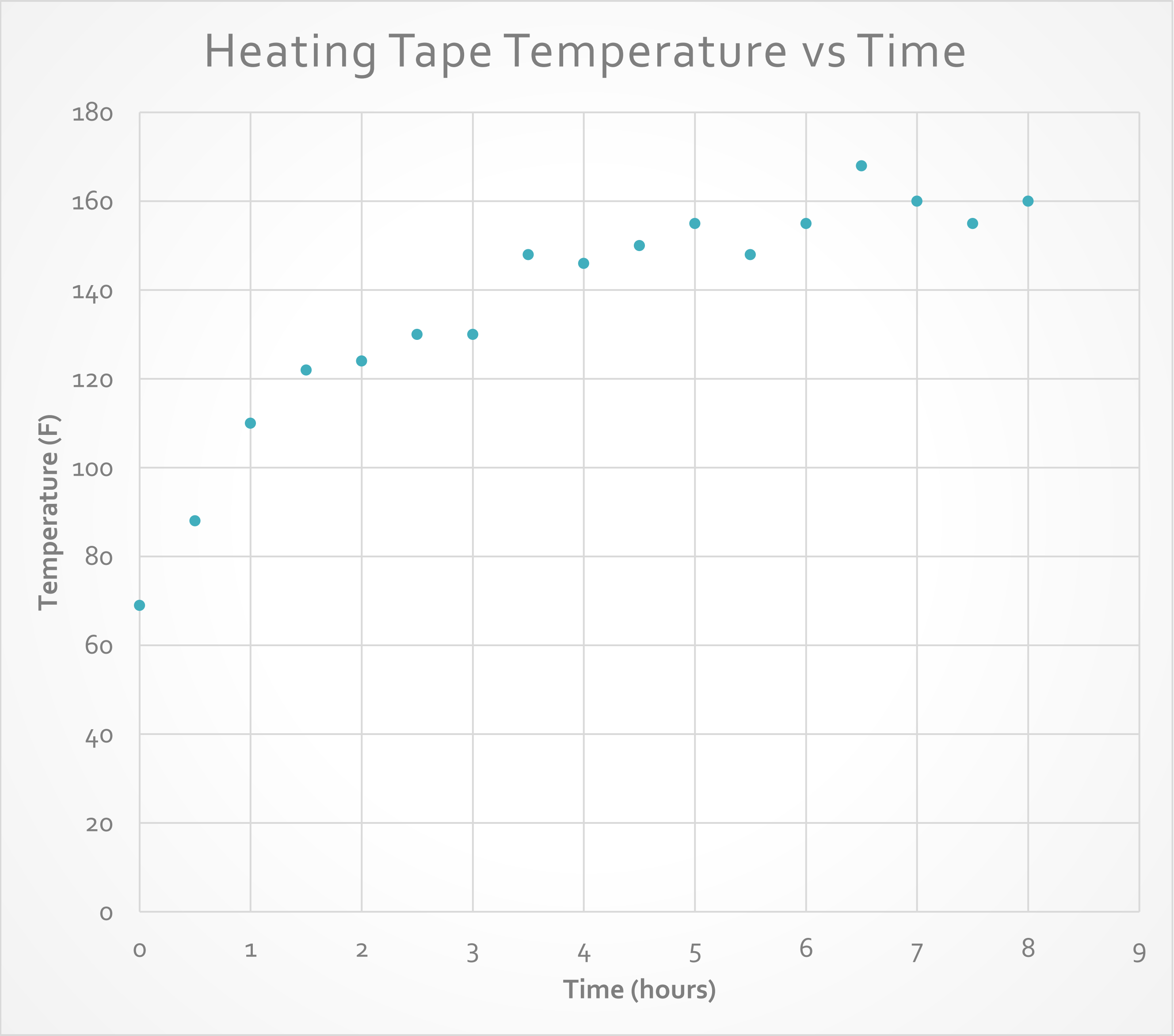


Figure 10: Heating Tape Temperature

8-hour Heating Test

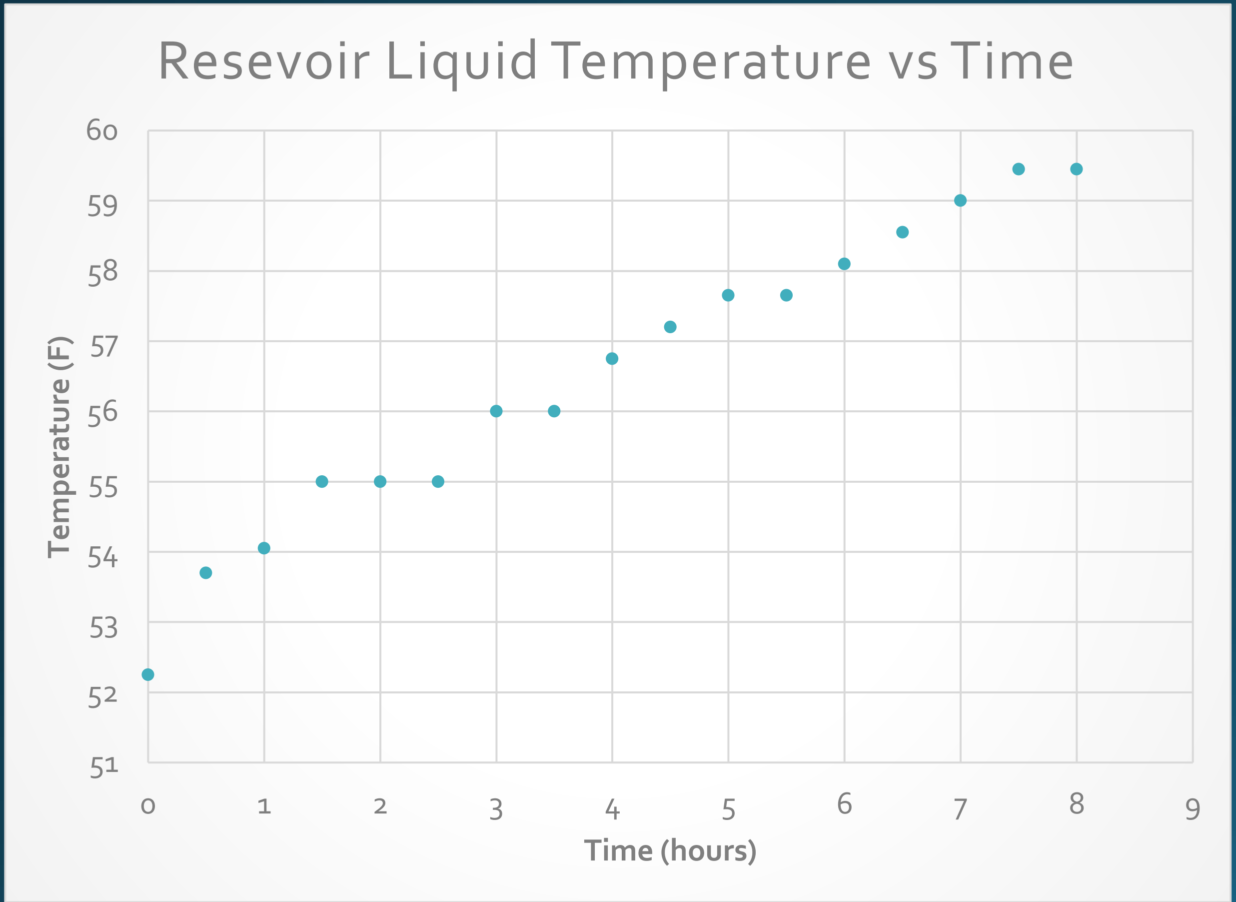


Figure 11: Reservoir Liquid Temperature over time

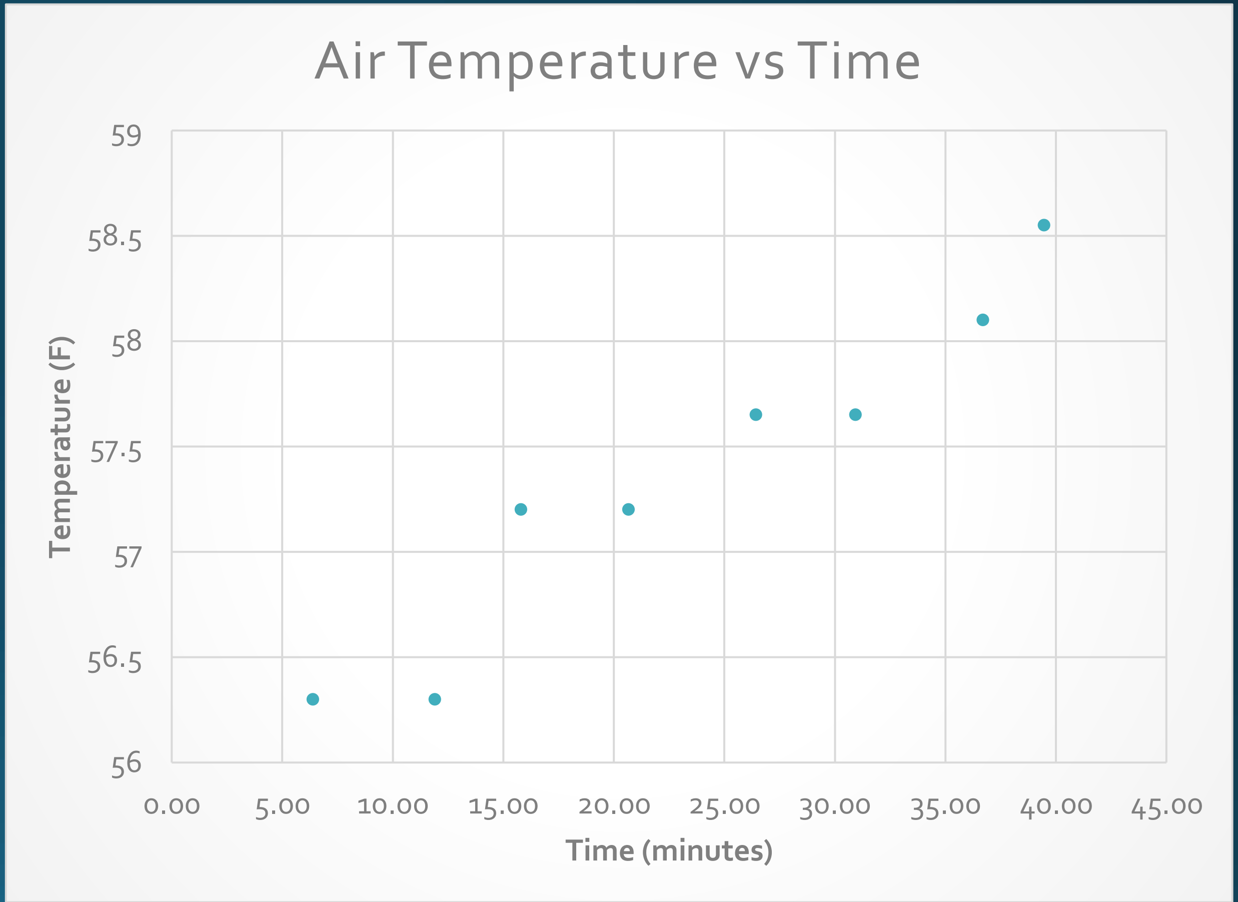


Figure 12: Air Temperature over time

Solar-Battery-Inverter Test

- Parallel panel connection is most efficient
- Testing compatibility of battery with solar panel, as well as compatibility with inverter
- The solar panel worked and was able to charge AirPods
- The solar panel appeared to charge the battery, but not sufficiently over the course of 2 days
- The inverter showed insufficient power from the battery to operate
  - This could have been because the battery was 6V and the inverter needs a minimum of 10V. There is incompatibility
  - This could have been because the connections to the battery were not secure/tight enough

Figure 13: Solar Panel with battery and inverter

Engineering Requirements (1-4)

Table 1: Engineering Requirements (pt. 1)

Engineering Requirement	Derived from this Customer Need.	Method of measurement	Unit of Measurement	Target ER	Testing Procedure	How they were fulfilled
Device maintains consistent house air temperature (60deg F)	Device should maintain comfortable indoor temperature throughout night.	Thermometer or Temperature Sensor for temperature of air	Fahrenheit BTU/h	60F 10,000 BTU/h	Over a 14-hour period, the device outputs 10,000 BTU/h	Acceptable heating source and 200 gallons of water
Device works in environments with outside temperatures ranging from 20 degrees to 60 degrees Fahrenheit.	Device should provide consistent heat source to keep houses warm at night, functioning within standard season range of Navajo Nation and Hopi Reservation temperatures.	Thermometer or Temperature sensor	Fahrenheit	20-60F	Run device for several day/night cycles with projected lows around 20 F; if device maintains minimum heat output over 20 or sub 20 F nights, it passes the test	Insulation around the tank and pipes housing over exposed piping
Device stores heat in an effective method.	Device should provide consistent heat source to keep houses warm at night AND device should store heat during the day and release it at night.	Heat equation, using mass, material qualities such as the specific heat of the medium fluid, and a measured change in temperature.	Fahrenheit	175F	Measure the temperature of the water of the storage tank. Over 14 hours, how much does the temperature decrease?	Water and propylene glycol store and transfer heat
Device budget is within $2,000.	Device should be within purchasing capabilities of Red Feather and the relevant clients.	Pricing	Dollars	$2,000	Bill of materials	Made our own heat transfer devices and used locally sourced materials

Engineering Requirements (5-9)

Table 2: Engineering Requirements (pt. 2)

Engineering Requirement	Derived from this Customer Need.	Method of measurement	Unit of Measurement	Target ER	Testing Procedure	How they were fulfilled
Device has no more than 12 unique parts.	Design should be straightforward.	Counting	Unitless	<=12	Bill of materials	The design is simple and compact
Device able to install onto a variety of homes.	Device geometry should fit a variety of housing situations (no roof cave-ins)	Device dimensions and wei ght	Feet, Lbs.	4ft.x 8ft <500 lbs.	Measuring tape Bill of materials	The dimensions of the device within desired constraints
Materials should have minimal delivery (transit) time.	Materials should be readily available in the region.	Transit time of materials	Miles	<150 miles	Odometer	All materials besides the tank were locally sourced
Device should work without interruption or maintenance.	Design a reliable design.	Amount of time device works without stopping.	Days	7 days	Device functions without stopping for at least one week.	Tested over longer periods to see how it would perform
Device should be able to withstand all weather conditions.	Create a durable and robust design.	Amount of water on the electronics case that can be withstood over time.	Lbf, Volume of water	5 gallons of water	Submerge the electronic components case within a bucket of water to see if the water is sealed out.	Large tank, durable material, proper insulation, and housing for exposed parts.

Technical Analysis: Piping/HVAC/Circulation

Primary Question:
How well will the chosen fluids move through the current piping systems? This includes the liquid to liquid and liquid to air heating loops.

Method:
In order to understand this the head loss experienced by the liquid in both loops was calculated.

Results:

- Liquid to Liquid Heating Loop: 64 feet of loss
- Liquid to Air Heating Loop: 21 feet of loss

Table 3: HVAC Analysis Table

Air Loss Equations:	Values	Units
Reynolds Number	919.8529	
Swamee-Jain	0.063578	
Major head loss	20.40386	ft
confusor	0.003421	
Minor Head loss	0.003421	ft

Liquid Loss Equations:	Values	Units
Reynolds Number	19952.15	
Swamee-Jain	0.024944	
Major head loss	61.76753	ft
Elbow	0.263975	
Minor Head loss	1.583851	ft

Technical Analysis: Liquid to Air Heat Exchanger

Table 3: Copper Piping Calculations

Coil Pipe Diameter	0.5	in
Outer Coil Diameter	11	in
Mean Diameter	10.5	in
Number of Coils	3	
Length of Pipe per Coil	98.96	in
Coil Pipe Area	0.19635	in^2
Straight Pipe Length	28.63	in
Total Pipe Length	127.59	in
Total Surface Area	200.42	in^2
Total Pipe Volume	11048.05	in^3

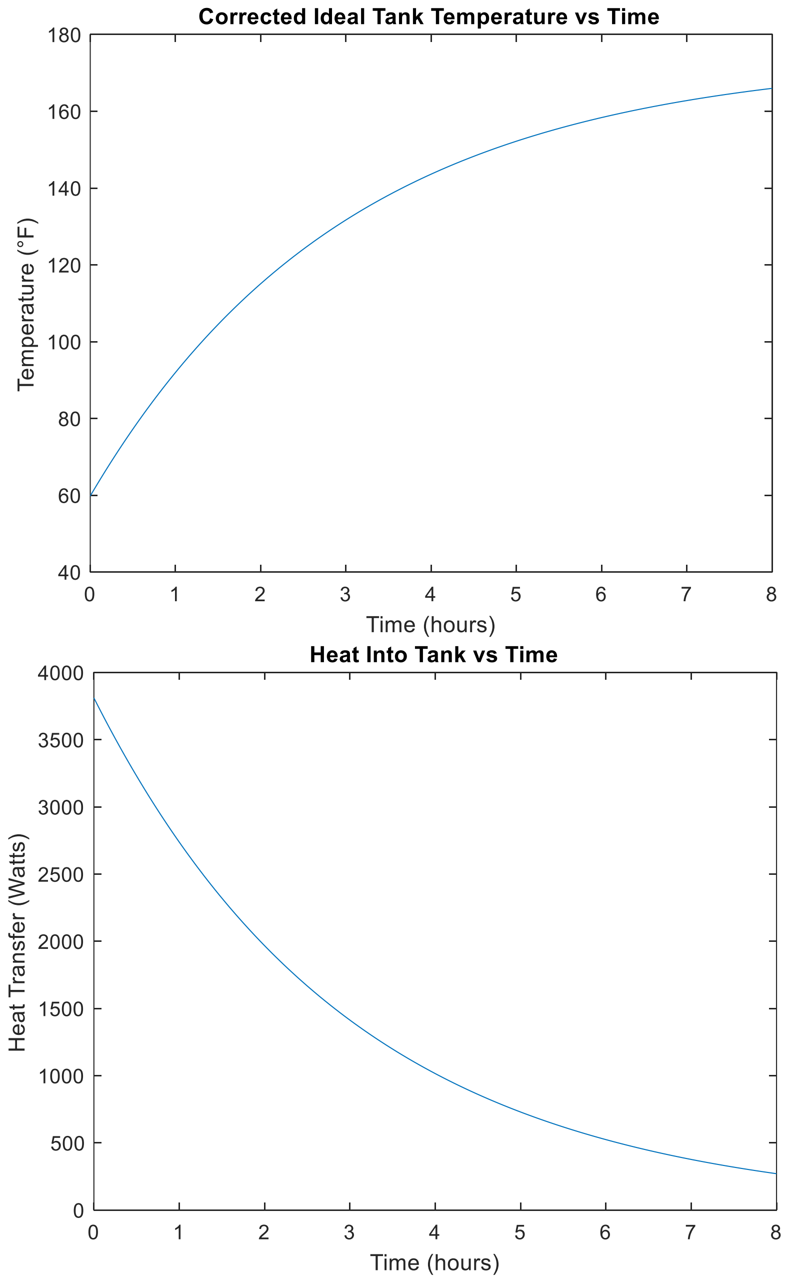
Table 4: Heat Transfer Coefficient (h) Calculations

Heat transfer coefficent (h) Calculations		
Suface Temperature(Ts)	175	F
Inlet Temperature(Ti)	40	F
Outlet Temperature(To)	150	F
Mean Temperature ™	95	F
Air Density(rho)	0.995	kg/m^3
Inlet Velocity(air)	5	m/s
Mass Flow Rate(air)	6.30E-04	kg/s
Specific Heat Capacity(air)	1.009	KJ/kgK
Delta Temperature Log Mean	65.23	K
Average Heat Transfer Coefficent(hbar)	1.12E-02	KW/m^2K
Heat transfer Value(Convection)	0.070	KW
	238.67	BTU/hr

- Assumed heat transfer through forced convection, constant surface temperature, fully developed internal flow, and log mean temperature difference.
- Governing equation, $qconv = \bar{h}As\Delta T$

Technical Analysis: Liquid-to-Liquid Heat Exchanger

- Used transient heat transfer analysis to examine internal temperature of the thermal storage tank, in addition to transfer across key boundaries
- Examined idealized heating case with charging loop temperature treated as constant at the specified target value of 175 °F
- Created first-order approximations of temperature and transfer with respect to time
- Demonstrated inadequacy of selected heat source (1250 Watt heating tape)
- Calculated comparatively negligible thermal losses for insulated tank
- Suggested need for improved heating method in order to attain the desired system parameters



Figures 14a and b: Heat Exchanger Analysis Plots

Technical Analysis: Solar PV

Table 5: Total Monthly Load Calculation		
Pump Load kWh	**Fan Load kWh**	**Total Load kWh**
1.6832	14.2673	15.9505

Figure 15: Pump for our Design

Figure 16: Blower Selection for our Design

Table 6: Solar Radiation Energy Table

RESULTS

Print Results

265 kWh/Year*

System output may range from 249 to 273 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	4.71	18	2
February	5.50	19	2
March	6.52	24	2
April	7.58	27	3
May	7.72	27	3
June	8.08	26	3
July	6.99	23	2
August	6.73	22	2
September	6.67	22	2
October	6.00	21	2
November	5.05	18	2
December	4.38	17	2
Annual	**6.33**	**264**	**$ 27**

Technical Analysis: Heating Element into the Liquid Loop (Heating Tape)

Key Takeaways:

- Heating tape reduced from 240V power inlet to 125V inlet. Specs say that with 240V input it should have 1250W output power. Output Power of Heating Tape Calculated from Experimental Data to be 216.2W.
- The amount of heat it produces is sufficient for heating the liquid-to-liquid heat exchanger and its heating loop (0.3291 gallons of propylene glycol) to 175°F in a short period of time, 124 minutes
- Likely insufficient for heating up 200 gallons of water. Future redesigns might consider smaller amount of water in the tank or lower heating temperature of water

Specific Heat Equation:

$$Q = mc\Delta T$$

$$P = \frac{mc\Delta T}{t}$$

$$t = \frac{mc\Delta T}{q}$$

Table 6: Heating Element Calculation Results

Description of the Calculation	Calculated Value	Units
Volume of piping of Heating Exchanger and External Piping of Liquid Heating Loop	0.044 0.3291 1.2458	ft^3 gal kg
Experimental Power of Heating Tape	216.2	W
Change in Temperature of 200 Gallons of Water over 8-hour period given the Heating Tape Power	1.97 35.55	°C °F
Time needed to increase temperature of propylene glycol in the liquid-to-liquid heat exchanger from 68°F to 175°F	7,443 124	s min
Power needed to heat 200 gallons of water to 175°F in 8 hours	4,566	W
Power needed to heat 100 gallons of water to 175°F in 8 hours	2,282	W
Power needed to heat 50 gallons of water to 175°F in 8 hours	1,141	W
Power needed to heat 50 gallons of water to 145°F in 8 hours	761	W

Decision-making Process

1. Original Design
- This design was backed up by the research carried out in the first semester and embodied basic heat transfer principals and design considerations

2. Coiled Piping/Duct
- Each piping was decided to be coiled in order to increase the surface area for heat transfer. Both loops were placed in a duct in order to hold the systems together and in place inside of the tank.

3. Reservoir/Tank Top Design
- It was later decided that the liquid moving through the liquid-to-liquid heating loop would need a reservoir in order to provide liquid into the pump. Along with this a platform was developed in order to support all the components that would need to sit at the top of the tank

4. Shortening of air loop piping/Housing
- After preliminary testing it was decided to cut a significant amount of length off the air-to-air loop piping in order to increase the movement of air through the pipe. Along with this it was decided to add a housing unit at the top of the pipe to add insulation and protection to the piping that comes out of the tank.

Prototyping Process: Heat Exchangers

Both heat exchangers began primarily as 50 ft worth of coiled soft copper piping. From there the required lengths were designed. This required that four Straight pipes were attached in order to allow for inflow and out flow through the system. This process would be easy to replicate in manufacturing of heat exchangers for a thermal storage device in the future.

Figure 17: Salt in HX Coil

Figure 18: Coil Reshaping

Prototyping Process: Heat Exchangers

Began with two sets coiled soft copper piping

Figure 19: Finished Coil

Four straight pipes and Elbow fittings were soldered to the coils

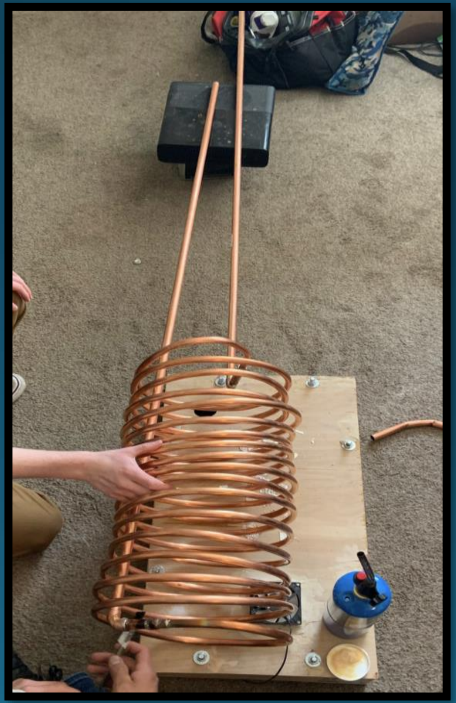


Figure 20: Lengthened Coil

Piping of air heat exchanger was cut down and resized to better accommodate design constraints and provide greater airflow

Figure 21: Finished HX Stack

Prototyping Process: Soldering & Pipe Fitting

Steps for soldering

1. Using 2 kinds of brushes the inside and outside of the pipe and fittings were cleaned
2. Next the two pieces were coated in flux paste
3. From there an industrial grade solder and blow torch were used to seal the two copper parts together

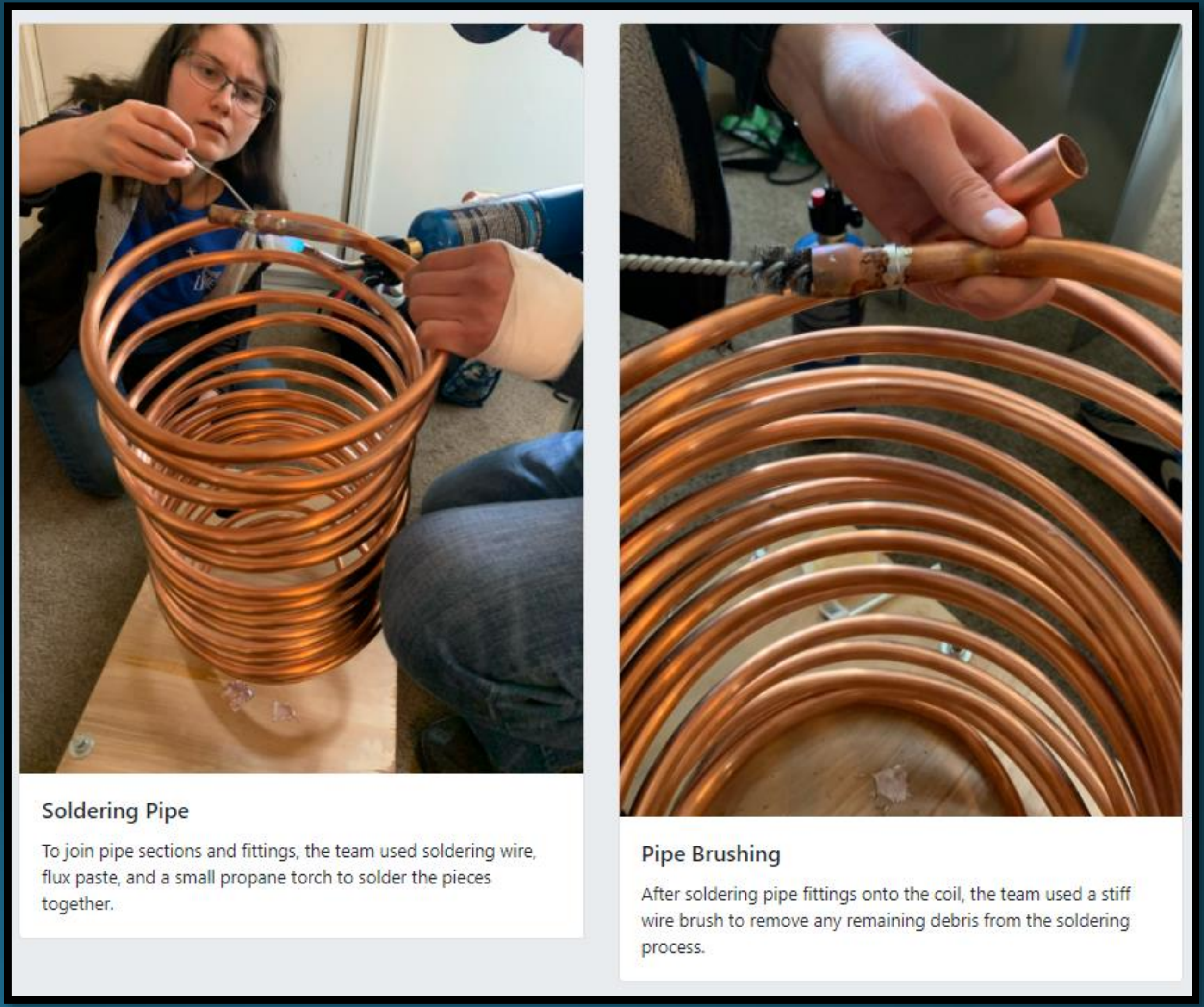


Figure 22a and b: Pipe Soldering and Brushing Processes

Prototyping Process: Above the Tank Work (Platform)

1. Using the predetermined dimensions of 4 by 8 ft the platform was assembled using several planks and boards of wood
2. The whole structure was then held together by screws and mended plates
3. After assessing which sides were strongest the platform was organized in a way that balanced all required components on top of the tank (Reservoir, Pump, and Blower.

Figure 23: Platform Frame

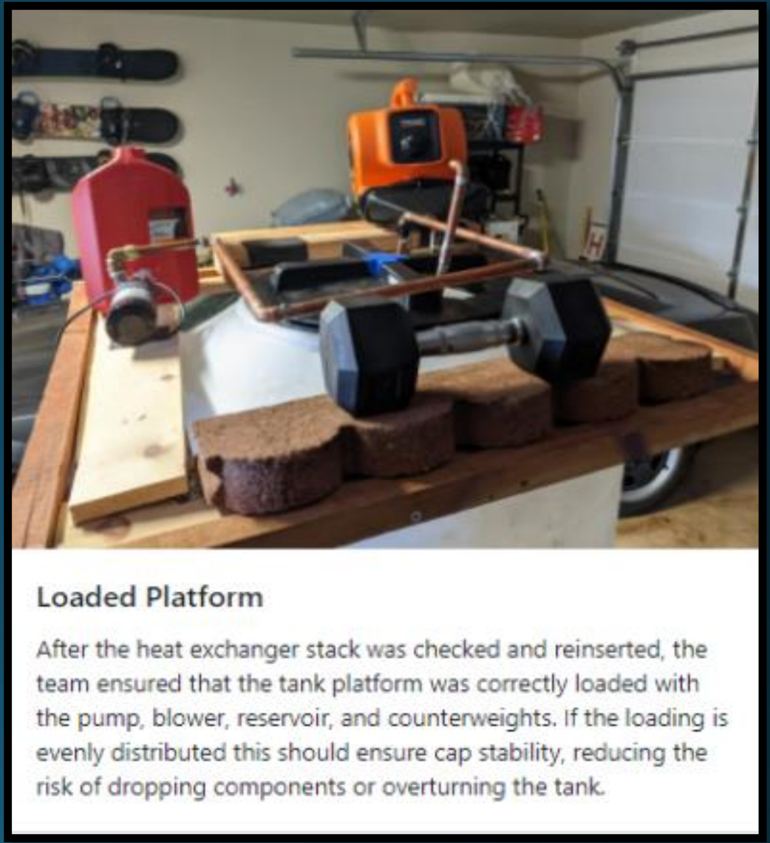


Figure 24: Counterweighted Platform

Current State of System

Our current system is fully assembled. Each heating loop is functional, and all electronics work together.

Figure 25: Full tank assembly

Figure 26: Top view of system

Bill of Materials and Budget

Table 7: Bill of Materials (pt 1)

Bill of Materials							
Part number	Part description	Manufacturer	Dimensions	Weight	Quantity	Unit Cost	Total Cost for Part
1	Heating Fluid Pump	Ferroday	10.2 x 7.6 x 6 inches	4.59 lbs.	1	$79.99	$79.99
2	Liquid to Liquid Heat Exchanger	AB	3"x8" 10 plates	3.29 lbs	1	$89.99	
3	Heating Band	heating Element Plus	1" x 96"		1	$119.90	$119.90
4	Copper Piping	Cambridge-Lee	10' and 1" dia		1	$34.77	$34.77
5	Storage Tank	Norwesco	32" dia. x 67"H and 210 gallons	65 lbs.	1	$578.33	$578.33
6	Fan	Ridgid	13 x 12.3 x 10.6 in	12.25 lbs	1	$79.97	$79.97
7	Battery	Crown	12.19 × 7.19 × 14.13 in	92 lbs.	1	$235.00	$235.00
8	Electricity Solar Panel	Grape Solar	26.18" x 24.4"	10.58 lbs	2	$51.41	$102.82
9	Arduino	ELEGOO	3.15 x 2.36 x 0.39 in	2.24 oz.	1	$12.98	$12.98
10	Thermocouples	Aideepen	3.7 x 3.1 x 0.3 in	0.81 oz.	5	$2.60	$13.00
11	Piping Clamp				1	$80.28	$80.28
12	Propylene Glycol	Dynalene		10 lbs	1 (gal)	$38.00	
13	Copper Piping	Home depot	10' and 1/2" dia		3	$11.27	$33.81
14	Round metal pipe duct	Home depot	12" x 5'		1	$16.80	$16.80
15	Gas can	Home depot	5 gallons; 14" x 7"		1	$23.97	$23.97

Bill of Materials and Budget

Table 8: Bill of Materials (pt 2)

16	Copper coil piping	AZ central supply	1/2" x 50' Copper coil		2	$62.00	$124.00
17	90-degree bronze fittings	Home depot	1/2" 90-degree bronze elbow		2	$7.93	$15.86
18	Solder	Home depot	8oz. lead free solder		1	$20.95	$20.95
19	90-degree fittings	Home depot	1/2"		12	$0.74	$8.88
20	cover	Home depot	20"		1	$39.98	$39.98
21	wood	Home depot			3	$1.69	$5.07
22	couplings	Home depot	3/8" x 1/2"		4	$1.76	$7.04
23	cpvc pipes	Home depot	3/4" x 2'		6	$2.16	$12.96
24	Sharkbite Coupling	Home depot	3/8" x 3/8"		1	$6.97	$6.97
25	PTFE Tape	Home depot	1/2" x 260" (width x length)		1	$0.98	$0.98
26	Male Adapter Fitting	Home depot	1/2" x 1/2"		1	$1.58	$1.58
27	Copper Coupling	Home depot	1/2" x 1/2"		3	$0.56	$1.68
28	Stud Size Ring Terminals	Home depot	0.8125" x 0.3125"		1	$1.98	$1.98
29	15A Straight-Blade Non-Grounded Plug	Home depot	1.5" x 2"		1	$2.19	$2.19
30	Fiberglass Pipe Wrap Insulation	Home depot	3" x 25'		1	$7.12	$7.12
31	Power Inverter	Walmart	3"x6"x8"		1	$34.99	$34.99
32	Female to Male Adapter	Home depot	3/4"x1/2"		1	$5.18	$5.18
33	Weather Resistant Electrical Tape	Home depot	3/4" x 66'		1	$2.98	$2.98
34	Rubber O-ring	Home depot	5/8"		1	$1.54	$1.58
					Pre-Tax Sum		$1,713.59
					Sales Tax (FLAGSTAFF)		$157.31
					Total Cost for Design		$1,870.90

Future Work Schedule

What's Left:

- Client Hand off (4/10/21)
- Operation/Assembly Manual (4/16/21)
- Final Report/Poster (4/19/21)
- CAD Package (4/26/21)
- Website (4/26/21)

Figure 26: Red Feather Development Group Logo

Figure 27: Full tank assembly

Future Design Recommendations

- Find a stronger heating source
  - Heat liquid outside of tank with solar thermal device
- Use an HVAC suction device with geometry that fits the system
- Use better insulation for tank and exposed piping
- Insulate the reservoir
- Further develop and research solar element of design
- Create a better-suited platform for devices on top of the tank
- Wider piping (large diameter) for liquid to air heat exchanger to increase air flow

Conclusion

- The concept works
- Need more thermal energy input into the system
- Future teams could improve viability of the design
- A working system that includes a fully-standalone system with a compatible solar system, 200-gallon tank, and electronic control systems would likely require a larger budget or improvisations
- Additional revisions could be made to make the full-scale system economically viable to manufacture on large scale

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