SRP EVAP

ME 486C Fall 2025

Samantha Synk – Project Manager
Lilliana Hadik-Barkoczy-Logistics Manager
Garet Bowels-Manufacturing Engineer
Trey Bushling-CAD Engineer
Jorge Cesin-Financial Manager
Brendan Steele-Test Engineer

Design Requirements

Table 1: Design Requirements Table

Customer Requirements	Engineering Requirements
CR1: Ability to control/maintain air temp	ER1: Precision of data collection
CR2: Ability to control/maintain water temp	ER2: Accuracy of sensors
CR3: Ability to control/maintain RH	ER3: Material durability and longevity
CR4: Ability to measure relative humidity	ER4: Geometric similarity
CR5: Ability to maintain convective flow regime	ER5: Similarity of Rayleigh number
CR6: Project stays within budget	ER6: Economic feasibility and practical implementation
CR7: Maintain water tightness	ER7: Adhere to scientific experimentation principles

Trey Bushling

QFD

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

System QFD

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

		Technical Requirements (0,3,9)							Competition (1-5)				
Customer Needs	Customer Weights	Precision of data collection	Accuracy 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	$5,740	90%					
Absolute Technical Importance		51	48	27	36	51	36	48					
Relative Technical Importance		1st	3rd	7th	5th	2nd	6th	4th					

Figure 1: QFD

NORTHERN ARIZONA UNIVERSITY

Samantha Synk

Top Level Testing Summary

Table 2: 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

Garet Bowles

Top Level Testing Summary

Table 2: Test Summary Table

Experiment	Relevant DR	Testing Equipment Needed	Other Resources
EXP 5- Ambient 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 Open/Covered(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/Covered 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

Top Level Testing Summary

Question:
How does a roof modify the Rayleigh, Sherwood, and mass transfer behavior of an open water surface?

DRs Tested:
CR1, CR2, CR3, CR4, CR5, CR7, ER1, ER5, ER7

Equipment needed:
Fully built Apparatus, Thermocouples, humidity sensors, siphon/ load cell, Arduino, SD card, Heater, Desiccants

Measure:
Air and Water Temperatures, Relative Humidity, and Mass Loss

Calculated:
Evaporation Rate, Heat Transfer Coefficient, Rayleigh's Number, Sherwood's Number and Sherwood's Correlation

Procedure:
1. Set up apparatus (covered/uncovered)
2. Calibrate thermocouples, humidity sensors, and scale.
3. Log initial values and start data acquisition(Temp, Humidity, Mass Loss) over several hours
4. Finish Test and record data in excel files
5. Rerun test multiple times with/without roof and different times of day
6. Compute Heat Transfer Coefficient, Rayleigh's Number, Sherwood's Number

Garet Bowles

Testing Final Results

Average mass transfer coefficient and Sherwood numbers for all covered tests:

$$\bar{h}_{m,\text{covered}} = 0.3737 \text{ m/s}$$

$$\bar{Sh}_{\text{covered}} = 3777.17$$

Average rate of evaporation from covered tests:

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

Average mass transfer coefficient and Sherwood numbers for all uncovered tests:

$$\bar{h}_{m,\text{uncovered}} = 0.6771 \text{ m/s}$$

$$\bar{Sh}_{\text{uncovered}} = 7250.13$$

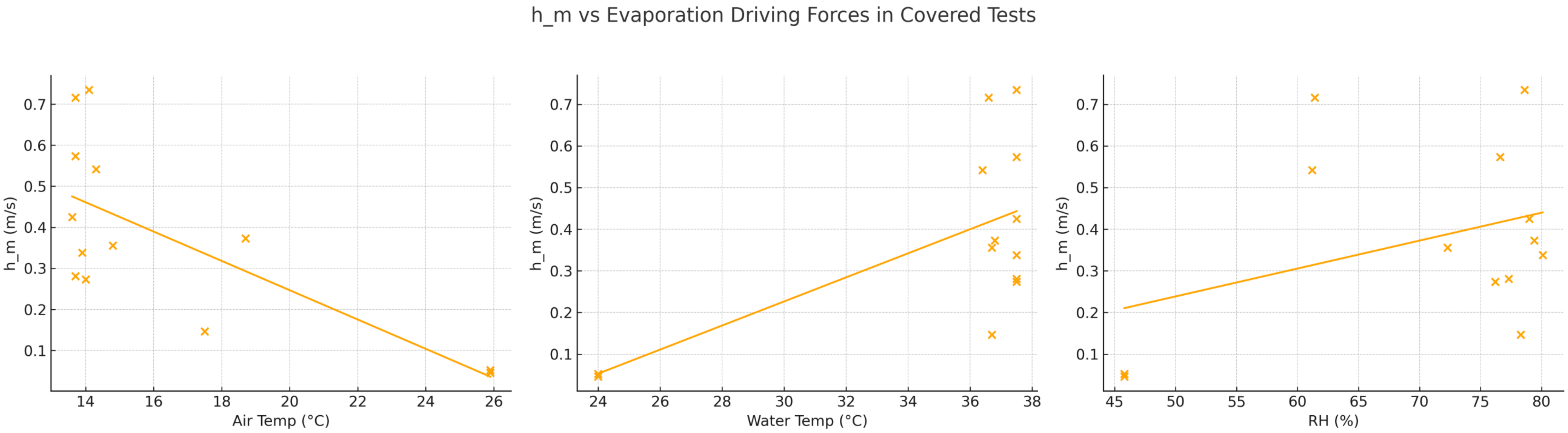
Average rate of evaporation from all uncovered tests:

$$\dot{m}_v = 0.114 \frac{g}{s} = 0.21 \frac{inches}{day}$$

These results are physically consistent with mass transfer theory. Covered tests have significantly lower convective mass transfer coefficient and Sherwood number, because the addition of the cover increases humidity which reduces the concentration gradient and consequently the water evaporation.

Trey Bushling

Testing Plan Final Results



- Negative correlation
- Increase of air temp ➡ increase of RH ➡ decrease of concentration gradient
- Leads to smaller h_m

- Positive correlation
- Increase in water temp leads to larger h_m and more evaporation

- Under covered test conditions, RH is driven by water temp
- Positive correlation of RH acts as a proxy to positive correlation of water temp vs h_m

Samantha Synk

Testing Plan Final Results

Sherwood Correlation From Tests with Covers:

$$Sh = 1.39\, Ra_m^{0.457}, \qquad R^2 = 0.78$$

R^2 value of 0.78 means that 78% of the Sherwood number's behavior is explained by the Rayleigh number.

The tests with roofs follow natural convection mass transfer trends, and a larger R^2 value implies that the buoyant forces in the Ra number have a strong effect on the evaporation in the Sh number.

$C = 1.39$ $\qquad$ $n = 0.457$

Both the C and n constants indicate that the evaporation increases when the buoyant forces increase and are comparable to other experimentally derived Sherwood correlations.

Sherwood Correlation From Tests without Covers:

$$Sh = 7.24 \times 10^{13}\, Ra_m^{-1.41}, \qquad R^2 = 0.53$$

R^2 value of 0.53 means that 53% of the Sherwood number's behavior is explained by the Rayleigh number.

The uncovered tests do not produce a strong enough correlation between the Ra and Sh numbers. This means that buoyant forces alone were not driving evaporation during the uncovered tests, which is represented by the non-physical C and n values in the correlation.

Possible factors why:

- Forced convection present
- Uncontrolled driving forces of evaporation i.e., relative humidity, air temp.

Lilliana HB

Testing Final Results

Linear plot of Sherwood correlation from covered tests:

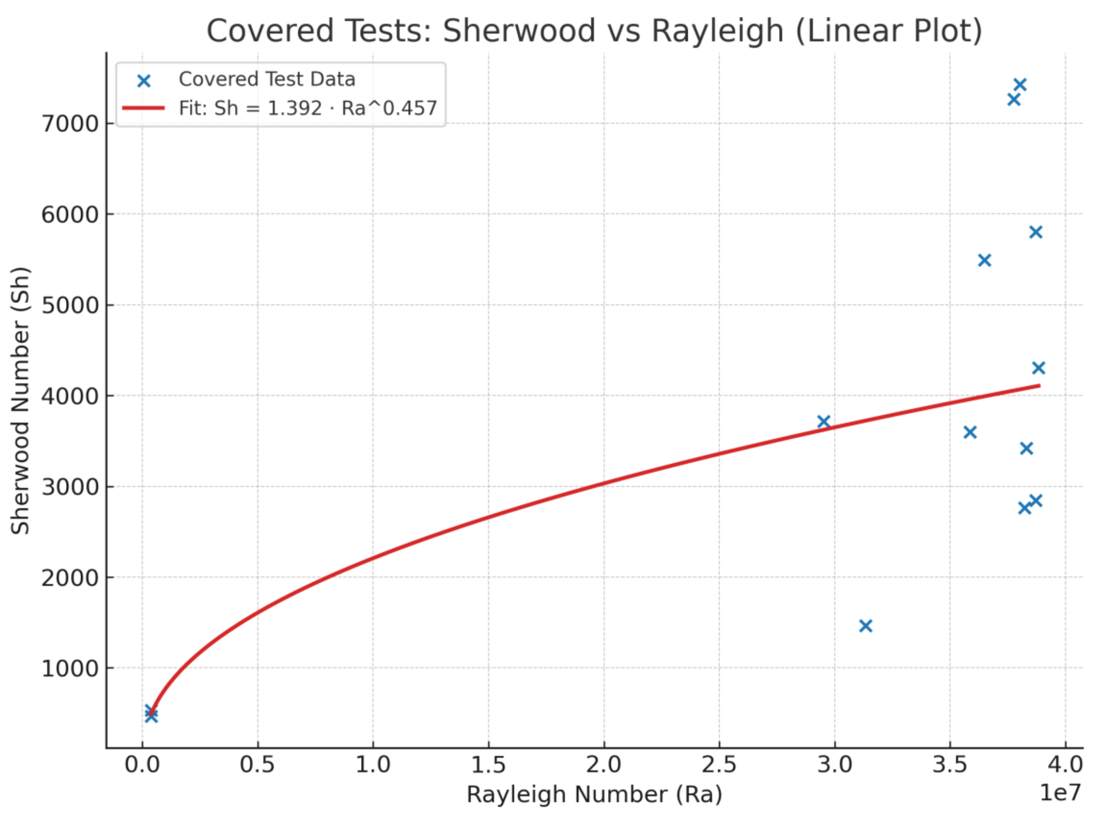


Figure 38: Line of best fit for the covered tests Sherwood correlation shown on a linear graph

Log-log plot of both correlations:

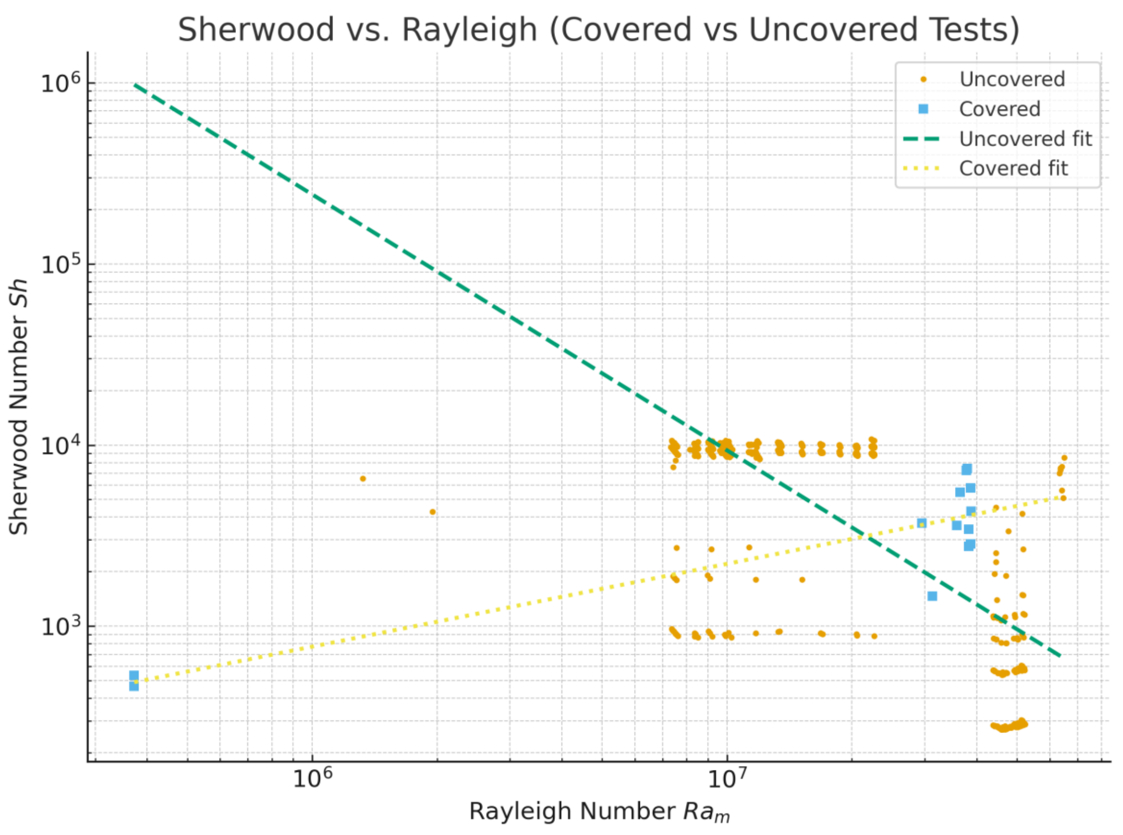


Figure 39: log-log plot showing lines of best fit for both Sherwood correlations

Final Results Instrument Error Propagation

Load Cell Uncertainty

$$\sqrt{0.0005^2 + 0.0003^2 + 0.0003^2} = 0.000656\ \%$$

$$0.00000656\ x\ 1000\ grams = \pm 0.00656\ grams$$

$$\sigma_{Lc}\ \frac{0.00656\ grams}{0.01\ grams} = 0.0656\ x\ 100 = \pm 65.6\%$$

Thermocouple Uncertainty

$$\frac{0.5°C}{33°C} = 0.0151\ x\ 100 = \pm 1.52\%$$

$$\sigma_{tc} = \sqrt{1.52^2 + 1.52^2} = \pm 2.15\%$$

Total Instrument Uncertainty

$$\sigma_{Total} = \sqrt{65.6^2 + 2.15^2 + 5.66^2 + 1.29^2} = 65.9\ \%$$

Humidity Sensor Uncertainty

$$\frac{2\%}{50\%} = 0.04\ x\ 100 = \pm 4\%$$

$$\sigma_{hs} = \sqrt{4^2 + 4^2} = \pm 5.66\%$$

Temperature Sensor Uncertainty

$$\frac{0.3°C}{33°C} = 0.009\ x\ 100 = \pm 0.91\%$$

$$\sigma_{ts} = \sqrt{0.91^2 + 0.91^2} = \pm 1.29\%$$

Brendan Steele

Specification Sheet

Table 3: 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	✓	✓

Jorge Cesin

Specification Sheet

Table 4: 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	N/A
ER2: Accuracy of sensors	±.5°C, ±3%RH ±0.02g	±0.1°C, ±1RH ±0.01g	±0.5°C, ±2%RH ±0.003g	✓	✓
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	✓

Jorge Cesin

Thank You!

NAU NORTHERN ARIZONA UNIVERSITY