ME 486C Capstone Project

Fall 2025

Initial Testing Results

Jacob Apodaca

Brendan Frazier

Tyler Hedgecock

Joseph Meza

Calvin Schenkenberger

Northern Arizona University

Flagstaff, AZ 86001

QFD

Quality Function Deployment

Project title: RE Lab Solar Heater
Project leader: Brendan Frazier
Date: 10/27/2025

Correlation:

+	0	-
Positive	No correlation	Negative

Relationships:

5	3	1	0
Strong	Moderate	Weak	None

	Energy Stored	Efficient Insulation	Thermostat	[redacted]	Flow Rate	Heat exchanger	Life expectancy	Cost	Mounting system
	0								
	0	0							
	+	0	-						
	+	+	-	[redacted]					
	+	+	0	[redacted]	0				
	+	+	0	[redacted]	0	0			
	+	+	0	[redacted]	+	0	0		
	+	+	0	[redacted]	+	+	0	-	
Desired direction of improvement (↑,0,↓)	↑	↑	↓	[redacted]	↑	↑	↑	↓	↓

1: low, 5: high — Competitive evaluation (1: low, 5: high)

	Customer importance rating	Engineering Requirements (How's) → / Customer Requirements - (What's) ↓	Energy Stored	Efficient Insulation	Thermostat	[redacted]	Flow Rate	Heat exchanger	Life expectancy	Cost	Mounting system	Weighted Score	Solar Water Rating	Solar Air Rating	Vacuum Tube Solar Collector Kit Rating	4000 Series Artica Solar Air Heater	Hybrid Solar rating
1	5	System must reduce heating load by 30% during worst case months (compared to baseline method)	5	5	0	[redacted]	4	5	0	0	0	50	4	3	5	4	5
2	5	System must operate in winter conditions	5	5	0	[redacted]	5	3	1	0	3	55	3	3	5	4	5
3	5	System must use RE solar as primary input	5	5	0	[redacted]	4	3	0	0	5	65	5	5	5	5	3
4	3	Installation must not require major mods to building	0	1	0	[redacted]	2	0	0	3	5	24	2	3	3	4	5
5	5	System must be safe and comply with codes	3	3	3	[redacted]	3	3	3	0	5	70	5	5	4	5	5
6	3	System must have minimal maintenance	1	1	1	[redacted]	2	5	5	1	4	38	3	4	4	5	5
7	3	Payback period must be under 10 yrs	5	5	3	[redacted]	2	5	3	5	4	66	5	5	1	3	4
8	1	System must have ability to include temp. and performance monitoring and visual indicator of operation status	3	0	5	[redacted]	4	3	0	0	1	12	5	5	4	4	5
9	3	System must not overheat or cause interior overheating	5	0	5	[redacted]	4	3	0	0	2	45	5	5	4	4	5
		Technical importance score	126	111	47	[redacted]	114	112	44	27	111	818	37	38	35	38	42
		Importance %	15%	14%	6%	[redacted]	14%	14%	5%	3%	14%	100%					
		Units	kWh	R Value	Watts	[redacted]	m^3/sec	Joules	Years	$	Kilograms						
		Target	30 kWh	10 R-Value	10 W	[redacted]	0.1 m^3/s	5 MJ	10 yrs	$3,000	20 kg						
		Priorities rank	1	5	7	[redacted]	3	4	8	9	6						

Figure 1: QFD

Calvin Schenkenberger

Design Requirements Summary

Customer Requirements

CR1: The system must reduce the heating load by 30% during the winter.
CR2: The system must function during the winter months and when sunlight is not obstructed by obstacles (i.e., clouds, trees, buildings, etc.).
CR3: The system must utilize renewable energy (i.e., sunlight) as its primary source and exclude non-renewable sources, such as fossil fuels or electricity, unless in an emergency.
CR4: Installing the system must not require making any significant modifications to the building.
CR5: The system must be safe and comply with codes established by ASHRAE, plumbing, electrical, and solar thermal standards.
CR6: The system must have minimal maintenance (<4 hours) by staff or building owners.
CR7: The payback period must be under 10 years.
CR8: The system must have a visual indicator of its operating status.
CR9: The system must have a monitoring system for temperature and performance.
CR10: The system cannot overheat or cause interior overheating.

Engineering Requirements

ER1: Energy Stored (kWh): The system must collect enough solar energy to both store and utilize during times when the sun is out.
ER2: Efficient Insulation (R value): Different types of insulation have a certain R value, and it is important to select one for our project.
ER3: Thermostat (Watts): A thermostat must be implemented into the system so the client can adjust the temperature to their liking and ensure that the system can be operated manually.
ER4: Flow rate (CFM): In accordance with ASHRAE standards, the fans must supply enough air in CFM so they won't provide too much heat to a small building.
ER5: Life Expectancy (years): We expect our product to last for a minimum of 10 years because of customer requirements.
ER6: Cost ($): This project was provided with $500 by the client and we were requested to raise another $500, bringing us to $1000. An additional $2000 was added to fix the roof, bringing the total to $3000.
ER7: Mounting System (kg): This represents the weight that the mounting system can sustain, ensuring that it won't be met with obstructions such as wind, snow, and other environmental factors.

Jacob Apodaca

Testing Summary

Table 1: Testing Plan Summary

Experiment	Relevant DRs	Testing Equipment Needed	Other Resources
EX1 - Output Temperature	CR1, CR2, CR3, CR8, CR9, CR10, ER1, ER2, ER3	Anemometer	A good sunny day
EX2 - Flow Rate	CR1, ER1, ER4	Anemometer	NA
EX3 - Wind Loading	ER5, ER6, ER7, CR5	NA	Weather station capstone data / Flagstaff airport weather data
EX4 – Voltage Drop	CR5, CR10, ER3, ER6	Multimeter	NA
EX5 – Air Leak Test	ER6, CR9, ER2	Fog Machine	NA
EX6 – Water Leak Test	CR6, ER7, ER5	NA	A rainy day
EX7 – Weather Data Collection	ER5, ER7	NA	Flagstaff airport weather data / weather station capstone data
EX8 – Performance Test	CR1, CR2, CR7, CR8, CR10, ER5, ER6	Hot Wire Anemometer and RTD	EX1 temperature data

Tyler Hedgecock

Experiment 2 – Flow Rate

Summary: Due to the ductwork system, it is likely that the volumetric flow rate will drop before reaching the output vents. To find the volumetric flow rate an anemometer will be used at all inputs and outputs. This test also verifies if the fans have a flow rate near the same value as stated in the spec. sheet which is 190 CFM. This test will also allow us to calculate the supplied heat load using the sensible heat formula.

Procedure:

- Hold anemometer at inputs and outputs
- Record data
- Calculate flow rate using speed and cross-sectional area of the ducts

Results:

- Front Room Inlet ≈ 107 CFM
- Main Room Inlet ≈ 86 CFM
- Flat Fan Outlet ≈ 129 CFM
- Angled Fan Outlet ≈ 119 CFM
- Vent 1 output (front room) ≈ 64 CFM
- Vent 2 output (main room) ≈ 53 CFM
- Vent 3 output (main room) ≈ 46 CFM

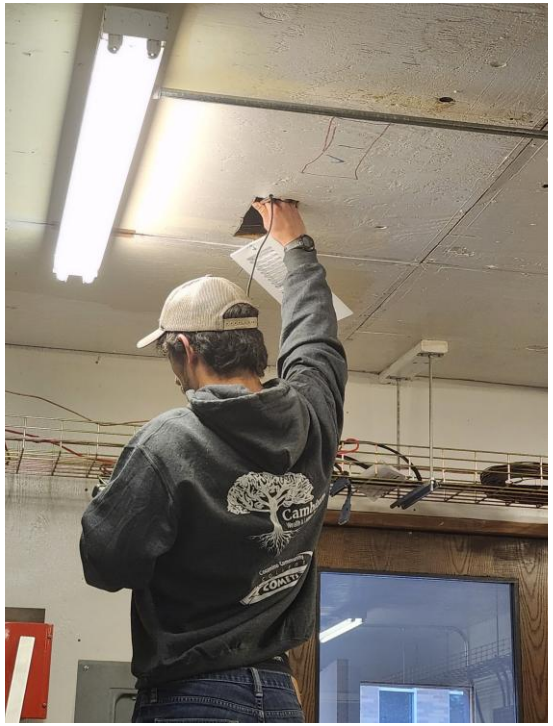

Figure 2: Vent 2 output flow rate test

Jacob Apodaca

Experiment 3 – Wind Loading

Summary:
- Mounting system designed for 120 mph wind
- Obstructions like buildings could funnel wind
- Confirm that RE Lab winds are less than Airport

Procedure:
- Windspeed data from NWS Flagstaff Airport
- Windspeed data from Weather Station Website
- Generate a line of best fit

Results:
- Maximum Windspeed at RE Lab: ≈66.3 mph
- Obstructions dampen wind load and the mounting system is satisfactory

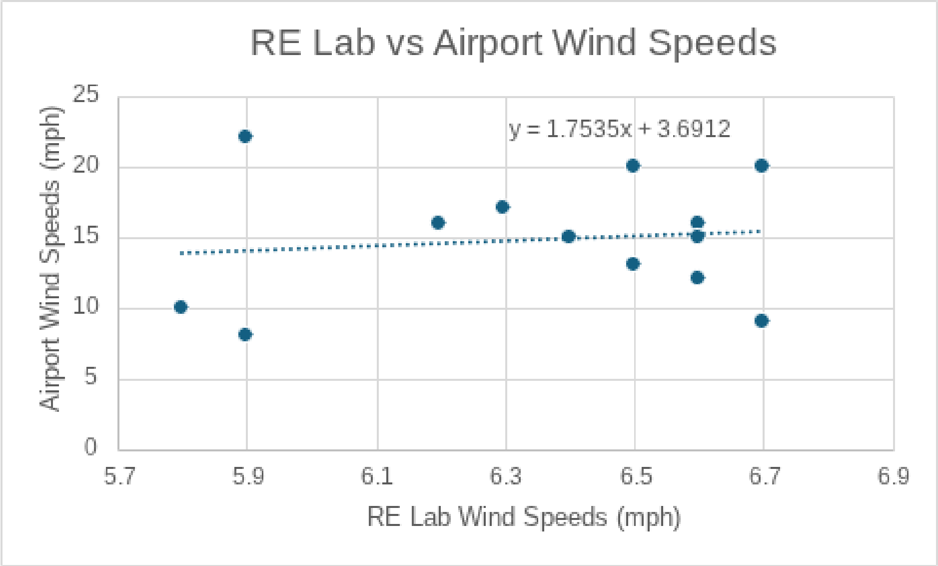

Figure 3: Initial RE Lab vs Airport Wind Speeds

Figure 4: Cup Anemometer at RE Lab ~90 ft from ground

Solved for RE Lab Windspeed: VreMax = 0.5703 * VairMax - 2.105
Assuming 120 mph at airport: Maximum velocity at RE Lab = 66.3 mph

Calvin Schenkenberger

Experiment 4 – Voltage Drop Test

Summary: Voltage drop occurs due to wire gauge size and length of wires. To determine the volt drop from the power supply (i.e. batteries) to the fans we will measure the voltage at different points along the electrical system to find the percentage of voltage drop which should be around 2%.

Procedure:

- Obtain multimeter
- Measure voltage at batteries
- Measure voltage at first j-box
- Measure voltage at second j-box (in attic)
- Measure voltage at fans

Results:

- Voltage at batteries **12.84V**
- Voltage at j-box **12.72V**
- Voltage at attic j-box **12.57V**
- Voltage at fans **12.39V**
- Percent voltage drop **≈3%**

Figure 5: Multimeter Voltage Test at First J-Box

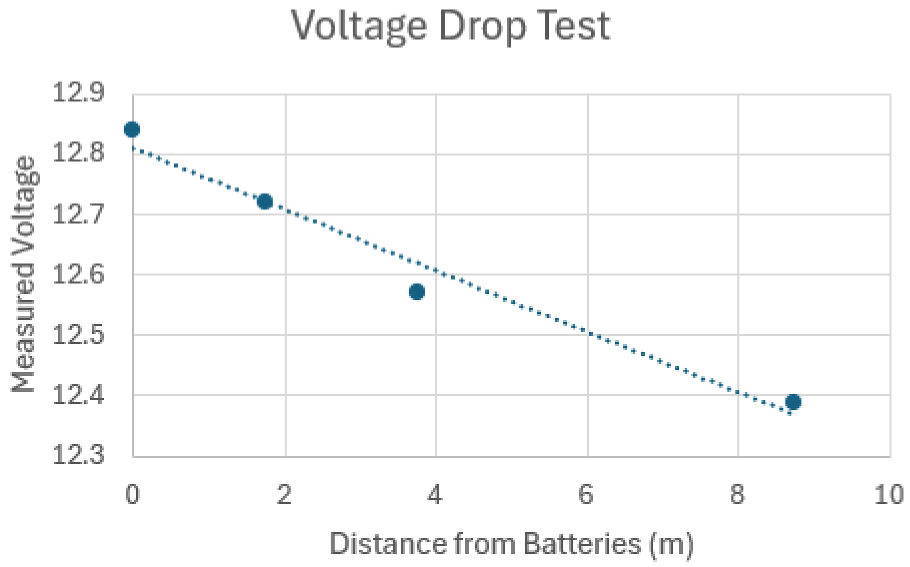

Figure 6: Voltage Drop Plot

NORTHERN ARIZONA UNIVERSITY

Brendan Frazier

Experiment 6 – Water Leak Test

Summary: During a rainy day all points of possible leakage will be monitored for water leakage. This includes lag screws mounting points, boot flashing, cover plates on panels, and any other point of leakage. This experiment is primarily visually confirmed with the only calculation being the volume of water across workspace.

Procedure:

- Every 30 minutes conduct visual inspection of attic
- After storm check solar panels for internal water
- Calculate total volume of water during storm

Results:

- During storm, no water leakage observed in attic
- Total rain fall resulted in 52.5 gallons over 18 hours

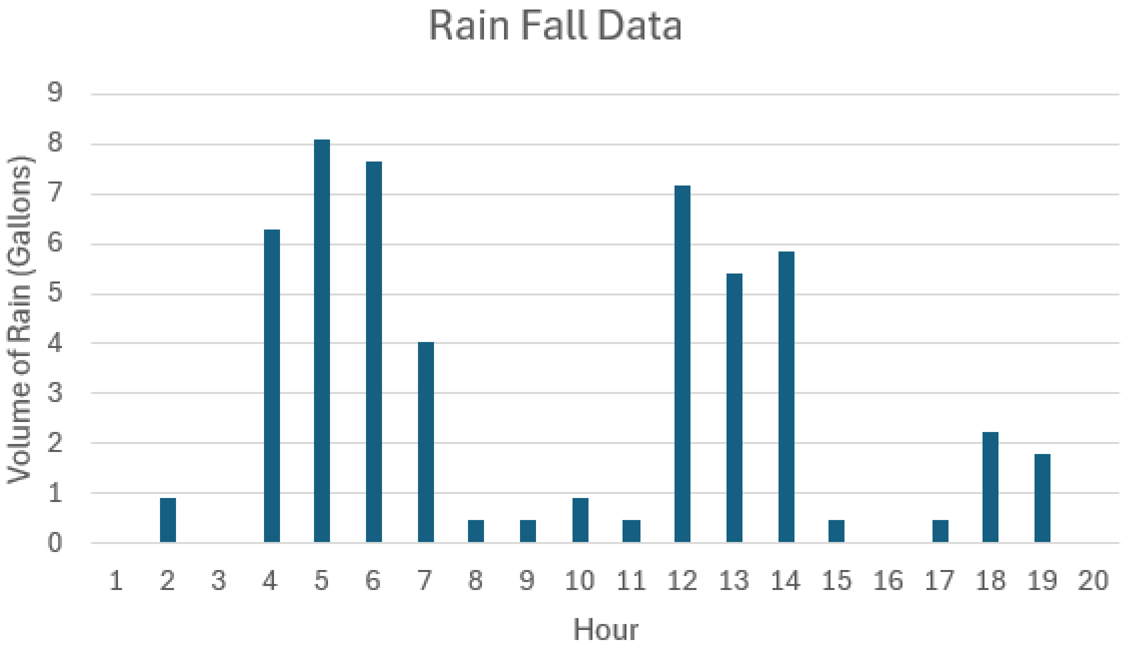

Figure 7: Rain Fall Data Plot

Brendan Frazier

Experiment 7 – Weather Data Collection

Summary:

- For this testing plan, several questions need to be answered including how much solar irradiance Flagstaff, AZ receives annually, what is its annual windspeed, rain fall, snow fall, and so forth.
- Equipment will not be necessary for this testing plan, although data from other sources will be needed for experiment seven.
- Variables that need to be calculated are the solar radiation the solar panel will be absorbing along with the wind speed, the weight of snow fall, and other environmental factors.
- Variables that can be ignored are convection from the surrounding air, wind speeds will be constant, and the weight of the snow is non-uniform.

Procedure:

- Solar irradiance data from the solar energy local website for Flagstaff, AZ
- Windspeed data from NASA POWER website for Flagstaff, AZ
- Data from other sources

Results:

- The amount of solar radiation that the inclined solar panel will be absorbing was approximately 226.73 W/m^2 while the flat solar panel absorbed little to no solar energy.
- According to NASA's website, the max windspeed is 2.81 m/s in the south south-west direction.

Tyler Hedgecock

Specification Sheet CRS

Table 2: Customer Requirements Specification Sheet

Customer Requirement	CR Met? (Yes or No)	Client Acceptable (Yes or No)
1) Reduce Load by 30%	Yes by EX2, Pending by EX1 and EX8	TBD
2) Function in Winter	Pending by EX1 and EX8	Yes
3) Use Renewable Energy	Yes by design	Yes
4) No Significant Mods	Yes by design	Yes
5) Must be Safe	Yes by EX3 and EX4	Yes
6) Minimal Maintenance	Yes by EX6	Yes
7) 10 Year Payback	Pending by EX8	TBD
8) Visual Indicator of Status	Pending by EX1 and EX8	Yes
9) Monitoring System	Pending by EX1	TBD
10) No Overheating	Yes by EX4, Pending by EX1 and EX8	Yes

Brendan Frazier

Specification Sheet ERS

Table 3: Engineering Requirements Specification Sheet

Engineering Requirement	Target	Tolerance	Measured/Calculated Value	ER Met? (Yes or No)	Client Acceptable (Yes or No)
ER1 – Energy Stored	30kWh	+/- 5	TBD	TBD	TBD
ER2 – Insulation	10R	+/- 2	8R	Yes	Yes
ER3 – Thermostat Control	~70F	+/- 3	40-70F	Yes	Yes
ER4 – Flow Rate	190CFM	+/- 20	129CFM	No	No
ER5 – Life Expectancy	10 Years	+/- 2	10-15 Years	Yes	Yes
ER6 - Cost	$3000	+/- 200	$2527.84	Yes	Yes
ER7 – Mounting Weight	20kg	+/- 5	11.4kg	Yes	Yes

Joseph Meza

Moving Forward

Testing

- Output Temperature Tests
- Air Leak Test
- Larger Data set for EX3 (Wind)

Project Deliverables

- Final poster and presentation
- Final report
- Final CAD

Joseph Meza

Thank You

Questions?