SRP EVAP

ME 486C Fall 2025

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BACKGROUND

Project Description

Project Background

The objective of this project is to design and operate a controlled apparatus that models canal conditions under turbulent free convection to measure and analyze evaporation rates.

Acknowledgments

Huge thanks to Dr. Thomas Acker, Professor Carson Pete, and Dr. Mani/ASU team for their support throughout this project.

Deliverables

- BUILD AN INSULATED SHELL
- BUILD A 10FT. X 2FT. WATER TANK
- CREATE DATA ACQUISITION SYSTEM FOR APPARATUS CONDITIONS
- COLLECT EVAPORATION DATA
- PRESENT PRELIMINARY DATA TO ASU RESEARCH TEAM

Success Metrics

- Water Tank Protected from Wind and Weather
- Water Temperature Controlled
- All sensors Collecting data
- Evaporation Rate calculated from data
- ASU Receives Viable Data For Further Research

Requirements

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Customer Requirements

- Control & Maintain Air Temperature
- Control & Maintain Water Temperature
- Control & Maintain Relative Humidity
- Ability to Measure Relative Humidity
- Maintain Convective Flow Regime
- Tank Maintains Water Tightness
- Project Stays Within Budget

Engineering Requirements

- Precision of Data Collection
- Sensor Accuracy & Calibration
- Material Durability & Longevity
- Geometric Similarity to Grand Canal
- Rayleigh Number Scalability
- Economic Feasibility
- Adhere to Scientific Standards & Procedures

Project: Captsone SRP QFD
Date: 9/4/2025

(Between 1 and 5, lowest rating to highest rating)
(0=N/A) (3 = weak) (6 = moderate) (9 = strong)

System QFD

		Technical Requirements (0,3,9)							Competition (1-5)				
Customer Needs	Customer Weights	Precision of data collection	Accuaracy of sensors	Material Durability & Longevity	Geometric Similarity	Similarity of Rayleigh number	Economic Feasibility & Practical Implementation	Adhere to scientific experimentation principles	*Casa Blanca Canal Solar Project*	*Project Nexus*	*Gujarat Canal Solar Project*		
Ability to control/maintain air temp.	9	9	9	3	6	9	6	9	1	1	1		
Ability control/maintain water surface temp.	9	9	9	3	6	9	6	9	1	1	1		
Ability control/maintain relative humidity	9	9	9	3	6	9	6	9	1	1	1		
Ability to measure relative humidity	9	9	9	0	6	9	3	9	2	2	1		
Ability to maintain convective flow regime	9	6	9	3	9	9	9	9	1	1	1		
Project stays within budget	9	0	3	6	0	6	9	0	3	3	3		
Maintain water tightness	9	9	0	9	3	0	6	3	5	5	5		
Technical Requirement Units		in/day	°C, RH%	Years	N/A	N/A	$	N/A					
Technical Requirement Targets		0.58 in/day	±1 °C, ±3% RH, ±0.02g	6 months	100%	3.18*10^8	$5,675	90%					
Absolute Technical Importance		51	48	27	36	51	36	48					
Relative Technical Importance		1st	3rd	7th	5th	2nd	6th	4th					

Figure 1: QFD

House of Quality:

Key ERs & CRs

- Precision of Data Collection
- Accuray of Sensors
- Ability to control water temp.
- Ability to maintain convective flow regime

Design Space Research

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Benchmarking

Casa Blanca Canal Solar Project

- Currently under construction on the Gila River
- Half mile long
- Reduces algae/aquatic plant growth
- Decreases evaporation up to 50%
- Increased water quality/quantity

Figure 2: Casa Blanca Project

Project Nexus

- Based in California
- Determine water evaporation due to shading
- Analyze how solar panel installations can reduced algae growth
- Provide renewable power generation to local communities

Figure 3: Project Nexus

Gujarat Canal Solar Project

- Located in India
- The first to create solar-over-canal technology in 2012
- Prevents 2 billion liters of water from evaporating annually
- Solar power is primarily used for irrigation pumps

Figure 4: Gujarat Canal Project

Literature Review

Literature Review (Samantha Synk)

Key References:

- Get Started with MATLAB [23]
- MATLAB Documentation for 3-D Scatter Plots [24]
- Array Indexing [25]
- Heat Transfer with MATLAB Curriculum Materials [26]
- Direct Numerical Simulation of Natural Convection Over Horizontal Plates [5]

Application:

- MATLAB documentation and engineering courseware were used to structure the script and guide our computational workflow.
- Research paper was used to support the theoretical background and validation of natural convection in our apparatus.

Literature Review (Lilliana HB)

Key References:

- Heat and Mass Transfer: Fundamentals and Applications [1]
- Fundamentals of Heat and Mass Transfer [2]
- An Experimental Investigation of Water Evaporation into Low-Velocity Air Currents [3]
- An Experimental Investigation of Combined Turbulent Free and Forced Evaporation [4]
- Natural Convection Mass Transfer Adjacent to Horizontal Plates [6]
- Natural Convection Adjacent to Horizontal Surface of Various Planforms [7]

Application:

- Heat and Mass Transfer books were used to build theoretical background of project as well as provided equations for mathematical modeling.
- Research papers provided experimentally derived Sherwood correlations from other mass transfer experiments, as well as inspiration for our apparatus design.

Literature Review (Garet Bowels)

Key References:

- Adafruit Learning Systems for Sensor Selection and Pre-calibration[13]
- Arduino Workshop Book: A Hands-On Introduction with 65 Projects [14]
- Programming Arduino: Arduino IDE Coding Sketches [15]
- Practical Electronics for Inventors Book [16]
- Arduino Cookbook [17]

Application:

- These Arduino and electronics sources provided the technical foundation for wiring, powering, and integrating all sensors in the system, while also guiding best practices for calibration, signal integrity, and noise reduction.
- Coding-focused references supported the development of reliable Arduino sketches, enabling stable data logging, multi-sensor communication, and long-duration environmental monitoring for the apparatus.

Literature Review (Trey Bushling)

Key References:

- Mass transfer from evaporating horizontal surfaces [8]
- Engineering Drawing Practices [9]
- SOLIDWORKS 2023 Reference Guide [10]
- Introduction to Fluid Mechanics [11]
- Correlating equations for laminar and turbulent free convection from a horizontal plate [12]

Application:

- Used natural convection and mass transfer literature to justify calculating Sherwood Rayleigh correlations for our evaporation analysis
- Applied CAD and engineering drawing standards to design, model, and document the experimental apparatus accurately
- Used fluid mechanics siphon theory to validate our mass loss measurement method and ensure reliable evaporation rate data

Literature Review (Jorge Cesin)

Key References:

- Effect of solar canals on evaporation, water quality, and power production [27]
- Quarterly Journal of the royal meteorological society [28]
- Evaporation from three water bodies of different sizes and climates: Measurements and scaling analysis [29]
- Flow of water in irrigation and similar canals [30]
- Estimating evaporation from irrigation canals in the midstream areas of the Heihe River basin [31]

Application:

- The three top sources link evaporation to ambient conditions and how each variable correlates to the rate of which evaporation occurs based off past research papers.
- For the bottom two sources, evaporation is measured based off data collected from other canals, while not very helpful too our exact conditions, it builds a relation to what should be expected.

Literature Review (Brendan Steele)

Key References:

- Basics to coding in HTML [18]
- Utilizing CSS styles when coding for website display [19]
- Variation of relative humidity as seen through linking water vapor to air temperature [20]
- Temporal analysis of long-term atmospheric moisture levels in Phoenix, Arizona [21]
- SOLIDWORKS Design Help 2025 Drawings & Assemblies [22]

Application:

- The first two sources are for creating the website and how to properly organize the code with clear example-based tutorials.
- The humidity-based sources were utilized to see how past studies showed the effect of varying humidity levels on the rate of evaporation.
- The final source was used to brush up on SOLIDWORKS modeling and assemblies when creating our final CAD model.

Mathematical Modeling

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Design Efforts & Engineering Calculations

1. Rayleigh number for Grand Canal in Phoenix:

$$Ra_m = Gr_m \cdot Sc = \left[\frac{g(\rho_s - \rho_\infty)L_c^3}{\rho_\infty \cdot \nu^2}\right] \cdot \frac{\nu}{D_{AB}}$$

$$Ra_m = \left[\frac{9.81\frac{m}{s^2}\left(1.151\frac{kg}{m^3} - 1.142\frac{kg}{m^3}\right)(1.143m)^3}{1.142\frac{kg}{m^3}\left(15.236\times10^{-6}\frac{m^2}{s}\right)^2}\right] \cdot 0.632 = 3.143\times10^8$$

2. Rayleigh number for apparatus water tank:

$$Ra_m = \left[\frac{9.81\frac{m}{s}\left(1.262\frac{kg}{m^3} - 1.138\frac{kg}{m^3}\right)(0.254m)^3}{1.262\frac{kg}{m^3}\left(15.255\times10^{-6}\frac{m^2}{s}\right)^2}\right] \cdot 0.633 = 4.31\times10^7$$

3. Difference in Rayleigh numbers:

$$\left(3.14\times10^8\right) - \left(4.31\times10^7\right) = 2.71\times10^8$$

4. Characteristic length for the 1:5 rectangle sample area of Grand Canal in Pheonix:

$$L_c = \frac{A_s}{P}$$

$$L_c = \frac{37.6m^2}{32.9m} = 1.143m$$

Design Efforts & Engineering Calculations

5. Sherwood correlation[7] produced from a published mass transfer experiment to model a convective mass transfer coefficient for the Grand Canal:

$$\overline{Sh} = 0.15(Ra_m)^{\frac{1}{3}} = 0.15\left(3.143 \times 10^8\right)^{\frac{1}{3}} = 101.986 \qquad \left(8 \times 10^6 \leq Ra \leq 1.6 \times 10^9\right)$$

$$\bar{h}_m = \frac{\overline{Sh} \cdot D_{AB}}{L_c} = \frac{101.986\left(2.41 \times 10^{-5}\,\frac{m^2}{s}\right)}{1.143m} = 0.00215\frac{m}{s}$$

6. Sherwood number and convective mass transfer coefficient for apparatus with scaled design parameters:

$$\overline{Sh} = 0.15\left(4.31 \times 10^7\right)^{\frac{1}{3}} = 52.6$$

$$\bar{h}_m = \frac{52.6\left(2.41 \times 10^{-5}\,\frac{m^2}{s}\right)}{0.254m} = 0.005\frac{m}{s}$$

Design parameters for apparatus to achieve the Rayleigh number:
$T_\infty = 45°F$ $T_s = 90°F$ $\phi = 2\%$ $L_c = \frac{A_s}{P} = 0.254m$

Design Efforts & Engineering Calculations

7. Using the Sherwood correlation and Rayleigh number, the theoretical rate of evaporation for the apparatus was calculated:

$$\dot{m}_v = \overline{h}_m \cdot A_s(\rho_{v,s} - \rho_{v,\infty})$$

$$\dot{m}_v = 0.005\frac{m}{s} \cdot 1.858m^2\left(0.0344\frac{kg}{m^3} - 0.000159\frac{kg}{m^3}\right)\left(\frac{1000g}{1kg}\right) = 0.318\frac{g}{s}$$

$$\dot{m}_v = 0.318\frac{g}{s} = 0.582\frac{inches}{day}$$

This is about 19 grams per minute of evaporation

Figure 5: 19 grams of water

Concept Generation and Selection

Functional Decomposition

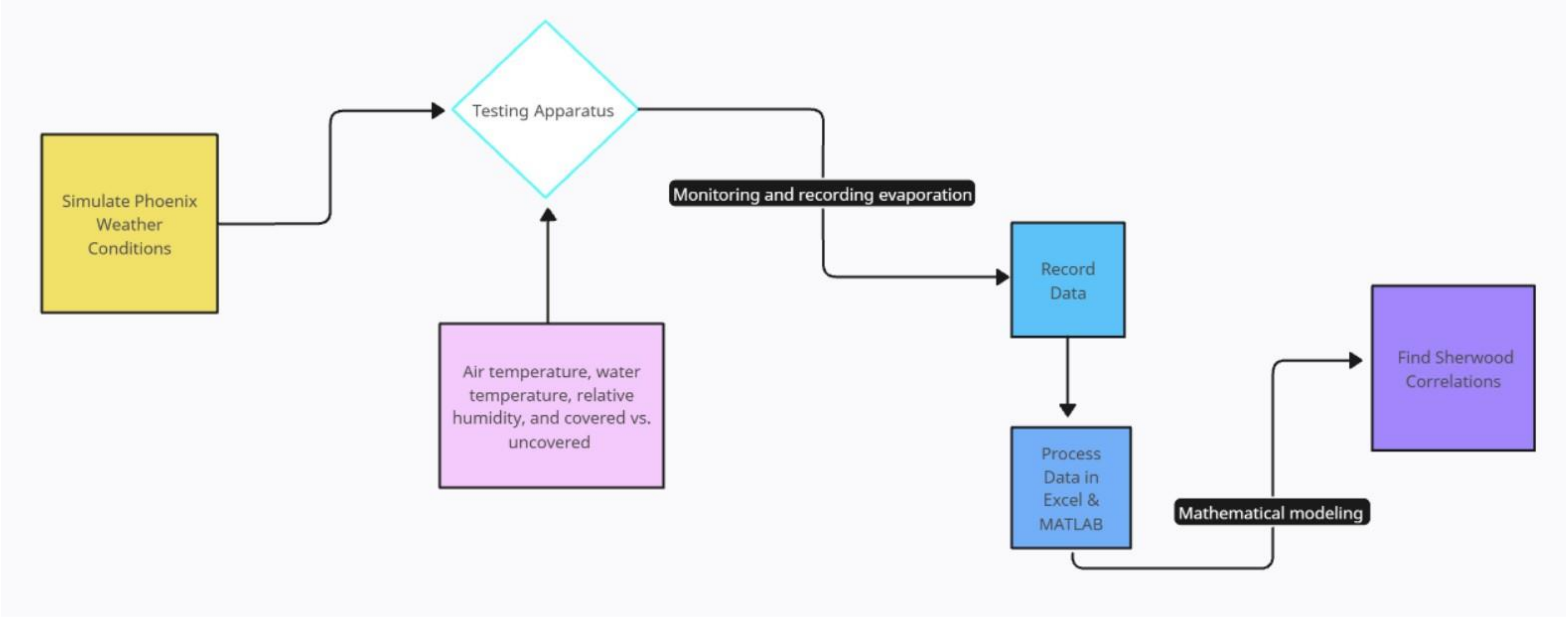


Figure 6: Flow Chart

Concept Generation

Table 1: Morphological Matrix

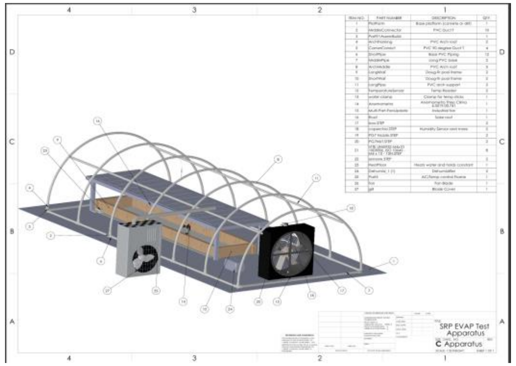
Concept	Option 1	Option 2	Option 3	Option 4
Humidity	Hydrometer	Hygrometer*	Gravimetric Humidity Sensor	Psychrometer
Scientific methods of recording the humidity within the test apparatus at multiple locations.	Cole-Parmer	 Fine Tools	 Livington Janice JABE	 Fine Art America
Temperature	Thermocouple*	Electric Thermometer	Analog Thermometer	
Methods of recording the temperature at multiple locations such as in the water above the water and the general apparatus.	 RAM-Sensors	 SP-Bell Art	 General Tools	
Wind	Digital Anemometer*	Robinson Anemometer		
Scientific methods of recording the wind speed directly over the surface of the water reservior.	 WinTact	 METEO OMINIUM		

Selection Criteria (Semester 1)

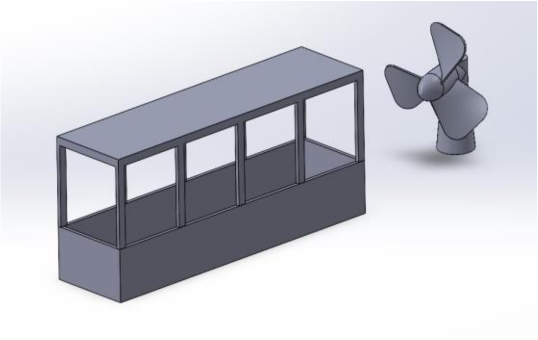
Table 2: Pugh Chart

PUGH Chart - SRP Evaporation				
		Concept		
		1	2	3
Criteria	Cost	-	+	-
	Power	+	0	0
	Mobility	+	-	-
	Aparatus Seal	+	-	0
	Size Smaller= better	+	0	-
	Temp Higher=better	+	+	-
	Accesible	-	-	+
	Monitorability	+	-	+
Sum of +		6	2	2
Sum of 0		0	2	2
Sum of -		2	4	4
Total		4	-2	-2

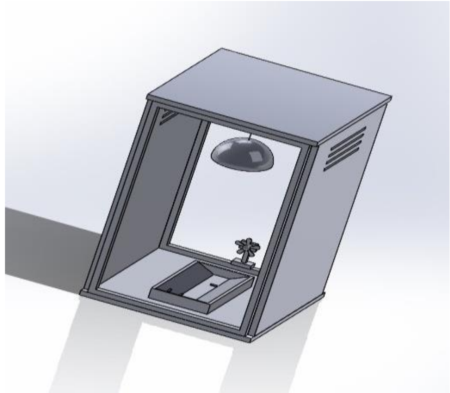
Design 1



Design 2



Design 3



Final Design CAD

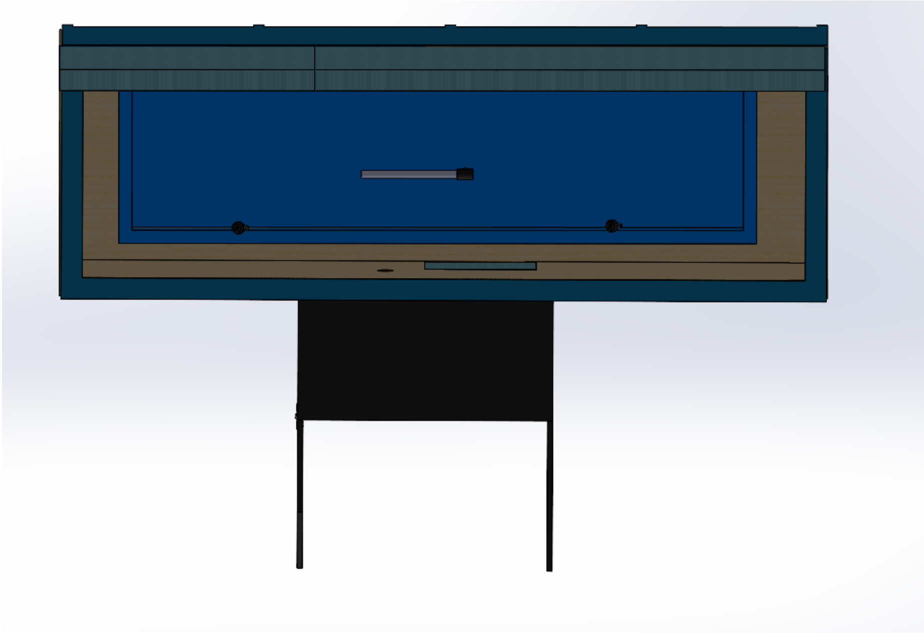


Figure 7: Final CAD View 1

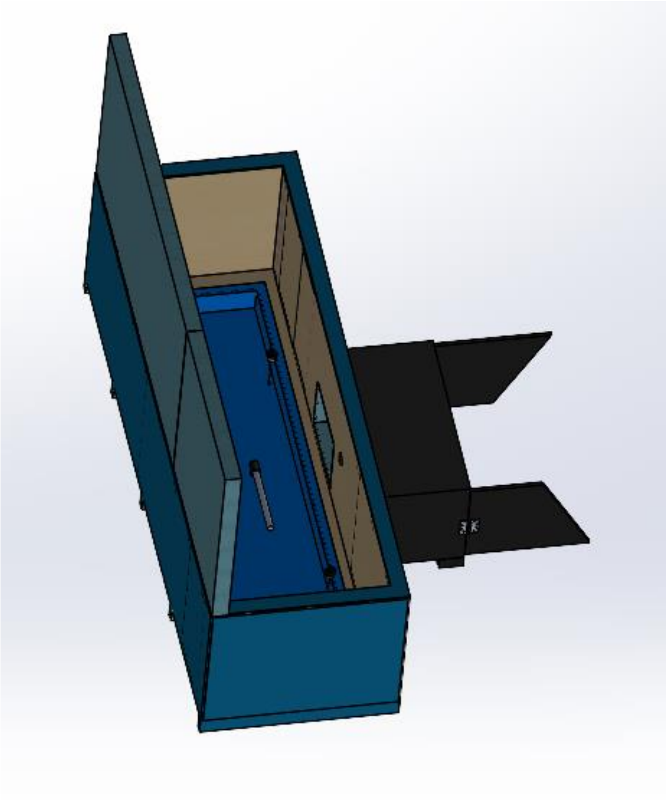


Figure 8: Final CAD View 2

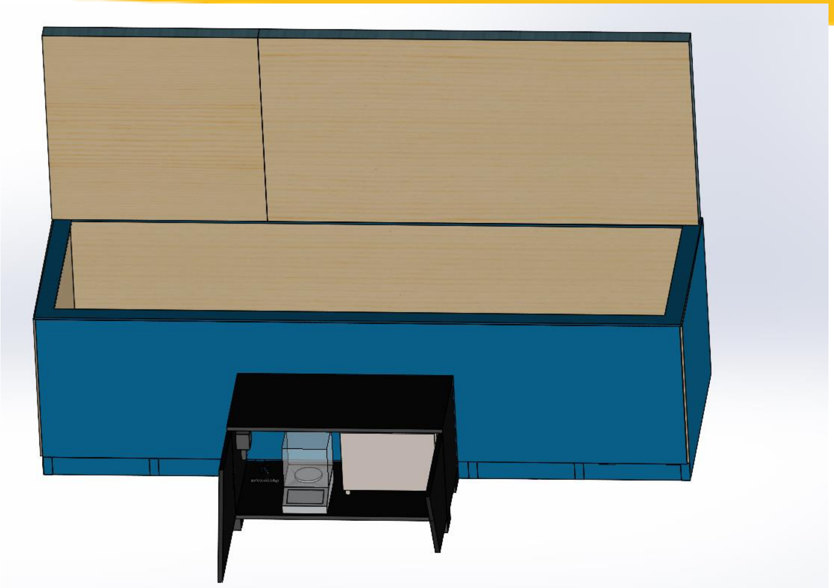
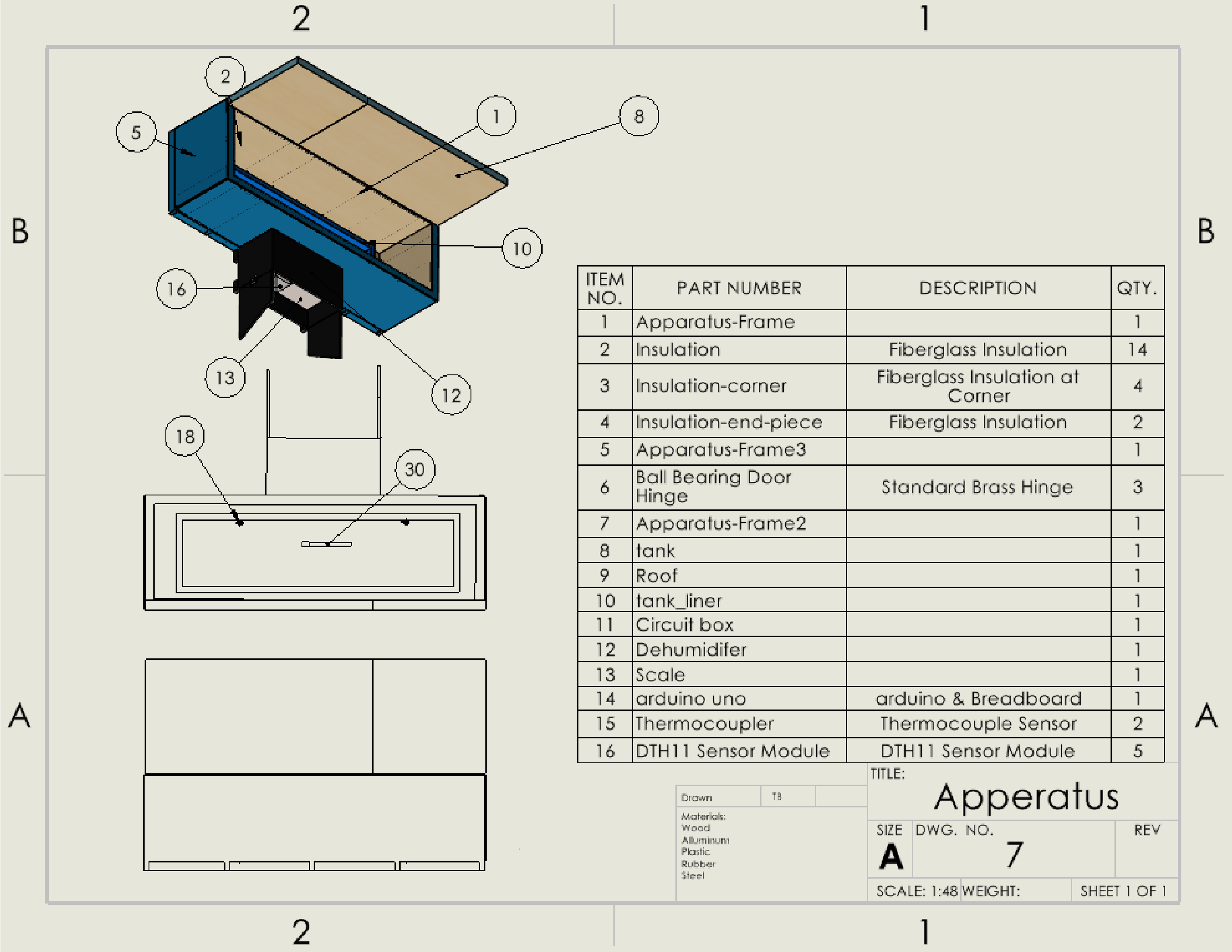


Figure 9: Final CAD View 3

CAD & Schematics



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Apparatus-Frame		1
2	Insulation	Fiberglass Insulation	14
3	Insulation-corner	Fiberglass Insulation at Corner	4
4	Insulation-end-piece	Fiberglass Insulation	2
5	Apparatus-Frame3		1
6	Ball Bearing Door Hinge	Standard Brass Hinge	3
7	Apparatus-Frame2		1
8	tank		1
9	Roof		1
10	tank_liner		1
11	Circuit box		1
12	Dehumidifer		1
13	Scale		1
14	arduino uno	arduino & Breadboard	1
15	Thermocoupler	Thermocouple Sensor	2
16	DTH11 Sensor Module	DTH11 Sensor Module	5

Figure 10: Final CAD Drawing

Project Management – Schedule & Budget

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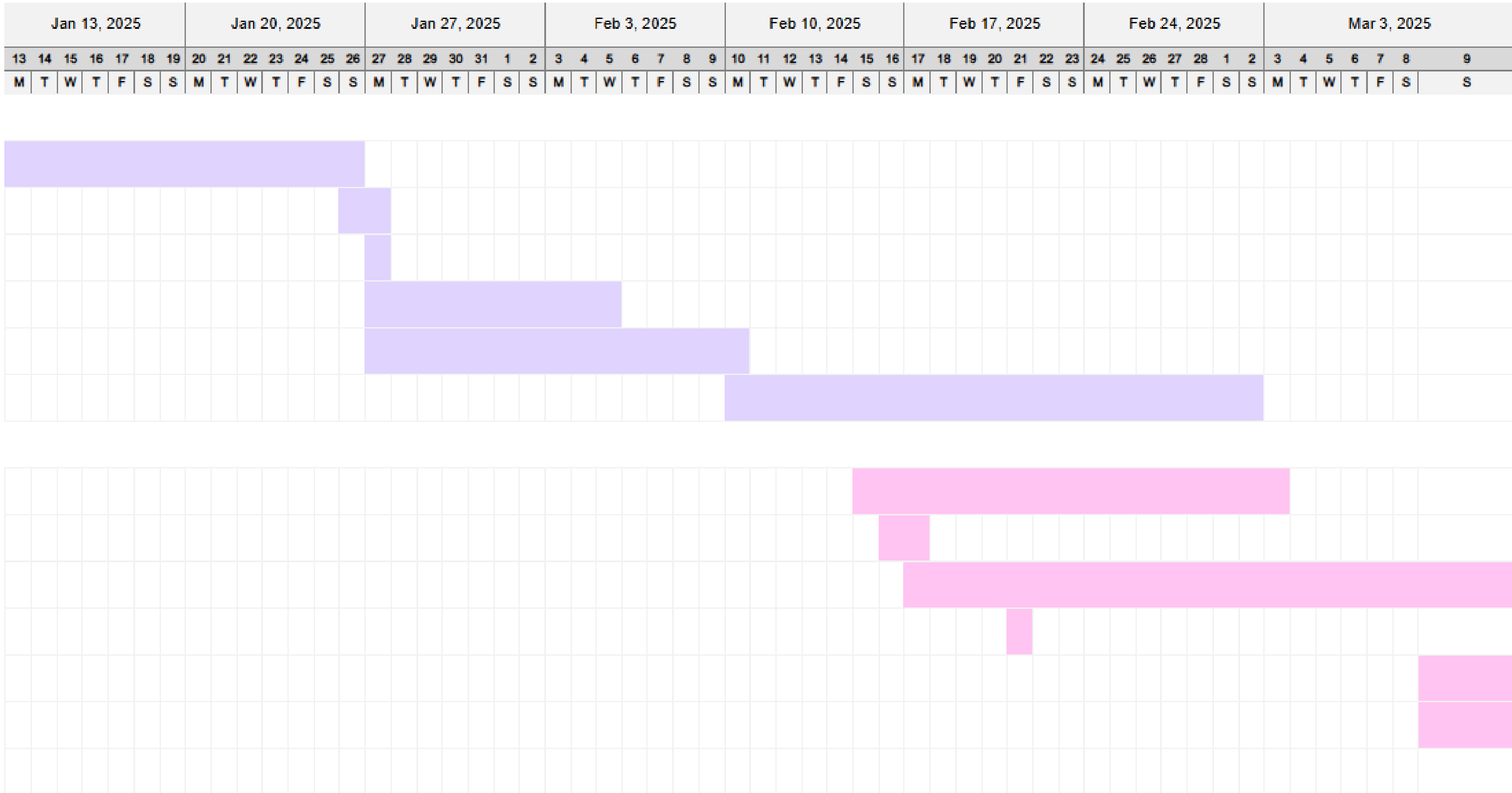
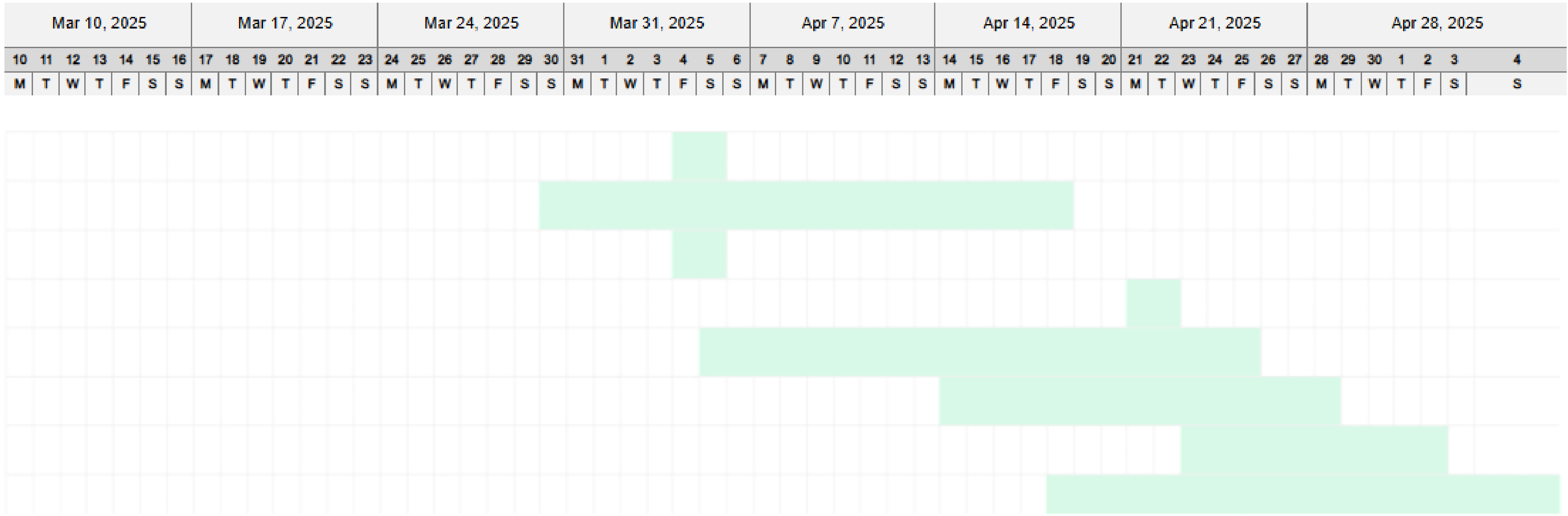
Schedule Spring 2025

TASK	ASSIGNED TO	PROGRESS	START	END
Problem Statement and Introduction				
Team Charter	Jorge	100%	1/13/25	1/26/25
Staff Meeting 3	Everyone	100%	1/26/25	1/27/25
First Team Meeting	Everyone	100%	1/27/25	1/27/25
First Client Meeting	Everyone	100%	1/27/25	2/5/25
Presentation 1	Liliana	100%	1/27/25	2/10/25
Report 1	Samantha	100%	2/10/25	3/2/25
Analysis, Prototyping, and Presentations				
Presentation 2	Trey	100%	2/15/25	3/3/25
Staff Meeting 5	Samantha	100%	2/16/25	2/17/25
Website Check #1	Brendan	100%	2/17/25	3/9/25
Client Meeting	Everyone	100%	2/21/25	2/21/25
Analysis Memo	Liliana	100%	3/9/25	3/22/25
Presnetation 3	Garet	100%	3/9/25	3/30/25
1st Prototype	Trey	100%	3/13/25	3/31/25



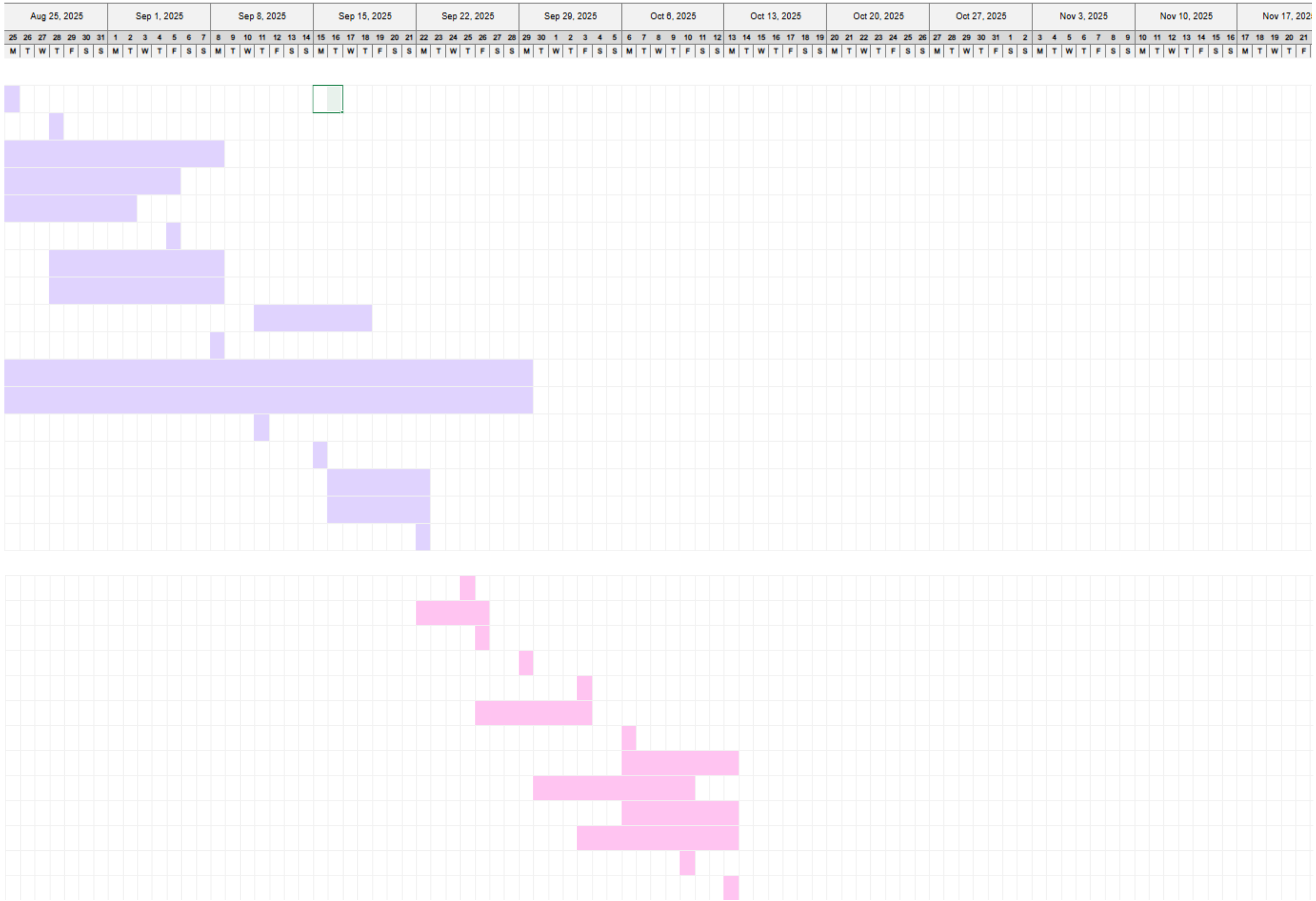
Schedule Spring 2025

TASK	ASSIGNED TO	PROGRESS	START	END
CAD, Technical analysis', Presentations, BOM, Prototypes, Website				
Staff Meeting 8	Everyone	100%	4/4/25	4/5/25
Report 2	Garet	100%	3/30/25	4/18/25
Client meeting	Liliana	100%	4/4/25	4/5/25
Final staff meeting	Everyone	100%	4/21/25	4/22/25
Final CAD and BOM	Trey and Jorge	100%	4/5/25	4/25/25
2nd prototype demo	Brendan, Garet, Lilian	100%	4/14/25	4/28/25
Poject management 486C	Samantha	100%	4/23/25	5/2/25
Websitre #2 check	Brendan	100%	4/18/25	5/4/25



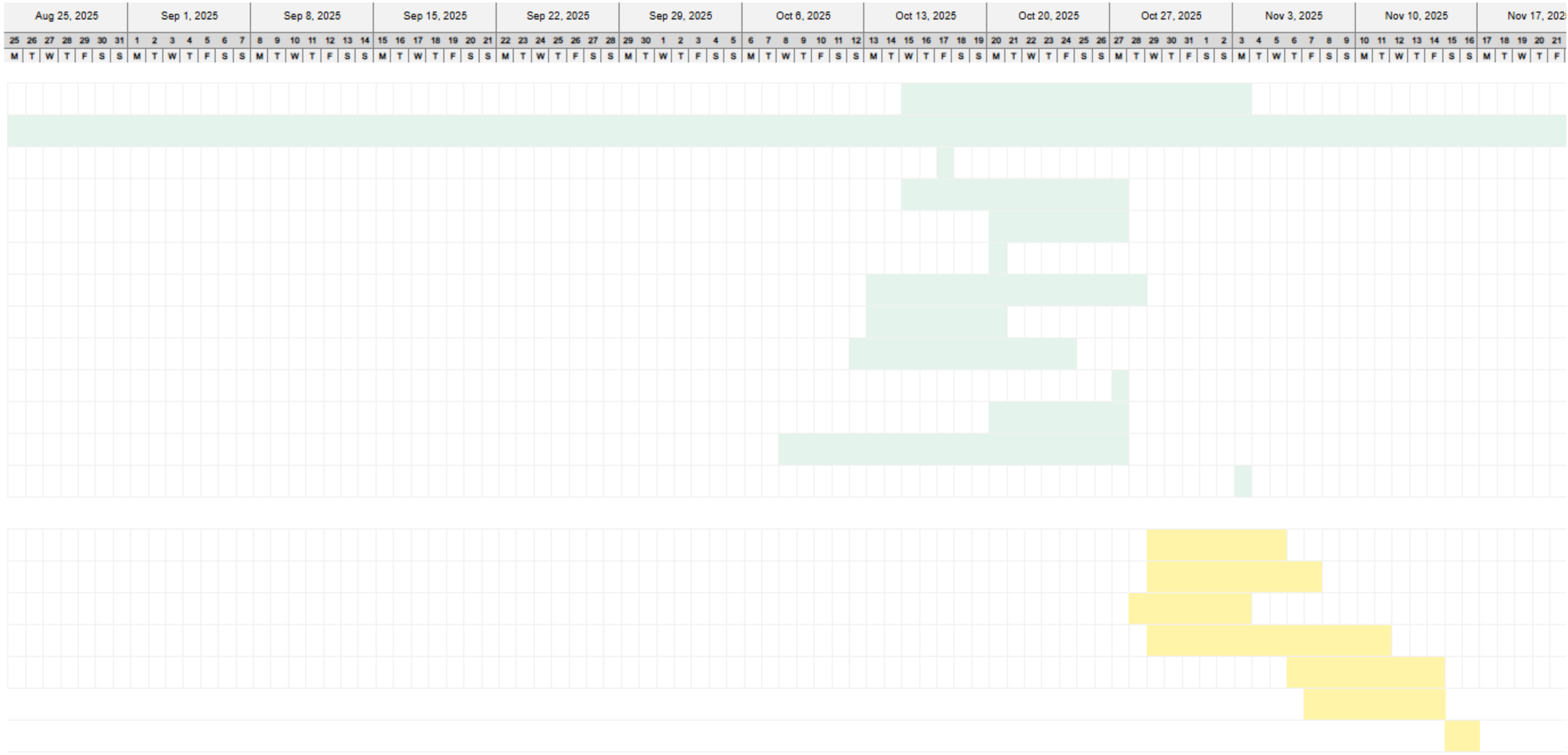
Schedule Fall 2025

TASK	ASSIGNED TO	PROGRESS	START	END
Task Leading up to 33% Build				
Team Meeting	All Members	100%	8/25/25	8/25/25
486C Kickoff Meeting	All Members	100%	8/28/25	8/28/25
Finalize Apparatus Design	All Members	100%	7/28/25	9/8/25
Establishing Scaling/ Getting Approved	Lilliana HB	100%	8/11/25	9/5/25
1st Order from BOM Approved	Jorge	100%	8/25/25	9/2/25
Client Meeting	All Members	100%	9/5/25	9/5/25
Finalizing CAD Drawing	Trey	100%	8/28/25	9/8/25
Finalizing Engineering Calcs	Sam	100%	8/28/25	9/8/25
Begin Assemble Climate Chamber	Brendan	100%	9/11/25	9/18/25
Staff Meeting	All Members	100%	9/8/25	9/8/25
Coding Arduino	Trey	100%	8/11/25	9/29/25
Finishing Circut Desgin	Garet	100%	8/18/25	9/29/25
Client Meeting	All Members	100%	9/11/25	9/11/25
Staff Meeting	All Members	100%	9/15/25	9/15/25
Began PowerPoint Presentation (33%)	Sam	100%	9/16/25	9/22/25
Complete BOM	Lilliana HB	100%	9/16/25	9/22/25
33% Build	All Members	100%	9/22/25	9/22/25
Task Leading up to 67% Build				
Client Meeting	All Members	100%	9/25/25	9/25/25
Everything Orderd for BOM	Jorge	100%	9/22/25	9/26/25
Begin Assemble Inside Chamber	Brendan	100%	9/26/25	9/26/25
Staff Meeting	All Members	100%	9/29/25	9/29/25
Client Meeting	All Members	100%	10/3/25	10/3/25
Build Water Tank	Jorge	100%	9/26/25	10/3/25
Staff Meeting	All Members	100%	10/6/25	10/6/25
Build Apparatus Roof	Brendan	100%	10/6/25	10/13/25
Build Apparatus Tank	Sam	100%	9/30/25	10/10/25
Start Testing Plan	Lilliana HB	100%	10/6/25	10/13/25
Sensors/arduino code ready for data colletion	Garet	100%	10/3/25	10/13/25
Client Meeting	All Members	100%	10/10/25	10/10/25
67% Build	All Members	100%	10/13/25	10/13/25



Schedule Fall 2025

TASK	ASSIGNED TO	PROGRESS	START	END
Task Leading up to 100% Build				
Complete Flow Visulization	Sam	100%	10/15/25	11/3/25
Finalize Website	Brendan	100%	8/25/25	12/3/25
Client Meeting	All Members	100%	10/17/25	10/17/25
Add Arduino	Trey	100%	10/15/25	10/27/25
Add complete circuit to apparatus	Garet	100%	10/20/25	10/27/25
Staff Meeting	All Members	100%	10/20/25	10/20/25
Start Building Siphon	Jorge	100%	10/13/25	10/28/25
Testing Plan Stage 2	Lilliana HB	100%	10/13/25	10/20/25
Housing for Arduino and dehumidifier	Garet	100%	10/12/25	10/24/25
Staff Meeting	All Members	100%	10/27/25	10/27/25
Draft Poster	Sam	100%	10/20/25	10/27/25
Have Full Testing Plan	Brendan	100%	10/8/25	10/27/25
100% Build	All Members	100%	11/3/25	11/3/25
Testing Plan				
Test 1: Measurement & Precison of Data	Garet	100%	10/29/25	11/5/25
Test 2: Accuracy of Relative Humidity	Trey	100%	10/29/25	11/7/25
Test 3: Siphon Accuracy	Sam	100%	10/28/25	11/3/25
Test 4: Data set for Ideal Scaled Conditios	Lilliana HB	100%	10/29/25	11/11/25
Test 5: Ambinet Open (Flagstaff)	Brendan	100%	11/6/25	11/14/25
Test 6: Controlled Variables (Flagstaff)	Jorge	100%	11/7/25	11/14/25
Test 7: Ambient Open (Pheonix)	Sam	100%	11/15/25	11/16/25



Budget

- The provided overall budget was $5,000, of which, the majority was used to construct the apparatus
- Additionally, over 10% of the budget was fundraised (a total of $765)

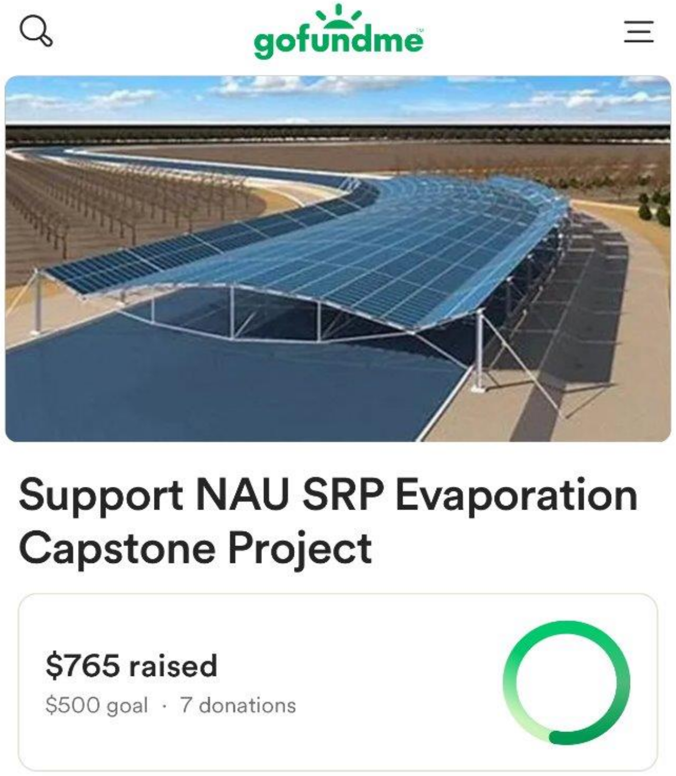


Figure 11: Gofundme

- The construction of the apparatus, as well as the equipment needed for testing cost the team ~$3500
- The remainder of the budget (~$1500) was used to deliver the apparatus to Phoenix
- Additionally, ~$200 was taken from the fundraiser money for the trip to phoenix which was primarily used on gas.

Bill of Materials

Table 3: BOM

Part	Vendor	Quantity	Unit Price ($)	Total Price ($)	Order Status
Plywood	Home Depot	15	14.98	224.7	Arrived
Wood Beams	Home Depot	35	2.98	104.3	Arrived
#8 2in Flat head Philips exterior screws (5lb pk of 6720)	Home Depot	1	33.39	33.39	Arrived
2" Corner Brace Zinc 20pk	Home Depot	5	14.97	74.85	Arrived
#6 3/4in Flat Head Philips metal to wood screws (50 pk)	Home Depot	4	5.98	23.92	Arrived
Waterproof floor putty	Home Depot	1	6.97	6.97	Arrived
5" x 5" Zinc T-Plate	Home Depot	12	2.86	34.32	Arrived
Insulation	Home Depot	2	20.67	41.34	Arrived
Reptile Humidity & Thermometer	Pet Smart	2	6.99	13.98	Arrived
Digital Water Thermometer	Pet Smart	2	11.99	23.98	Arrived
Plastic Water Container	Target	3	4	12	Arrived
Hot Glue Sticks	Micheals	2	3	6	Arrived
1500W Water Heater	Briidea	1	104.5	104.5	Arrived
LED Detachable Tripod Light	Home Depot	3	24.88	74.64	Arrived
Wall & Cavity Foam	Home Depot	1	199.98	199.98	Arrived
Wide Spray Foam Sealant	Home Depot	4	39.98	159.92	Arrived
Arduino	Amazon	1	0	0	Arrived
Vinyl Pool liner	Home Depot	1	104.97	104.97	Arrived
Hinges	Home Depot	3	10.47	31.41	Arrived
Silicone Caulk	Home Depot	5	6.89	34.45	Arrived
Caulk Gun	Home Depot	1	11.98	11.98	Arrived
Construction Mask	Home Depot	6	2	12	Arrived
4mm Rubber Gloves (200 count)	Uline	2	13	26	Arrived
GFCI Outlet box	Home Depot	3	10.48	31.44	Arrived
Desiccant	Uline	1	215	215	Arrived
Gap Sealent	Home Depot	1	173.92	173.92	Arrived
Scientific Balance	US Solid	1	157	157	Arrived
Rubber Siphon Tube	Home Depot	1	0	0	Arrived
GFCI Outlet	Home Depot	3	15.51	46.53	Arrived
Insulation Spray Foam Adhesive Guru	Home Depot	1	169.99	169.99	Arrived
Arduino Sensors	Amazon	6	10.93	46.53	Arrived

Part	Vendor	Quantity	Unit Price ($)	Total Price ($)	Order Status
Electrical Box For Arduino	Amazon	1	12.99	12.99	Arrived
Flat Brackets	Home Depot	10	4.72	46.53	Arrived
Rubber Fridge Liner	Amazon	1	19.99	19.99	Arrived
Heavy Duty Tarp	Home Depot	1	77.97	77.97	Arrived
Weather Proof Coating	Home Depot	1	22.5	22.5	Arrived
Paint Brush	Home Depot	3	1.87	5.61	Arrived
Paint Holder	Home Depot	2	0.98	1.96	Arrived
Dehumidifyer	Airecoler	1	393	393	Arrived
Arduino Loading Cells	Amazon	4	15.99	15.99	Arrived
Weather Proof Paint	Shermin Williams	2	0	79.06	Arrived
PVC Glue	Home Depot	1	5.85	5.85	Arrived
PVC Male Adapter	Home Depot	1	2.7	2.7	Arrived
PVC Bushing	Home Depot	1	4.17	4.17	Arrived
PVC Spigot	Home Depot	1	10.65	10.65	Arrived
PVC Sealent Tape	Home Depot	1	0.98	0.98	Arrived
Syphon Pump	Home Depot	1	17.5	17.5	Arrived
10T Bucket	Home Depot	1	2.5	2.5	Arrived
Grommets	Harbor Freight	1	4.99	4.99	Arrived
Rubber Tires	Harbor Freight	6	21.95	131.7	Arrived
Tire Stop	Harbor Freight	1	5.5	5.5	Arrived
Door Wedge	Harbor Freight	1	6	6	Arrived
Vinyl Tube	Home Depot	1	16	16	Arrived
Clamp	Home Depot	1	2	2	Arrived
Syphon Tube (Skinny)	Home Depot	1	10.93	10.93	Arrived
Door Hinges(small)	Home Depot	3	3.64	14.56	Arrived
Grove Pliers	Home Depot	1	23.97	23.97	Arrived
Mixing Buckets	Home Depot	2	5.15	10.3	Arrived
Hotel	NAU	3	246.98	740.95	Arrived
Transport	NAU	1	950	950	Arrived
Gas	SRP Evap Group	2	300	300	Arrived
			Total Spent ($):	5,245.88	

Design Validation & Prototyping

NORTHERN ARIZONA UNIVERSITY

Table 4: FMEA

Product Name: EvapBox 1.0		Development Team: SRP-EVAP25				Page No 1 of 1			
System Name: Evaporation Apparatus SRP						FMEA Number: 1			
Subsystem Name: EVP						Date: 12/05/2025			
Component Name	: Scale Canal								
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurence (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
1.Scaled Roof Covering of Canal Vessel	Error in Scalability or ratio	Distorts radiation input; affects evaporation simulation	7	Incorrect geometric scaling or not matching thermal properties	5	Visual Inspection; energy input simulation	4	140	Use IR lamps or heaters to replicate solar; perform thermal matching test, heat flux sensor
2. Scaled Canal Vessel	Error in Scalability or ratio	Misrepresentation of measurements	5	Incorrect fluid depth, surface area ratio, or boundary conditions	5	Dimensional verification through are calculations	3	75	Apply scaling analysis (Re, Sh, Sc) to ensure dynamic similarity, CFD simulation
4. Vented Wall (Sealed Container)	Improper Sealing or leaking	Alters pressure and humidity balance; hinders boundary layer	8	Clogged vents or improper sealing method	6	Leak test; humidity stability test	5	240	Hydrophobic filters, check valves, multi-layer seals, RT humidity sensor
5. Standard Wall (Sealed Container)	Air Leakage or wall condensation	Alters internal properties; skews evaporation rate	7	Seal failure or thermal gradient across walls	4	Seal integrity test; IR camera for condensation	5	140	Thermal insulation, Transparent materials with low thermal cond.
6. Temperautre Controller	Drift or response lag	Inaccurate water/air temp; invalid evaporation rate	8	Faulty sensor, lag, or calibration error	4	Thermocouple cross-check	6	192	Digital feedback, software-based calibration checks
7. Humidity Controller	Poor regulation or sensor inaccuracy	Relative humidity error; mass flux error	9	Senor degradation; delay in humidity response	4	RH logging and error analysis	5	180	High resolution and fast RH sensor, calibration checks

Build Process: Apparatus

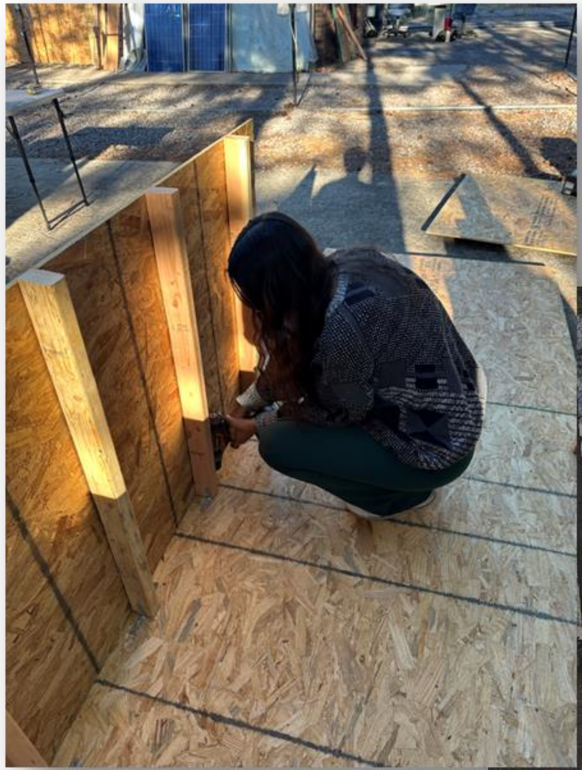


Figure 12, 13, 14, & 15: Base and Walls Phase

Build Process: Apparatus

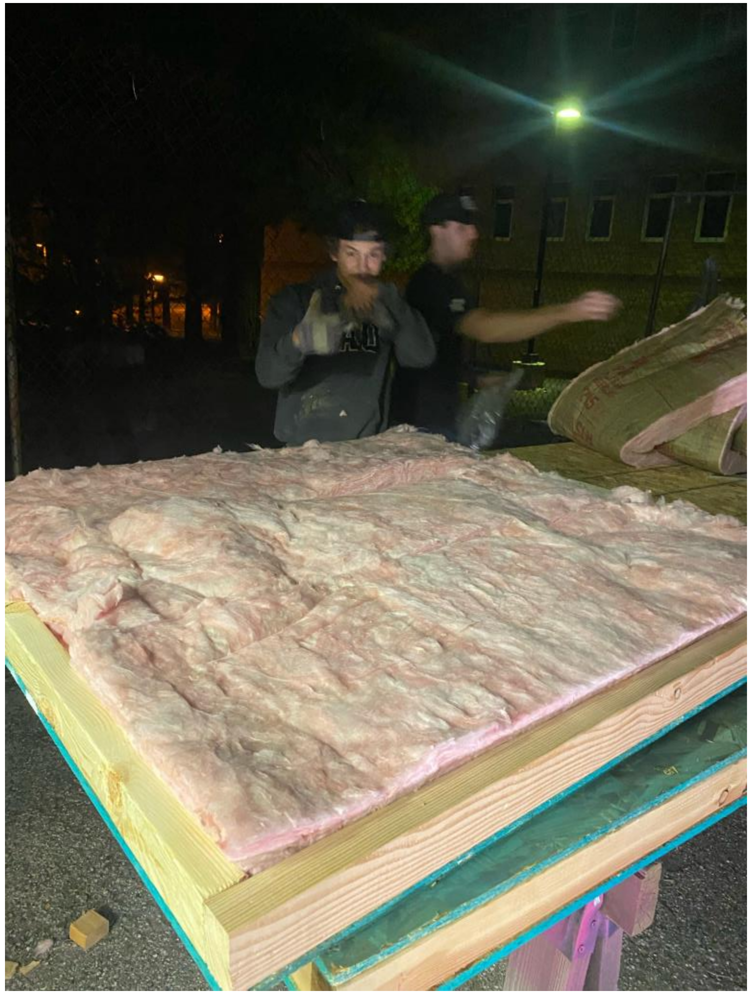


Figure 16, 17, & 18: Roof and Insulation Phase

Build Process: Circuit

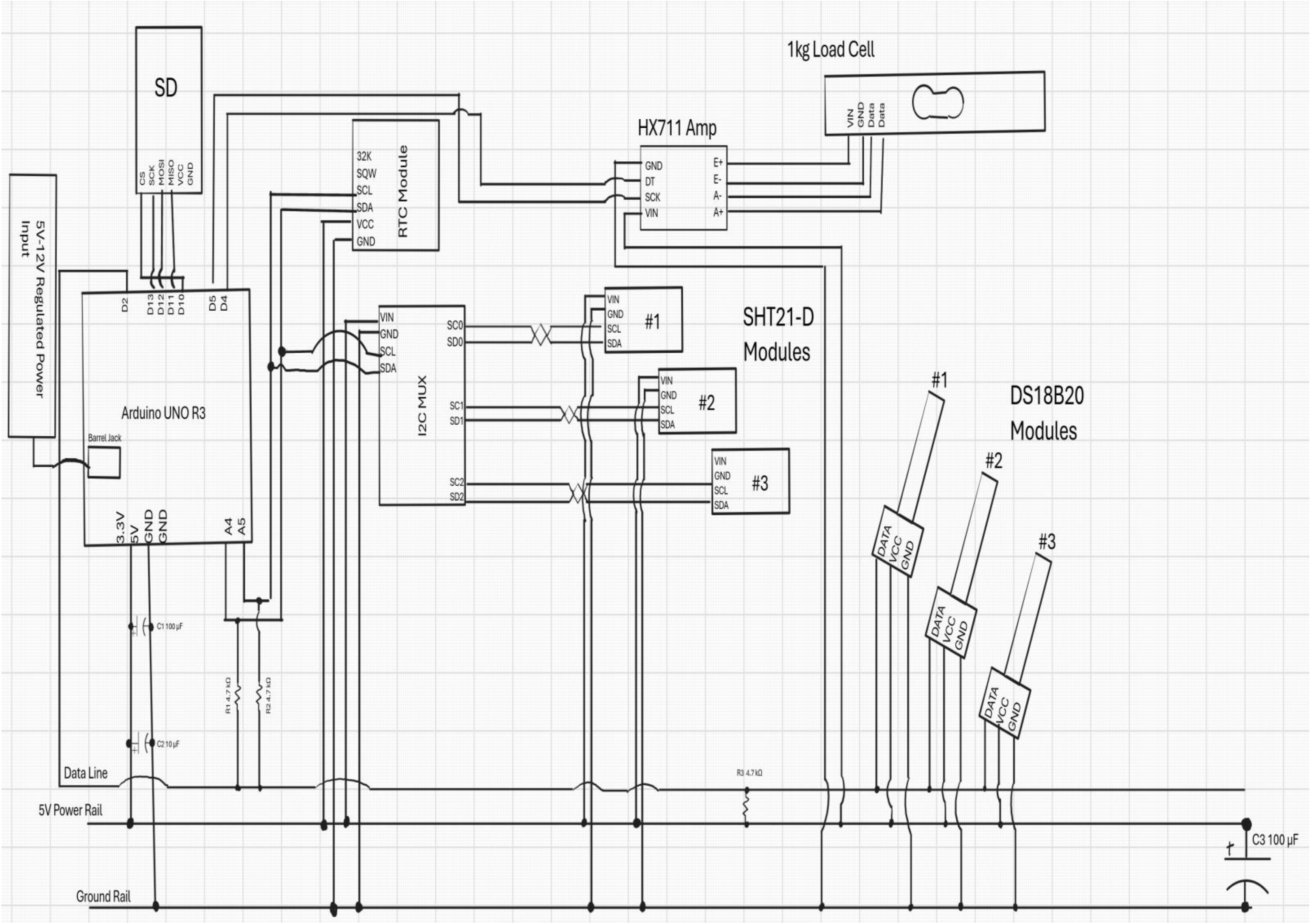


Figure 19: Circuit Diagram

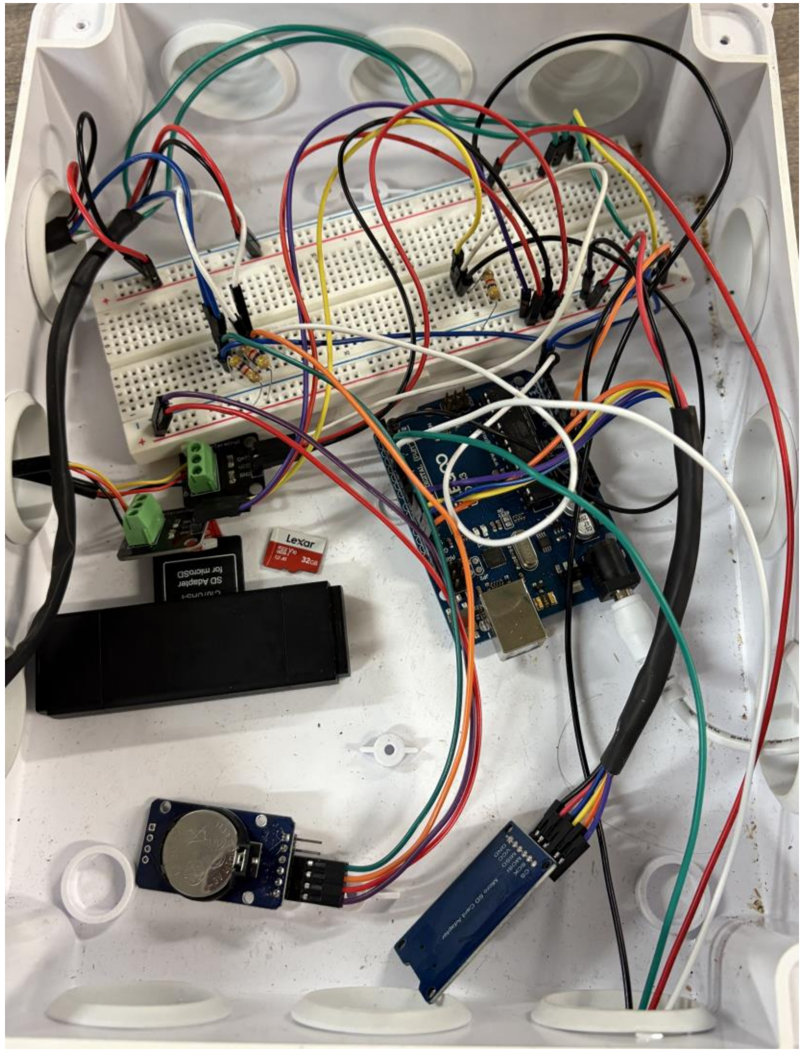


Figure 20: Physical Circuit Build

Build Process: Circuit

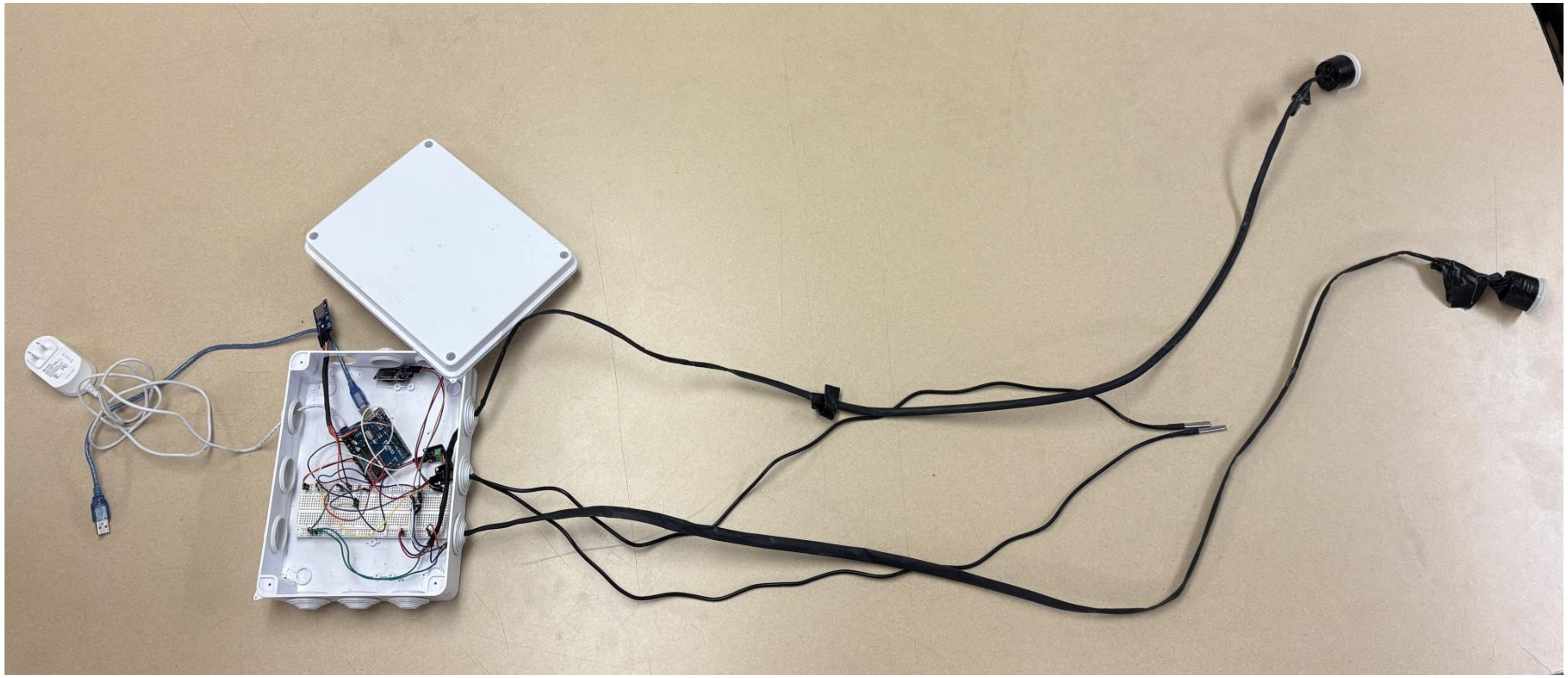


Figure 21: Full Circuit Build W/o Load Cell

Figure 22: Load Cell With 3D Printed Mount

SHT31-D Calibration Verification

SHT31-D

Relative Humidity

Parameter	Condition	Value	Units
Resolution [1]	12 bit	0.04	%RH
	8 bit	0.7	%RH
Accuracy tolerance [2]	typ	±2	%RH
	max	see Figure 2	%RH
Repeatability		±0.1	%RH
Hysteresis		±1	%RH
Nonlinearity		<0.1	%RH
Response time [3]	τ 63%	8	s
Operating Range	extended [4]	0 to 100	%RH
Long Term Drift [5]	Typ.	< 0.25	%RH/yr

Temperature

Parameter	Condition	Value	Units
Resolution [1]	14 bit	0.01	°C
	12 bit	0.04	°C
Accuracy tolerance [2]	typ	±0.3	°C
	max	see Figure 3	
Repeatability		±0.1	°C
Operating Range	extended [4]	-40 to 125	°C
Response Time [7]	τ 63%	5 to 30	s
Long Term Drift [8]	Typ.	< 0.02	°C/yr

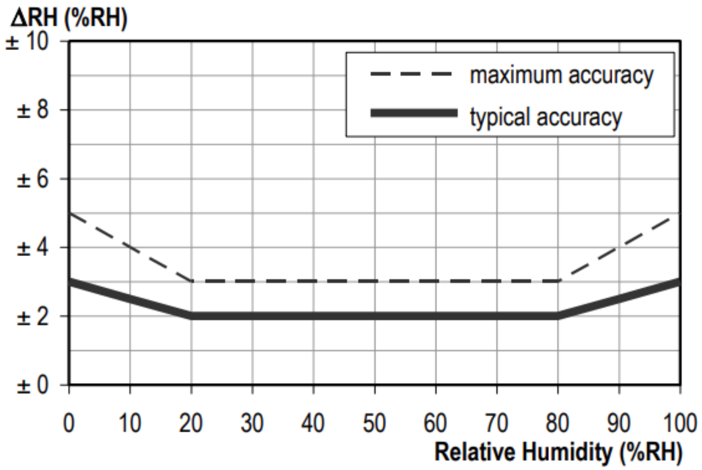


Figure 23: Performance Curve for %RH

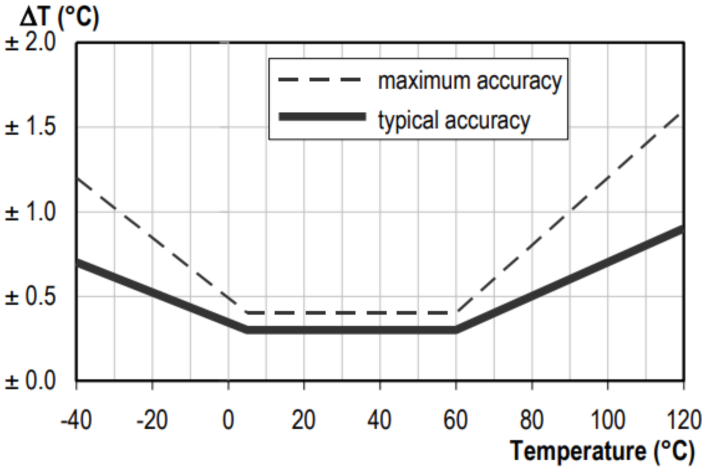


Figure 24: Performance Curve for Temperature

Relative Humidity

- Mean Error: ±2 % RH
- Max Error: ±3 % RH
- Expecting a little error due to our low %RH needed

AIR Temperature (°C)

- Mean Error: ± 0.3 °C
- Max Error: ± 0.4 °C
- Error is limited due to our expected temperatures used

DS18B20 Calibration Verification

DS18B20

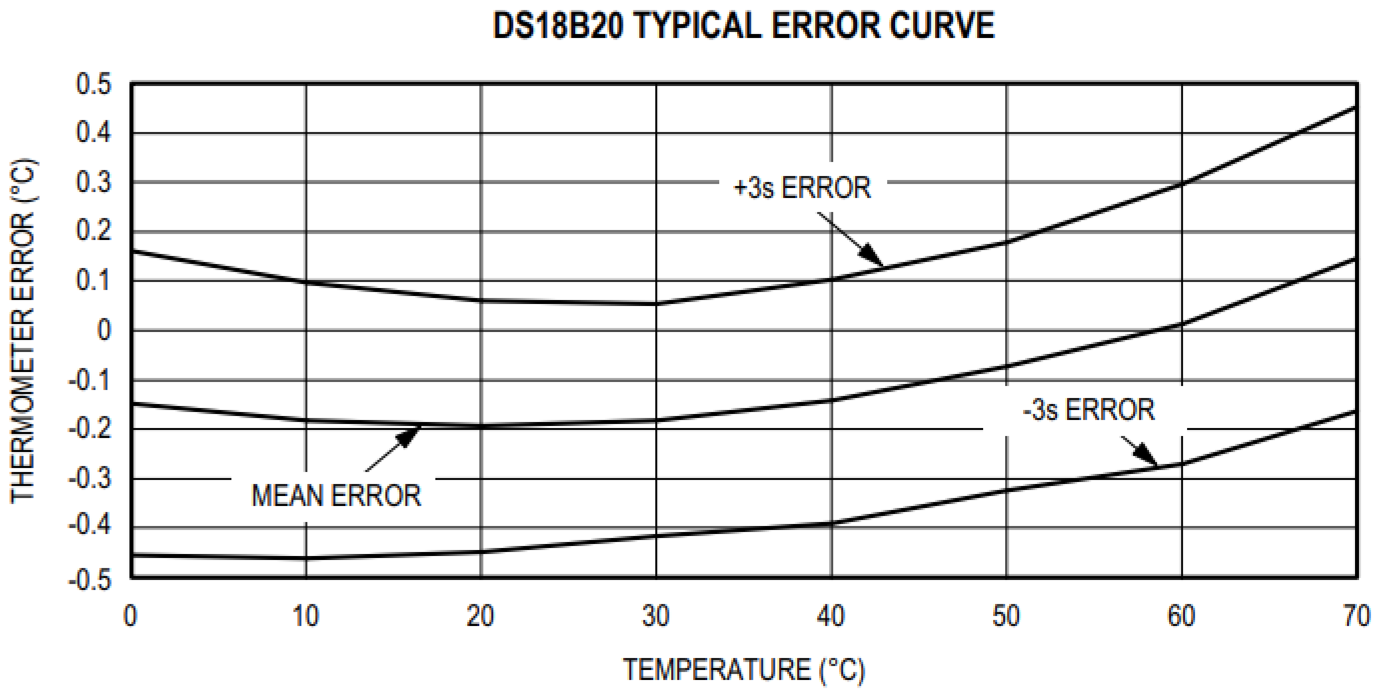


Figure 25: Performance Curve for Water Temp Sensor

Water Temperature (°C)

- Mean Error: ± 0.2 °C
- Standard Deviation: ±3 ≈ ±0.5°C
- Stable accuracy within our temp ranges 8°C – 40 °C

Final Design

Figure 26: Apparatus View 1

Figure 27: Apparatus View 2

Figure 29: Apparatus View 3

Figure 28: Apparatus View 4

Testing

Top Level Testing Summary

Table 5: Test Summary Table

Experiment	Relevant DR	Testing Equipment Needed	Other Resources
EXP 1– Flow Visualization	CR5: Natural Convection CR2: Heated Water CR1: Air Temperature Control	Outdoor incense Black backdrop Camera/Tripod Water Heater	Good weather (low wind)
EXP 2- Measurement & Precision of Collected Data with Arduino	ER1: Accurately Collect Data ER2: Sensor Accuracy	Arduino/breadboard Thermocouples Humidity sensors Load cells SD card	Excel access Power source
EXP 3- Relative Humidity	ER3: Closed lid CR1: Air Temperature Control CR2: Heated Water CR3: Accurately Control RH% ER2: Sensors reading	Dehumidifier Desiccant Arduino/breadboard SD card Water Heater	Power source
EXP 4- Siphon Functionality	CR8: Water Tightness ER1: Data Collection ER2: Sensor Accuracy	Graduated cylinder Vinyl tube Camera Tape measurer	N/A

Top Level Testing Summary

Table 5: Test Summary Table

Experiment	Relevant DR	Testing Equipment Needed	Other Resources
EXP 5- Ambient Open Test (Flagstaff)	CR4: Accurately Measure RH% CR5: Natural Convection CR7: Accurately Measure Water ER1: Data Collection ER5: Scalability of Rayleigh ER7: Scientific principals	Apparatus Arduino/Breadboard/sensors Siphon/Scale SD Card Desiccants	Good weather conditions
EXP 6- Ideal Scaled Conditions (Flagstaff)	CR1: Air Temperature Control CR2&3: Accurately Control H20 Temp and RH% CR4: Accurately Measure RH% and Temp CR5: Natural Convection CR7: Accurately Measure Water Loss ER1: Data Collection ER5: Scalability of Rayleigh ER6: Practicality ER7: Scientific principals	Apparatus Arduino/Breadboard/sensors Siphon/Scale SD Card Water tank heater Desiccants	Air temperature outside 45F Low humidity outside
EXP 7- Ambient Open Test (Phoenix)	CR4: Accurately Measure RH% CR5: Natural Convection CR7: Accurately Measure Water ER1&2: Data Collection ER5: Scalability of Rayleigh ER7: Scientific principals	Apparatus Arduino/Breadboard/sensors Siphon/Scale SD Card Desiccants	Good weather conditions

Flow Visualization

Conditions: 90°F Water, 22% RH

Exterior Conditions: 44°F, 3 mph, 101.73 kPa

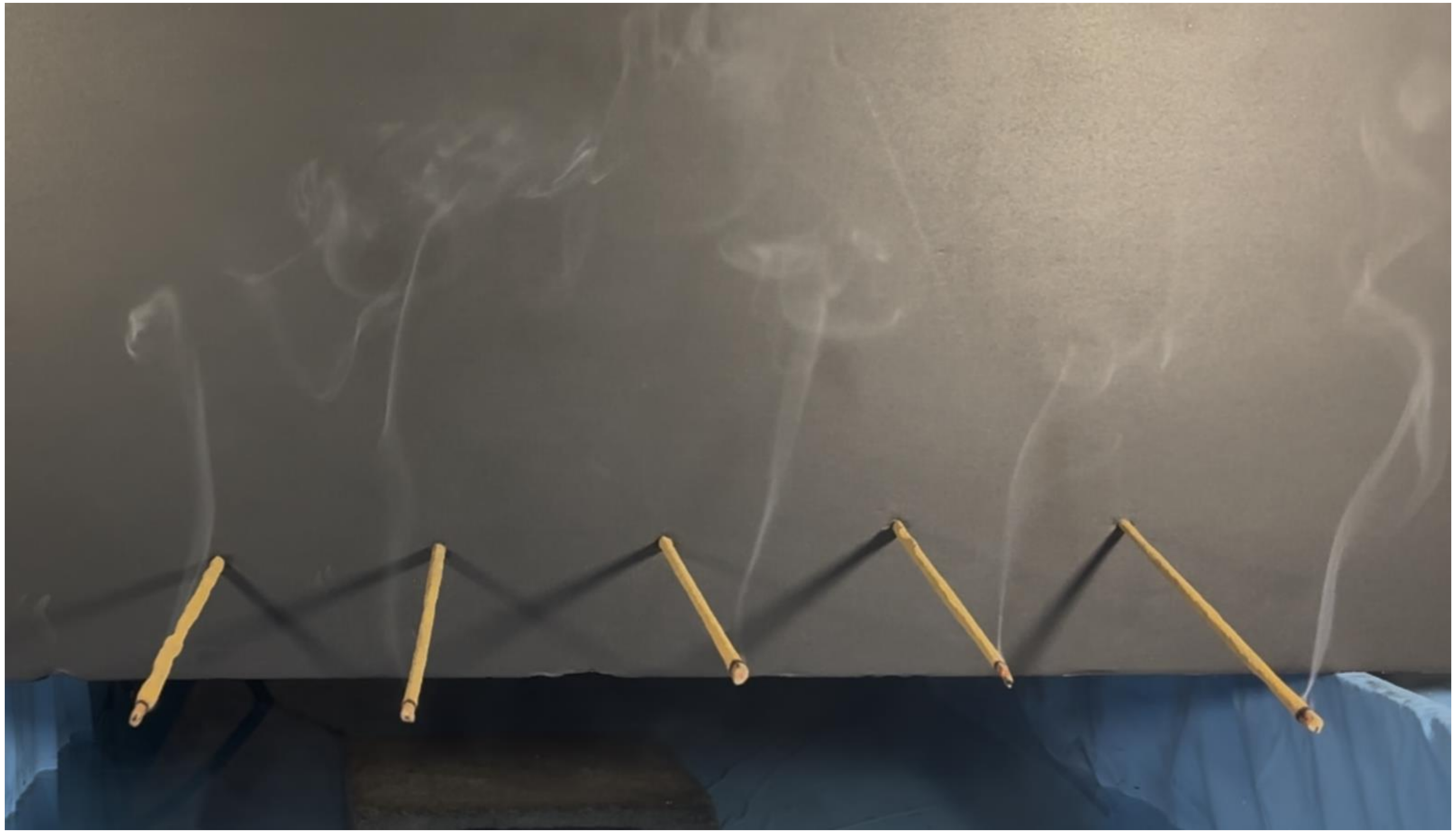


Figure 30: Flow Visualization 1

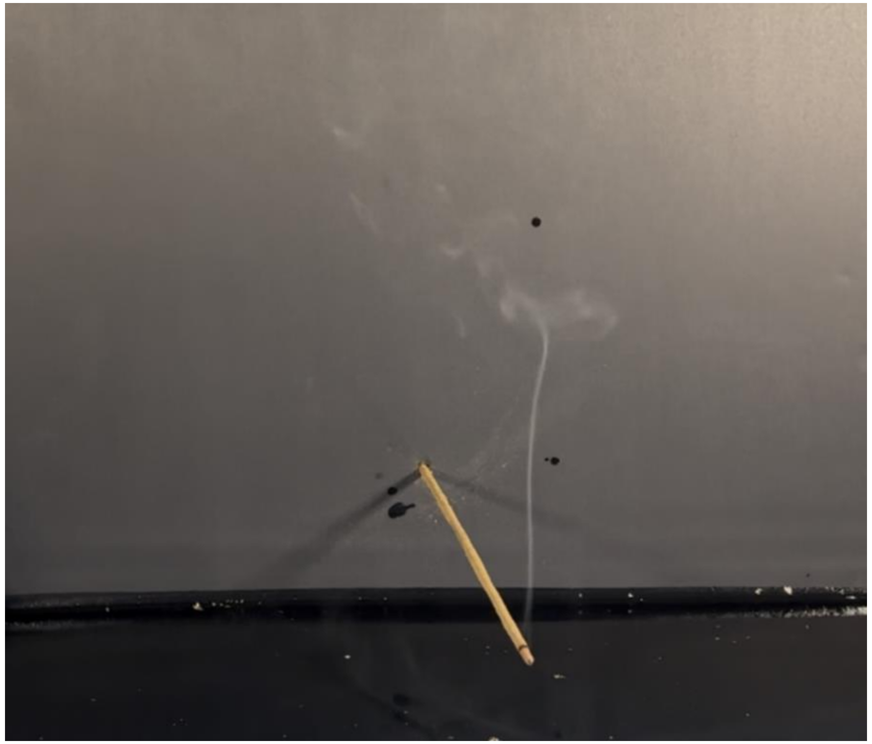


Figure 31: Flow Visualization 2

Load Cell Test

Figure 32: Load Cell with 3D Printed Mount

Test Summary:

- Will load cells be accurate?
- Equipment entails mount, load cells, 50g weight, and Arduino
- Weight variable is Isolated
- Goal is useable data to third decimal place

Procedure:

- Upload code, tare load cell without weight, place known weight, confirm weight

Results:

- Mean absolute error of ± .03g from a 255 data points during calibration

Siphon Testing

How accurate is the siphon?
Test: connected siphon for water transfer between tank and a graduated cylinder

Results:

- Siphon successfully transferred water from the main tank to the scale container having similar water levels
- Mass readings: Scale captured small, rapid changes in water level with good consistency.

Importance:
Verified whether the siphon method could capture tiny evaporation losses in a measurable way and Evaluates a big requirements: *precision of data collection* (ER1).

Figure 33: Siphon

Humidity Test

Figure 34: Desiccant Packets in Apparatus

Figure 35: Dehumidifier

- Weight before use: 3.79 lbs
- Weight after use: 4.80 lbs

Question: How well can we control Humidity

Test: Ran three humidity control trials (1) operating a dehumidifier alone, (2) placing desiccant packets in the test area, and (3) running both simultaneously. Humidity sensors recorded the rate of moisture removal and the stability of each method.

Results

- With the roof on, overall humidity rose too high for any method to be effective.
- Dehumidifier: Provided a small reduction, but nowhere near enough to offset moisture buildup.
- Desiccant packets: Showed almost no noticeable impact on humidity levels.
- Combined setup: Still couldn't overcome the trapped humidity environment.

Demonstrated whether the apparatus could actively control RH%, which directly connects to customer requirements CR1–CR3.

Testing Final Results

Log-log plot of Sherwood correlation from open-air tests:

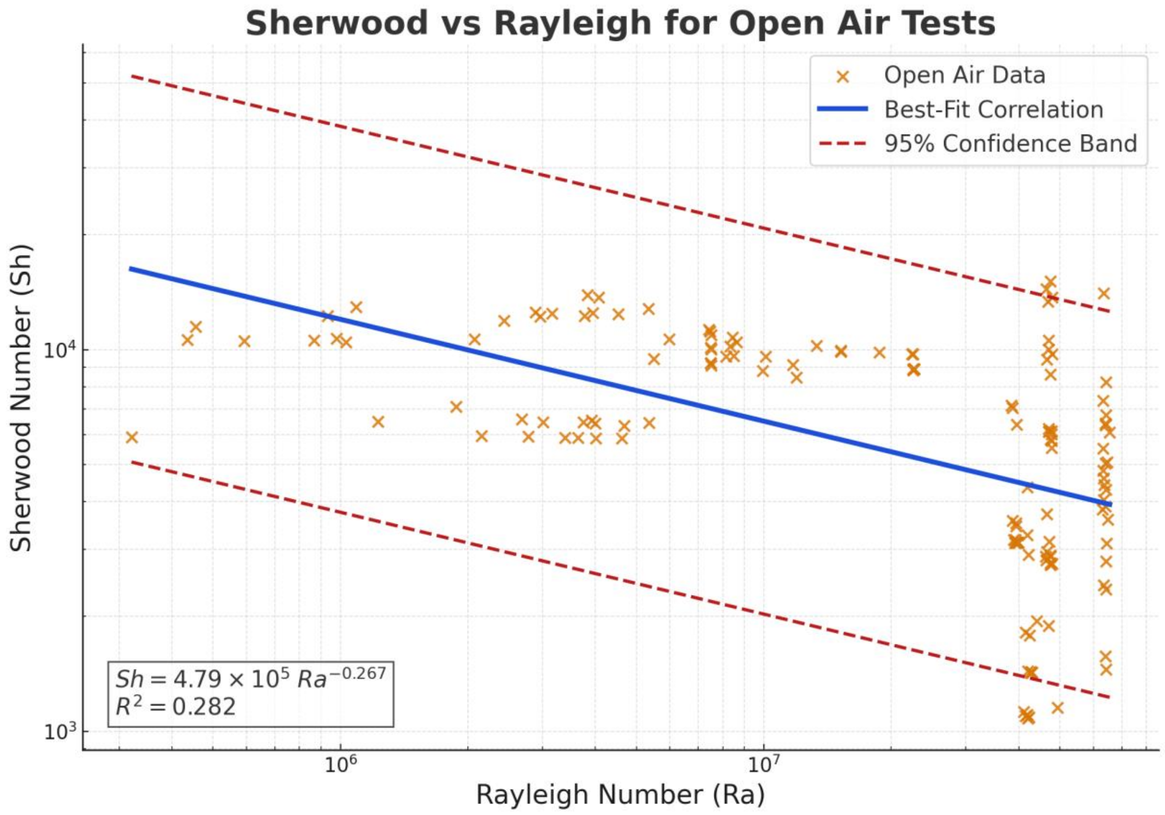


Figure 37: Line of best fit for the open-air tests Sherwood correlation shown on a log-log graph

Log-log plot of Sherwood correlation from covered tests:

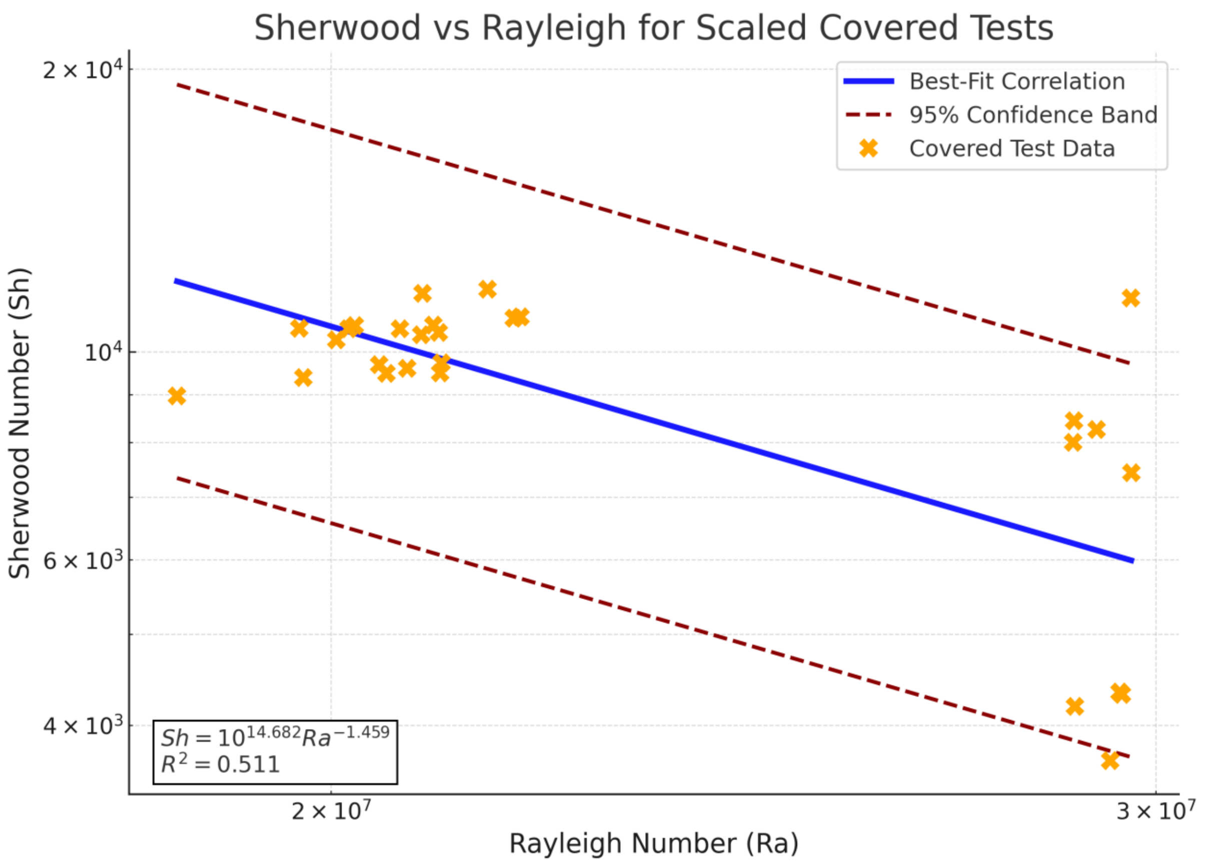


Figure 37: Line of best fit for the covered tests Sherwood correlation shown on a log-log graph

Testing Final Results

Average mass transfer coefficient and Sherwood numbers for 10.1 inches covered tests:

$$\overline{h_m} = 0.23096 \text{ m/s}$$

$$\overline{Sh} = 2311.83$$

Average rate of evaporation from covered tests:

$$\dot{m}_v = 0.0056\frac{g}{s} = 0.01\frac{inches}{day}$$

These results are physically consistent with mass transfer theory.

Sherwood correlation for tests with a 10.1 inch scaled cover over specific Rayleigh number range:

$$Sh = 1.63 \times 10^{-6}\ Ra_m^{1.372}$$

$$R^2 = 0.974$$

R^2 value of 0.97 means that 97% of the Sherwood number's behavior is explained by the Rayleigh number.

This correlation is only valid over the range:

$$4.3 \times 10^6 \leq Ra_m \leq 5.0 \times 10^6$$

Final Results Error Propagation

Relative Surface Vapor Uncertainty

$$\rho_{v,s} = \frac{2.02205}{0.4615 \times 291.05} = 0.015055\ kg/m^3$$

$$\frac{\partial \rho}{\partial P_v} = \frac{1}{R_v T} = \frac{1}{0.4615 \cdot 291.05} = 0.007446 \frac{kg}{m^3 \cdot kPa}$$

$$\frac{\partial \rho}{\partial T} = -\frac{P_v}{R_v T^2} = -\frac{\rho}{T} = \frac{0.015055}{291.05} = -5.17\ x\ 10^{-5} \frac{kg}{m^3 \cdot K}$$

$$u_{\rho_{v,s}} = \sqrt{(0.007446 \cdot 0.001)^2 + (5.17\ x\ 10^{-5} \cdot 0.5)^2} = 2.69\ x\ 10^{-5} \frac{kg}{m}$$

Relative Ambient Vapor Uncertainty

$$\rho_{v,\infty} = \frac{0.5228}{0.4615\ x\ 294.65} = 0.003846 \frac{kg}{m^3}$$

$$\frac{\partial \rho}{\partial P_v} = \frac{1}{R_v T} = \frac{1}{0.4615 \cdot 294.65} = 0.007354 \frac{kg}{m^3 \cdot kPa}$$

$$\frac{\partial \rho}{\partial T} = -\frac{P_v}{R_v T^2} = -\frac{\rho}{T} = \frac{0.003846}{294.65} = -1.31\ x\ 10^{-5} \frac{kg}{m^3 \cdot K}$$

$$u_{\rho_{v,\infty}} = \sqrt{(0.007354 \cdot 0.001)^2 + (1.31\ x\ 10^{-5} \cdot 0.5)^2} = 9.83\ x\ 10^{-6} \frac{kg}{m}$$

Combined Vapor Uncertainty

$$\Delta\rho_v = \rho_{v,s} - \rho_{v,\infty} = 0.015055 - 0.003846 = 0.011209 \frac{kg}{m^3}$$

$$u\Delta_{\rho_v} = \sqrt{u_{\rho_v}^2 + u_{\rho_v}^2} = \sqrt{(2.69\ x\ 10^{-5})^2 + (9.83\ x\ 10^{-5})^2} = 2.87\ x\ 10^{-5} \frac{kg}{m^3}$$

$$\frac{u\Delta_{\rho_v}}{\Delta_{\rho_v}} = \frac{2.87\ x\ 10^{-5}}{0.011209} = 0.00256\ (0.256\%)$$

Relative Area Uncertainty

$$A_s = LW = 3.048\ x\ 0.6096 = 1.85806\ m^2$$

Propagating $u_A = \sqrt{(0.6096 \cdot 0.0015875)^2 + (3.048 \cdot 0.0015875)^2} = 4.94\ x\ 10^{-3}\ m^2$

$$\frac{u_A}{A_s} = \frac{4.94\ x\ 10^{-3}}{1.85806} = 0.00266\ (0.266\%)$$

hm Uncertainty

$$\bar{h}_m = \frac{\dot{m}}{A_s \Delta_{\rho v}} = \frac{0.000318}{1.8508\ x\ 0.011209} = 0.005 \frac{m}{s}$$

$$\frac{u_h}{h} = \sqrt{0.00727^2 + 0.00266^2 + 0.00256^2} = 0.00815$$

$$u_h = 0.00815\ x\ 0.005 = 4.075\ x\ 10^{-4} \frac{m}{s}$$

With 95% CI

$$t_{95} = 1.96\ u_h = \pm 7.9\ x\ 10^{-4} \frac{m}{s}$$

Specification Sheet

Table 6: CR Summary Table

Customer Requirements	CR Met (✓ or X)	Client Acceptable (✓ or X)
CR1: Ability to control/maintain air temp	X	✓
CR2 - Ability to control/maintain water temp	✓	✓
CR3: Ability to control/maintain RH	X	✓
CR4: Ability to measure relative humidity	✓	✓
CR5: Ability to maintain convective flow regime	✓	✓
CR6: Project stays within budget	✓	✓
CR7: Maintain water tightness	✓	✓

Specification Sheet

Table 7: ER Summary Table

Engineering Requirements	Target	Tolerance	Calculated/ Measured	ER Met (✓ or X)	Client Acceptable (✓ or X)
ER1: Precision of data collection	0.58 inches/day	±0.15 inches/day	0.21 inches/day	X	✓
ER2: Accuracy of sensors	±.5°C, ±3%RH ±0.02g	±0.1°C, ±1RH ±0.01g	±0.5°C, ±2%RH ±0.03g	✓	✓
ER3: Material durability and longevity	6 months(full test semester)	±0.5 months	>6months	✓	✓
ER4: Geometric similarity	100%	-10%	100% for 45ft by 9ft section	✓	✓
ER5: Similarity of Rayleigh number	2x10^8 - 3.5x10^8	±1x10^8	8%	X	✓
ER6: Economic feasibility and practical implementation	≤ $5,740	No Tolerance	$5,155	✓	✓
ER7: Adhere to scientific experimentation principles	≥ 90% of tests follow planned	±5%	50%	X	✓

Future Work

Future Work (System Improvements)

- Increase focus on forced convection to better isolate mass transfer effects to realistic standards
- Improve siphon design (better load cell)
- Add more sensors (temperature, humidity, air velocity) for higher resolution data
- Consider a heat pump for stable temperature and humidity control

Future Work (Apparatus Expansion)

- Build a larger test apparatus to reduce wall effects and improve airflow realism
- Expand multi-day continuous testing to capture humidity/temperature patterns
- Implement improved humidity control measures to limit moisture buildup in the system.
- Complete testing over larger range of Rayleigh numbers for more expansive Sherwood correlations

Figure 37: Team Photo in Phoenix

Future Work (ASU Continuation)

- Provide ASU with our complete dataset, analysis scripts, and full documentation package
- ASU will design and build their own expanded apparatus informed by our Phase 1 system
- ASU will refine, validate, and extend our Sherwood–Rayleigh correlations for broader canal applications
- Dr. Mani and ASU team expressed strong support for our progress, noting how far the project has advanced and recognizing our team's dedication and effort

Thank You!

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