NORTHERN ARIZONA UNIVERSITY

ME 476C Capstone Project

Summer 2025

RE Lab Solar Heater

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Project Description

Primary Goal

- Implement a solar air heater to provide heat to the Renewable Energy Lab to offset the current, nonrenewable, method of heating.

Important

- Help achieve NAU carbon neutrality plan
- Keep stored batteries above 40 °F
- Provide affordable renewable heating for low infrastructure areas

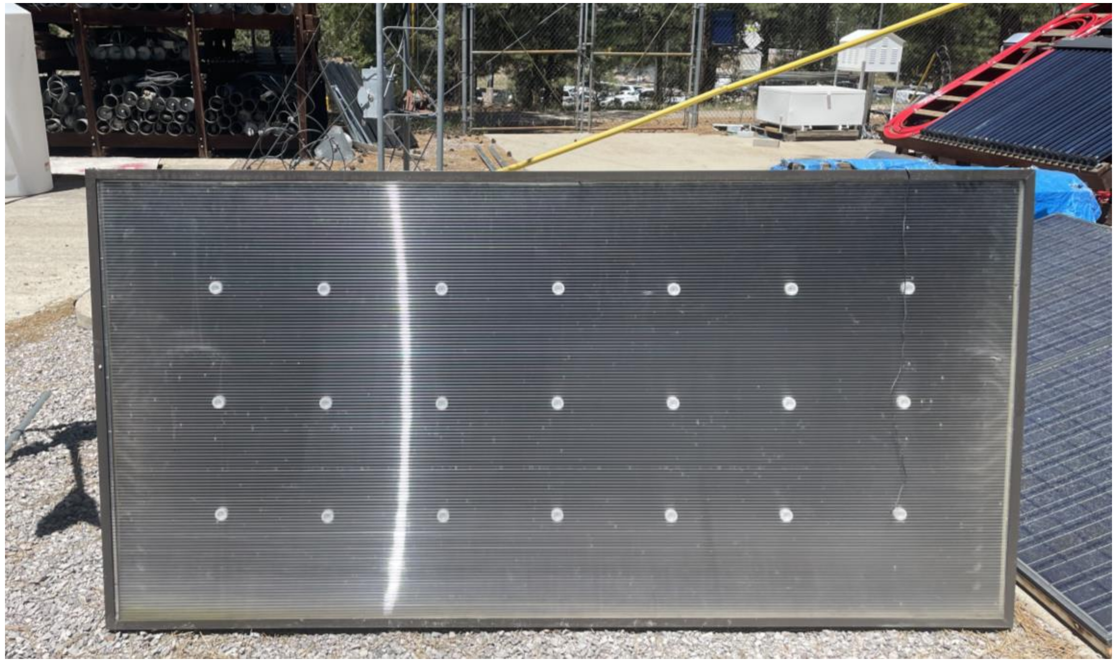


Figure 1: Air-Based Solar Thermal Panel

Brendan Frazier

SolidWorks Assembly

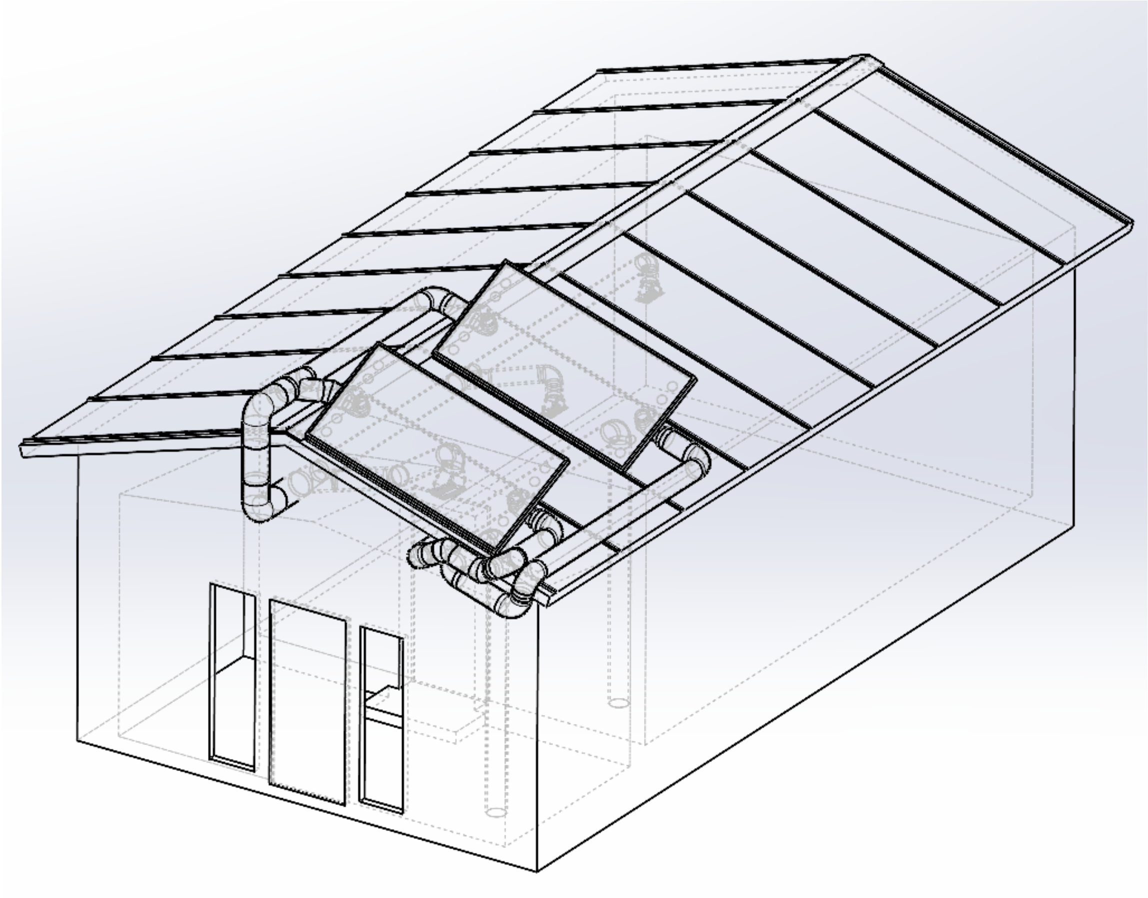


Figure 2: CAD Model

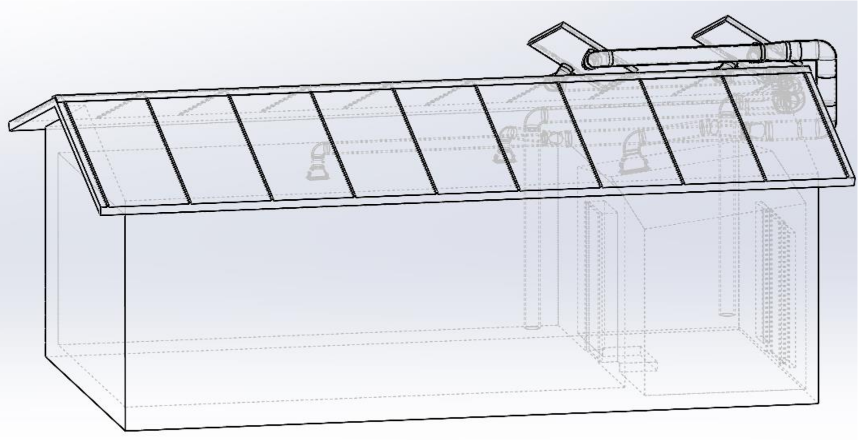


Figure 3: CAD Model

- 2 cold air inlets (1 in big room and 1 in smaller room)
- 3 heated outlets (2 in big room and 1 in smaller room)

Design Description:

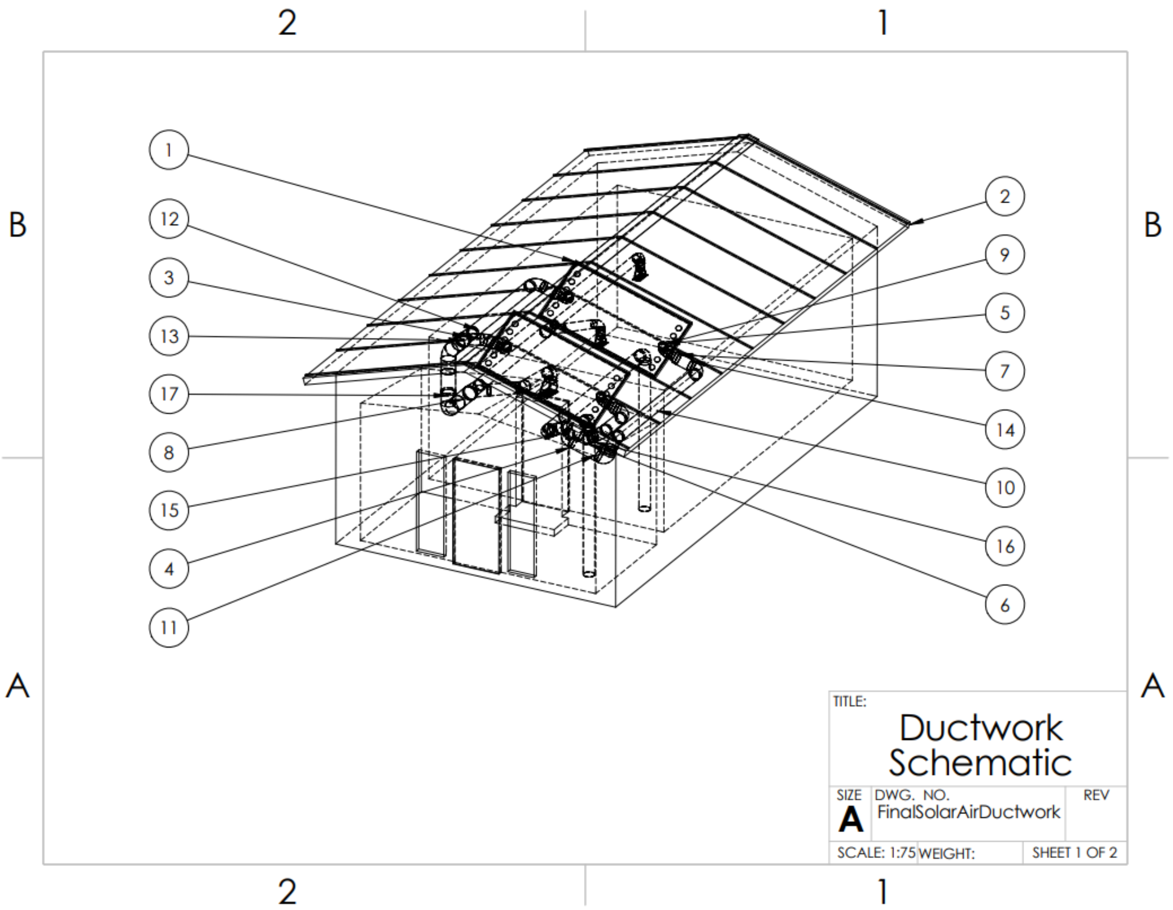
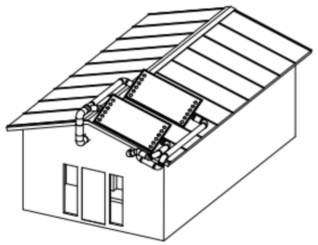


Figure 4: Ballooned CAD Drawing

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	solaraircollector	Solar Air Panel Assembly	2
2	FinalCAD_Building - Copy	Renewable Energy Building	1
3	10x8x8wye	10 inch x 8 inch x 8 inch Wye	2
4	8inch90elbow	8 inch Diameter Elbow 90	11
5	6inchelbow	6 inch Diameter Elbow 90	6
6	8inch_45_Degree	8 inch Diameter Elbow 45	4
7	8x6adapter	8 inch x 6 inch Adapter	4
8	10inchEblow	10 inch Diameter Elbow 90	2
9	6x2Duct	6 inch Diameter x 2 inch Duct	4
10	112x8inchDuct	8 inch Diameter x 112 inch Duct	4
11	21x8inchDuct	8 inch Diameter x 21 inch Duct	4
12	83x8inchDuct	8 inch Diameter x 83 inch Duct	1
13	6Inch10DiaDuct	10 inch Diameter x 6 inch Duct	1
14	10x8inchDuct	8 inch Diameter x 10 inch Duct	3
15	8DiaX6long duct	8 inch Diameter x 6 inch Duct	1
16	8DiaX4long duct	8 inch Diameter x 4 inch Duct	2
17	16x10inchDuct	10 inch Diameter x 16 inch Duct	2
18	10x4RegisterBoxSLDPRT	Back Hot Air Supply	2
19	10x4Vents	Back Hot Air Cover	2
20	14x6inchRegisterBox	Front Hot Air Supply	1
21	14x6Vents	Front Hot Air Cover	1
22	8x6x6 (1)	8 inch x 6 inch x 6 inch Wye	1
23	120x6inchDuct	6 inch Diameter x 120 inch Duct	1
24	96x8InchDuct	8 inch Diameter x 96 inch Duct	1
25	6x6_InchDuct	6 inch Diameter x 6 inch Duct	2
26	21x8inchDuct (1)	8 inch Diameter x 21 inch Duct	1
27	20x6_InchDuct	6 inch Diameter x 20 inch Duct	1
28	33x8_InchesDuct	8 inch Diameter x 33 inch Duct	1



TITLE: Ductwork Schematic

SIZE A | DWG. NO. FinalSolarAirDuctwork | REV

SCALE: 1:150 WEIGHT: SHEET 2 OF 2

Figure 5: Bill of Materials

Circuit Diagram

Components

1. PV/T Panel (V1) – DC Volage Supply
2. Fuse (F1) – Current Control
3. Buck Converter (R1) – Voltage Control
4. Mechanical Relay (RLY1) – On/Off Switch
5. Fan – Electrical Load
6. Thermostat (V2) - Voltage Supply for Relay

Future Additions

- In depth routing configuration
- Implement emergency shutoff

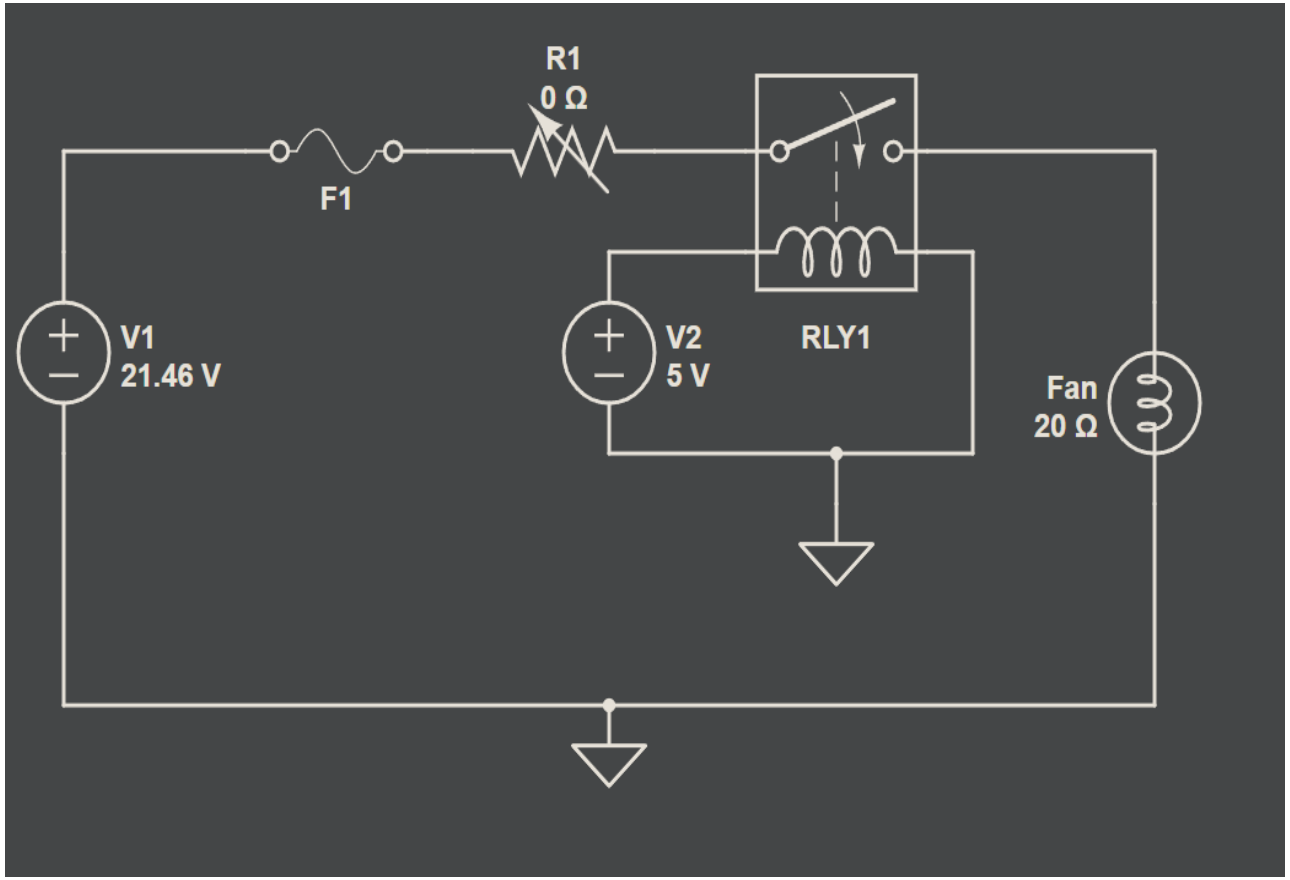


Figure 6: Circuit Diagram for Solar Thermal System

Brendan Frazier

QFD

Quality Function Deployment

Project title: RE Lab Solar Heater
Project leader: Brendan Frazier
Date: 6/10/2025

Correlation:

+	0	-
Positive	No correlation	Negative

Relationships:

5	3	1	0
Strong	Moderate	Weak	None

	Energy Stored	Efficient Insulation	Relay	Head Pressure	Flow Rate	Heat exchanger	Life expectancy	Cost	Mounting system
	0								
	0	0							
	+	0	-						
	+	+	-	0					
	+	+	0	0	0				
	+	+	0	+	0	0			
	+	+	0	+	+	0	0		
	+	+	0	+	+	+	0	-	

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	Relay	Head Pressure	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
		Desired direction of improvement (↑,0,↓)	↑	↑	↓	↑	↑	↑	↑	↓	↓						
1	5	System must reduce heating load by 30% during worst case months (compared to baseline method)	5	5	0	4	4	5	0	0	0	50	4	3	5	4	5
2	5	System must operate in winter conditions	5	5	0	5	5	3	1	0	3	55	3	3	5	4	5
3	5	System must use RE solar as primary input	5	5	0	4	4	3	0	0	5	65	5	5	5	5	3
4	3	Installation must not require major mods to building	0	1	0	2	2	0	0	3	5	24	2	3	3	4	5
5	5	System must be safe and comply with codes	3	3	3	4	3	3	3	0	5	70	5	5	4	5	5
6	3	System must have minimal maintenance	1	1	1	3	2	5	5	1	4	36	3	4	4	5	5
7	3	Payback period must be under 10 yrs	5	5	3	2	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	5	4	3	0	0	1	12	5	5	4	4	5
9	3	System must not overheat or cause interior overheating	5	0	5	5	4	3	0	0	2	45	5	5	4	4	5
		Technical importance score	126	111	47	126	114	112	44	27	111	818	37	38	35	38	42
		Importance %	15%	14%	6%	15%	14%	14%	5%	3%	14%	100%					
		Units	kWh	R Value	Watts	meters	m^3/sec	Joules	Years	$	Kilograms						
		Target	30 kWh	10 R-Value	10 W	5 m	0.1 m^3/s	5 MJ	10 yrs	$1,000	20 kg						
		Priorities rank	**1**	**5**	**7**	**2**	**3**	**4**	**8**	**9**	**6**						

Figure 7: QFD

Mounting Analysis

Assumptions:

-Uniform Snow Distribution of 20.9 in on solar collector [40]

-35° tilt

-Wind speed is 25 mph or 11.176 m/s [41]

-Snow is "normal"

Results:

Diameter of bolts ¼"

Table 8–11

Metric Mechanical-Property Classes for Steel Bolts, Screws, and Studs

Property Class	Size Range, Inclusive	Minimum Proof Strength,* MPa	Minimum Tensile Strength,* MPa	Minimum Yield Strength,* MPa	Material	Head Marking
4.6	M5–M36	225	400	240	Low or medium carbon	4.6

Figure 8: Bolt Size Table [39]

Dead Load = weight / Area = 100 lbs / 33 ft² = 3.03 psf

Wind:

dynamic pressure = $\frac{1}{2}\rho v^2 = \frac{1}{2}(1.125 \frac{kg}{m^3})(11.176\ m/s)^2 = 70.26 \frac{kg \cdot m}{s^2}$

Surface Area = 33 ft² × sin(35°) = 18.93 ft² = 0.83 m²

live load = $70.26 \frac{kg}{m \cdot s^2} \times 0.83\ m^2 = 58.31 \frac{kg \cdot m}{s^2} = 58.31\ N$

Snow:

live load = $\rho \times h = 1.25 \frac{psf}{in} \times 20.9\ in = 26.125\ psf$

Weight = live load × A = 26.125 psf × 33 ft² = 862.125 lb

F_{design} = Sum of forces per bolt × F.O.S

F_{design} = 219.57 lb × 2 = 439.13 lb

$F = \tau A$

$439.13\ lb = 58.0151\ kPsi \times \frac{\pi}{4} d^2$

$d^2 = 0.009637451\ in^2$

$d = 0.0982\ in = 2.5\ mm$

Figure 9: Mounting Calculations

Energy Analysis

Assumptions

- Building Temperature 55 Fahrenheit
- ASHRAE Solar Irradiation Data
- Incident Radiation Angle from 0 to 71.25 degrees
- Inlet Temperature same as building temperature

Energy Equations

$$q_{in} = \dot{m} * c_p * (T_{air} - T_{building})$$

Fundamental Heat Transfer Equations

$$q_r = A_s \varepsilon \sigma (T_s^4 - T_{surr}^4)$$

$$q_{conv} = hA_s(T_{mo} - T_{mi})$$

$$q_{cond} = kA(T_1 - T_2)$$

Temperature Equations

$$\overline{Nu} = 0.023 * Re^{0.8} * Pr^{0.4}$$

$$T_{out} = T_{in} + \frac{hA_s(T_{inner} - T_{in})}{\dot{m}c_p}$$

Brendan Frazier

Energy Calculation: Dynamic Output

```matlab
for k = 1:length(winter_months)
    month = winter_months(k);
    T_amb = T_K_amb(month);
    G_month = G(month);

    q_net_total = 0;
    q_net_array = zeros(1, length(theta_sequence));

    for i = 1:length(theta_sequence)
        theta = theta_sequence(i);
        G_tilted = G_month * sin(theta);
        if G_tilted < 0, G_tilted = 0; end  % prevent negative irradiance

        q_abs = alpha * G_tilted * A_proj;

        % Iterative calculation for T_plate_est
        T_plate_est = T_K + 20;
        error = 1;
        while error > 0.01
            q_loss = U_loss * A_proj * (T_plate_est - T_amb);
            q_net = q_abs - q_loss;
            T_plate_new = T_K + q_net / h;
            error = abs(T_plate_new - T_plate_est);
            T_plate_est = T_plate_new;
        end

        T_out = T_K + q_net / (m_dot * cp);
        T_out = min(T_out, T_plate_est);  % Clamp outlet temp

        deltaT = T_out - T_K;
        q_interval = m_dot * cp * deltaT * 1800;  % J over 30-min interval

        q_net_array(i) = q_interval;
        q_net_total = q_net_total + q_interval;
    end

    energy_kWh = q_net_total / 3.6e6;
    energy_BTU = q_net_total / 1055.06;
    q_net_avg = q_net_total / (length(theta_sequence) * 1800);

    T_plate_final = T_K + q_net_avg / h;
    T_out_final = T_K + q_net_avg / (m_dot * cp);
    T_out_final = min(T_out_final, T_plate_final);

    fprintf('\nMonth: %s\n', datestr(datetime(2000, month, 1), 'mmmm'));
    fprintf(' Tilted Irradiance (peak): %.2f W/m^2\n', G_month * sin(theta_max));
    fprintf(' Absorber Plate Temp (est.): %.2f °C\n', T_plate_final - 273.15);
    fprintf(' Outlet Temperature (est.): %.2f °C\n', T_out_final - 273.15);
    fprintf(' Energy Input: %.2f kWh or %.2f BTU\n', energy_kWh, energy_BTU);

    % Plot 30-min interval kWh for this month
    energy_interval_kWh = q_net_array / 3.6e6;
    plot(time_vec, energy_interval_kWh, 'DisplayName', month_names{k}, 'Color', colors(k,:));
end
```

Figure 10: Energy MATLAB Code

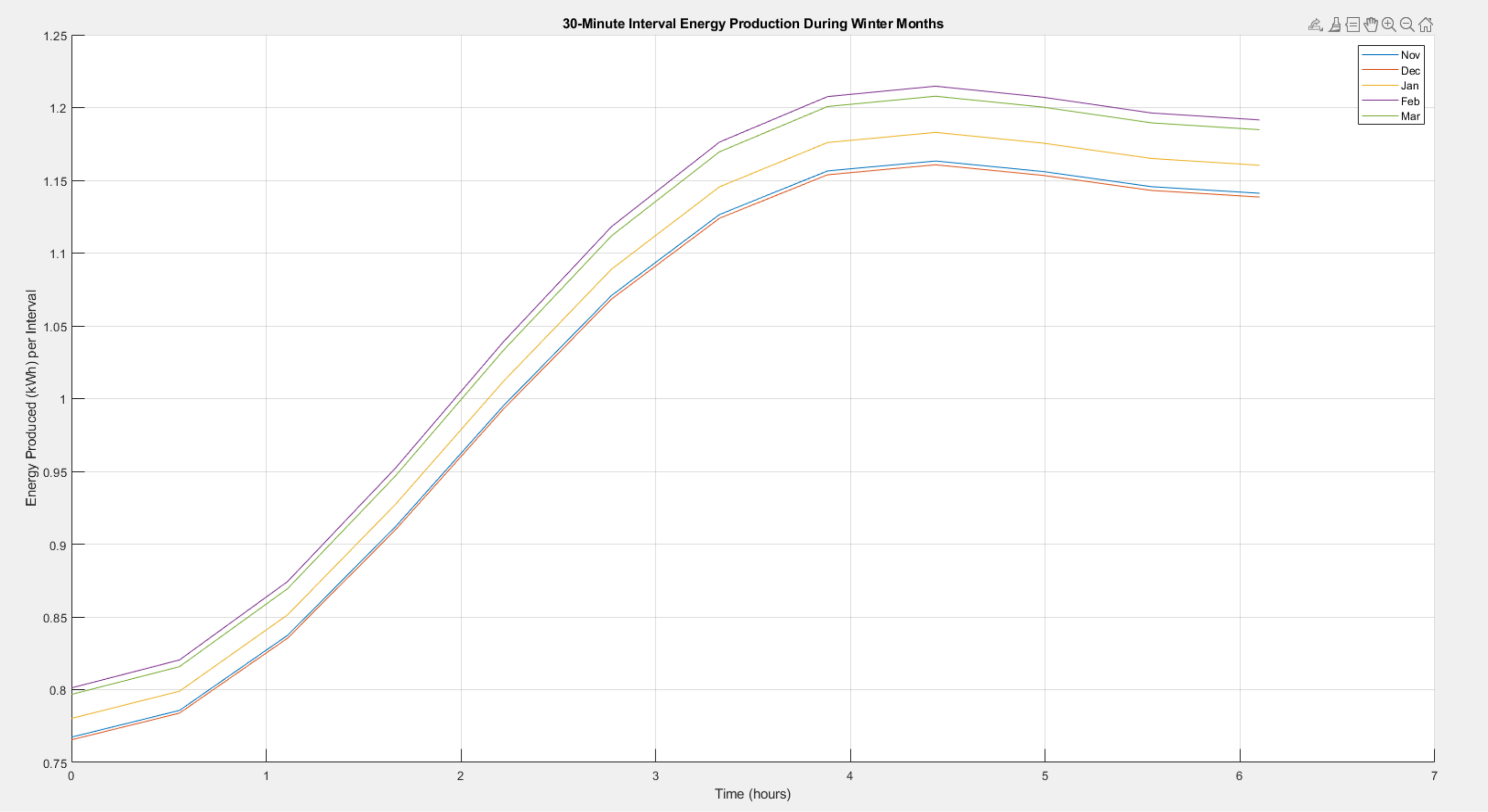


Figure 10: Dynamic Angle Energy Output

NORTHERN ARIZONA UNIVERSITY

Brendan Frazier

Energy Calculations: Daily Output

Importance

- Evaluate solar thermal energy captured with a dynamic angle
- Are we still meeting 30% requirement in winter

Results

- December – 15% Heat Load Covered
- January – 15% Heat Load Covered
- February – 16% Heat Load Covered

```
--- Energy Inputs for Winter Season (Dynamic Angle) ---

Month: November
 Tilted Irradiance (peak): 939.35 W/m^2
 Absorber Plate Temp (est.): 63.53 °C
 Outlet Temperature (est.): 24.41 °C
 Energy Input: 12.26 kWh or 41823.18 BTU

Month: December
 Tilted Irradiance (peak): 937.46 W/m^2
 Absorber Plate Temp (est.): 63.39 °C
 Outlet Temperature (est.): 24.36 °C
 Energy Input: 12.23 kWh or 41726.93 BTU

Month: January
 Tilted Irradiance (peak): 955.45 W/m^2
 Absorber Plate Temp (est.): 64.51 °C
 Outlet Temperature (est.): 24.74 °C
 Energy Input: 12.46 kWh or 42528.31 BTU

Month: February
 Tilted Irradiance (peak): 981.02 W/m^2
 Absorber Plate Temp (est.): 66.11 °C
 Outlet Temperature (est.): 25.27 °C
 Energy Input: 12.80 kWh or 43670.39 BTU

Month: March
 Tilted Irradiance (peak): 975.34 W/m^2
 Absorber Plate Temp (est.): 65.77 °C
 Outlet Temperature (est.): 25.15 °C
 Energy Input: 12.73 kWh or 43423.75 BTU
```

Figure 11: Daily Energy Output

Brendan Frazier

Photovoltaic Solar Analysis

Assumptions:

1. Polycrystalline panels: λ_a = 0.85 [15]
2. Glass panels: λ_c = 0.7 [10]
3. Solar panels positioned on roof: θ = 16.77°
4. Absorber plate temperature: T_a=333.15K
5. Cover plate temperature: T_c = 313.15K
6. G = 5.461 kWh/m^2 [38]
7. Diffuse Surface: ε = α

Solar Energy Absorbed

$$\lambda_T = 0.85\mu m * 5800K = 4930\mu m * K$$

$$F(0 \longrightarrow 0.85\mu m) = 0.616725 * From\ Table\ 12.2$$ [10]

$$\alpha = 0.8(0.616275) + 0.25(1 - 0.616725) = 0.589199$$

$$G = \frac{5.641\frac{kWh}{m^2}}{7.667hrs} * \frac{1000W}{1kW} = 712.17\frac{W}{m^2}$$

$$G_{abs} = \alpha G cos(90 - \theta) = 121.07\frac{W}{m^2}$$

Voltage

$$36.68\frac{W}{m^2} * 0.9144m * 1.524m = 51.115W$$

$$V = \frac{51.115W}{1.6A} = 31.9V$$

Heat loss

$$\lambda_a * T_a = 283.1775\mu m * K$$

$$\varepsilon_a = 0.25$$

$$\lambda_c * T_c = 219\mu m * K$$

$$\varepsilon_c = 0.75$$

$$q"_{rad} = \frac{\sigma(T_a{}^4 - T_c{}^4)}{(\frac{1}{\varepsilon_a} + \frac{1}{\varepsilon_c} - 1)} = 35.36\frac{W}{m^2}$$

$$Ra_L = \frac{g\beta(T_a - T_c)L^3}{\nu\alpha} = 168773.51$$

$$\overline{Nu}_L = 4.4457\ (9.54)$$ [10]

$$\bar{h}_L = \frac{\overline{Nu}_L * k_f}{L} = 2.4513\frac{W}{m^2 * K}$$

$$q"_{conv} = \bar{h}_L(T_a - T_c) = 49.03\frac{w}{m^2}$$

$$q"_{total} = 121.07\frac{W}{m^2} - \left(49.03\frac{w}{m^2} + 35.36\frac{W}{m^2}\right) = 36.68\frac{W}{m^2}$$

Tyler Hedgecock

HVAC Routing Analysis

$$AirFlow = RFL_{Rooms\ floor\ area} \times Ceiling\ height(ft) \times \frac{ACH}{60}$$

Big Room

$$205.98\ CFM = 356.5\ ft^2 \times 104in \times \frac{4}{60}$$

Small Room

$$67.08\ CFM = 115\ ft^2 \times 105in \times \frac{4}{60}$$

Assumptions :
ACH is 4 (the recomended value to satisfy ASHRAE)
Square ft is 471.f ft^2

Results: We will need a minimum of 273.15 CFM to maintain the buildings safety requirements

Rectangular and Round Duct

Air Volume CFM	Rectangular Duct Height (inches)					Equivalent Round Duct (inches)	Air Volume CFM
	4"	6"	8"	10"	12"		
50	6 x 4					5	50
75	6 x 4					6	75
100	8 x 4	6 x 6				6	100
125	10 x 4	6 x 6				7	125
150	10 x 4	8 x 6				7	150
175	12 x 4	8 x 6				8	175
200	14 x 4	8 x 6				8	200
225	16 x 4	10 x 6				8	225
250	16 x 4	10 x 6				9	250
275		12 x 6	8 x 8			9	275
300		12 x 6	8 x 8			9	300
400		14 x 6	10 x 8			10	400
500		18 x 6	12 x 8	10 x 10		11	500
600		20 x 6	14 x 8	12 x 10		12	600
700		24 x 6	16 x 8	12 x 10		12	700
800		26 x 6	18 x 8	14 x 10	12 x 12	13	800
900		30 x 6	20 x 8	16 x 10	12 x 12	14	900
1000			22 x 8	16 x 10	14 x 12	14	1000
1100			24 x 8	18 x 10	16 x 12	15	1100
1200			26 x 8	20 x 10	16 x 12	15	1200
1300			28 x 8	20 x 10	18 x 12	16	1300
1400			30 x 8	22 x 10	18 x 12	16	1400
1500				24 x 10	20 x 12	16	1500
1600				24 x 10	20 x 12	17	1600
1700				26 x 10	22 x 12	17	1700
1800				28 x 10	22 x 12	18	1800
1900				30 x 10	22 x 12	18	1900
2000					24 x 10	18	2000

Figure 12: Duct sizing by CFM

Joseph Meza

Ductwork Cost Analysis

Table 1: Ductwork BOM

Bill of Materials				
Name	SKU Number	Quantity	Cost	Total Cost
10x8x8Wye	590430	2	30.94	61.88
8x6x6 Wye	643092	1	17.98	17.98
8 inch 90	148768	15	9.98	149.7
6 inch 90	148733	6	8.68	52.08
8 x 6 adapter	148857	4	14.28	57.12
10 inch 90	569844	2	14.87	29.74
6 inch duct	1013032134	1	59.98	59.98
8 inch duct	1013032129	3	67.98	203.94
10 inch duct	688736	1	24.2	24.2
10 x 4 to 6 register box	148962	2	12.49	24.98
14 x 6 to 8 register box	351407	1	14.98	14.98
10 x 4 vent	324411	2	13.98	27.96
14 x 6 vent	497808	1	14.98	14.98
Total				739.52

- $740 Spent on Ductwork
- Ductwork is not cheap
  - $150 Spent on 8 inch elbows
- Majority of our design

Calvin Schenkenberger

Future CR and ER Calculations

Table 2: Customer Requirement Fulfillment

Customer Requirement	Status	Future Work
Reduce Headload 30%	Completed	Improvements on irradiance angle
Operate in Winter	Completed	None
Primarily use renewable energy	Completed	None
No major modifications	Partially Completed	Perform validation on mounting
Comply with codes	Not Completed	Reconfirm design against relevant building codes
>4 hours of maintenance annually	Not Completed	Perform maintenance time approximations
10-year payback period	Not Completed	Perform cost and time analysis
Must not overheat the building	Partially Completed	Reconfirm thermostat configuration

Jacob Apodaca

Failure Mode and Effect Analysis (FMEA)

Table 3: FMEA Breakdown

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Electrical Fuse	Fuse popping	Overheating & Fire Hazard	9	Over Current	2	Inspection 2x Per year	4	72	Follow safety standards
Buck Converter	Excessive Voltage Supply	Burn out fans	7	Over Voltage	3	Display of output voltage	1	21	Follow safety standards
Relay	Over cycled	Constant or zero operation	7	Over Cycled	1	Inspection 1x Per year	6	42	Moderate cycles completed
	Contact or Coil corrosion	Constant or zero operation	7	Over current/voltage	1	Inspection 1x Per year	6	42	None
Fans	Short circuit	Burn out fans resulting in no operation	7	Assembly error	1	Inspection as needed	3	21	Follow electrical safety standards
Thermostat	Under powered	Unable to supply power to relay	4	Assembly error	4	Battery Charge Display	2	32	Provide battery storage for thermostat
L Bracket	Buckling	Loss of optimal angle	4	Excessive snow fall	2	Inspection 2x Per year	4	32	Apply FOS ~2
	Shear failure	Complete system failure	10	Excessive wind	1	Inspection 2x Per year	4	40	Apply FOS ~2.5
Rail	Bending	Loss of optimal angle	5	Excessive snow fall	2	Inspection 2x Per year	4	40	Apply FOS ~2
	Shear failure	Complete system failure	10	Excessive wind	1	Inspection 2x Per year	4	40	Apply FOS ~2.5
Bolts	Shear failure	Complete system failure	10	Excessive wind	1	Inspection 2x Per year	4	40	Apply FOS ~2.5
Ducts	Compressive Load	Lack of air flow	5	Excessive snow fall	3	Inspection 2x Per year	4	60	Rigid outdoor ducts
	Dust Collection	Decreased energy absorption	2	Lack of maintenance	5	Inspection as needed	6	60	None
	Blocked Inlet	Lack of air flow	1	Lack of maintenance	3	Inspection as needed	9	27	None
	Humidity	Uncomfortable environment	3	System overuse	1	None	10	30	None
Solar Heater	Excessive bending moment	Lack of air flow	2	Excessive snow fall	2	Inspection 2x Per year	4	16	Improve structural setup of panels
		System failure	10	Excessive snow fall	1	Inspection 2x Per year	4	40	Improve structural setup of panels
	Particulates covering solar panel	Lack of energy absorption	2	Lack of maintenance	2	Inspection as needed	9	36	None
PV/T Panel	Excessive bending moment	No electrical power	9	Excessive snow fall	1	Inspection 2x Per year	4	36	Change PV/T panel selection (improved strength)
	Particulates covering solar panel	Low voltage and current output	3	Lack of maintenance	2	Inspection as needed	9	54	None
Mesh	Rodent breaking and entering	Loss of efficiency and air flow	1	Lack of maintenance	3	Inspection as needed	9	27	None
Weather Sealant	Cracking or lack if fill	Leaking water	5	Assembly error	4	None	10	200	None

Primary Subsystems

- Electrical Controls
  - Fuse
  - Relay
  - Buck Converter
- Mounting System
  - Brackets
  - Rails
  - Bolts
- Energy Harvesting
  - PV/T and Air Solar Panels
- HVAC Routing
  - Ducts
  - Insulation

Brendan Frazier

Failure Mode and Effect Analysis (FMEA)

Future Testing

- Structural testing on mounting brackets and rails
- Improved volumetric flowrate testing
- Improved temperature input to the building (constant inlet temperature)

Equipment Required

- FEA Analysis on brackets and tensile testing machine required
- Hot wire anemometer (specifically built for HVAC testing)
- K-type thermocouples and DAQ software and program

Tyler Hedgecock

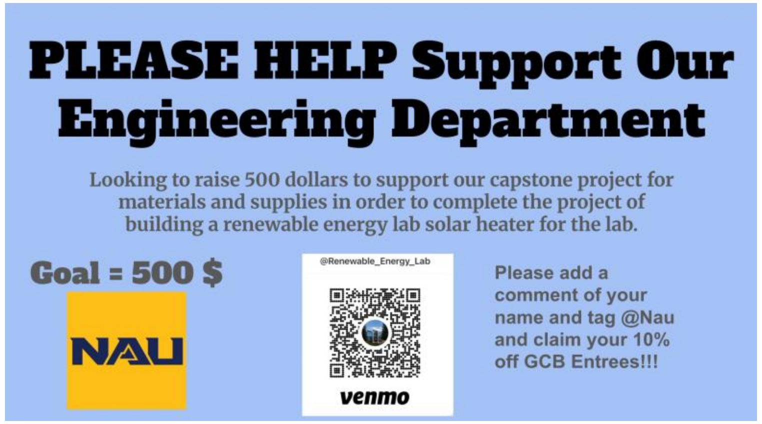
Schedule & Budget

Total Budget Available: $1,092 total

- $500 provided by the Renewable Energy Lab
- $500 provided by Home Depot Bill of materials
- $92 dollars raised from GCB fundraising

Anticipated Expenses

- Roof mounting
- Ducts, insulation, Vents
- Electrical
- Misc



Tentative Budget Schedule

- BOM due 08/7/2025
- $350 dollar remain
- Important dates 08/25, 10/16, 11/6

Joseph Meza

Summer Gantt Chart

2nd Prototype Demo	Everyone	100%	7/24/25	7/31/25
Presentation 3	Everyone	100%	7/28/25	7/31/25
>Project Description		100%	7/28/25	7/31/25
>Design Description		100%	7/28/25	7/31/25
>Design Requirements		100%	7/28/25	7/31/25
>Engineering Calculations		100%	7/28/25	7/31/25
>Design Validation		100%	7/28/25	7/31/25
>Schedule and Budget		100%	7/28/25	7/31/25
Website Check #2	Everyone	0%	7/29/25	8/5/25
Project Management (for 486C a draft version)	Everyone	50%	7/15/25	8/1/25
Report 2 (Final Report)	Everyone	75%	7/25/25	8/5/25
>Executive Summary	Jacob Apodaca	80%	7/25/25	8/5/25
>Background (Proj. Des., Deli., and Success Metrics)	Brendan Frazier	95%	7/25/25	8/5/25
>Requirements (CR's, ER's, and QFD)	Jacob, Tyler, Calvin	95%	7/25/25	8/5/25
>Benchmarking	Jacob, Tyler, Calvin	95%	7/25/25	8/5/25
>Literature Review	Everyone	75%	7/25/25	8/5/25
>Mathematical Modeling	Everyone	90%	7/25/25	8/5/25
>Design Concepts	Everyone	90%	7/25/25	8/5/25
>Schedule	Jacob Apodaca	95%	7/25/25	8/5/25
>Budget	Joeseph Meza	80%	7/25/25	8/5/25
>BOM	Joeseph Meza	60%	7/25/25	8/5/25
>FMEA	Everyone	100%	7/25/25	8/5/25
>Initial Prototyping	Everyone	90%	7/25/25	8/5/25
>Other engineering calcs.	Everyone	65%	7/25/25	8/5/25
>Future Testing Potential	Everyone	70%	7/25/25	8/5/25
>Conclusion	Everyone	25%	7/25/25	8/5/25
>References	Everyone	25%	7/25/25	8/5/25
>Appendices	Everyone	25%	7/25/25	8/5/25
HW04 Individual Analysis	Everyone	0%	7/28/25	8/4/25
Final CAD & Final BOM	Everyone	0%	7/28/25	8/5/25

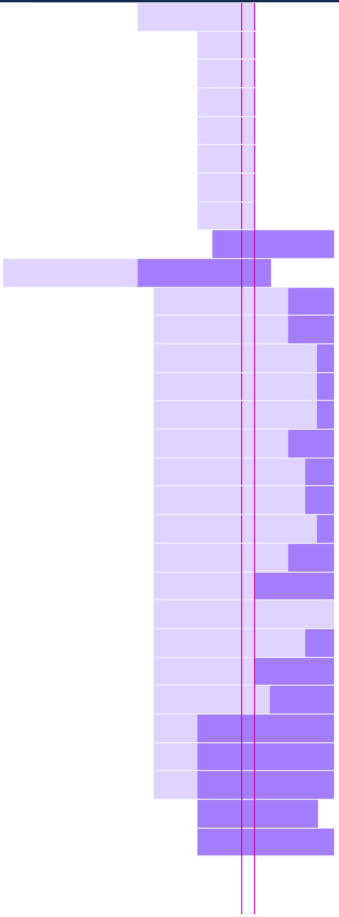


Figure 12: Summer Gantt Chart

Fall Gantt Chart

RE LAB Solar Heater

NAU Capstone Project FALL 2025

Project start: **Mon, 8/25/2025**

Display week: **1**

Aug 25, 2025							Sep 1, 2025							Sep		
25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10
M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W

Role and Tasks	ASSIGNED TO	PROGRESS	START	END
			8/25/25	12/12/25
Project Management	Everyone	0%		
Engineering Model Summary	Everyone	0%		
Self Learning / Individual Analysis	Everyone	0%		
Peer Evaluation 1	Everyone	0%		
Website Check #1	Everyone	0%		
Peer Evaluation 2	Everyone	0%		
Testing Plan (draft)	Everyone	0%		
UGRADS Registration	Everyone	0%		
Draft of Poster	Everyone	0%		
Finalized Testing Plan	Everyone	0%		
Peer Evaluation 3	Everyone	0%		
Final CAD Packet	Everyone	0%		
Final Poster & PPT	Everyone	0%		
Final Report & Final Website Check	Everyone	0%		
Peer Evaluation 4	Everyone	0%		
Client Handoff - Spec Sheet & Assembly Manual	Everyone	0%		

Figure 13: Fall Gantt Chart

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Thank You
Questions?

ME 476C Capstone Project

Summer 2025

RE Lab Solar Heater

Jacob Apodaca

Brendan Frazier

Tyler Hedgecock

Joseph Meza

Calvin Schenkenberger

Northern Arizona University

Flagstaff, AZ 86001

Customer Requirements

Customer Requirement	Software Simulation	Mathematical Modeling	Physical Prototyping	CR Status
Reduce heat load by 30% in winter	☑	☑	☑	Mostly Fulfilled
Operates in winter climate conditions	☑	☑	☑	Mostly Fulfilled
Use primarily solar energy	⊗	☑	☑	Mostly Fulfilled
No major structural modifications	☑	☑	⊗	Mostly Fulfilled
Comply with relevant codes	⊗	⊗	⊗	Not Fulfilled
>4 hours of maintenance yearly	⊗	⊗	⊗	Not Fulfilled
Must not cause building to overheat	⊗	⊗	☑	Partially Fulfilled

Calvin Schenkenberger

Physical Prototyping

How does variable voltage affect flow rate?

- Approximately 20% drop in CFM for every 2 volts

Design Information

- Provide battery power to fans to ensure max operation and efficiency

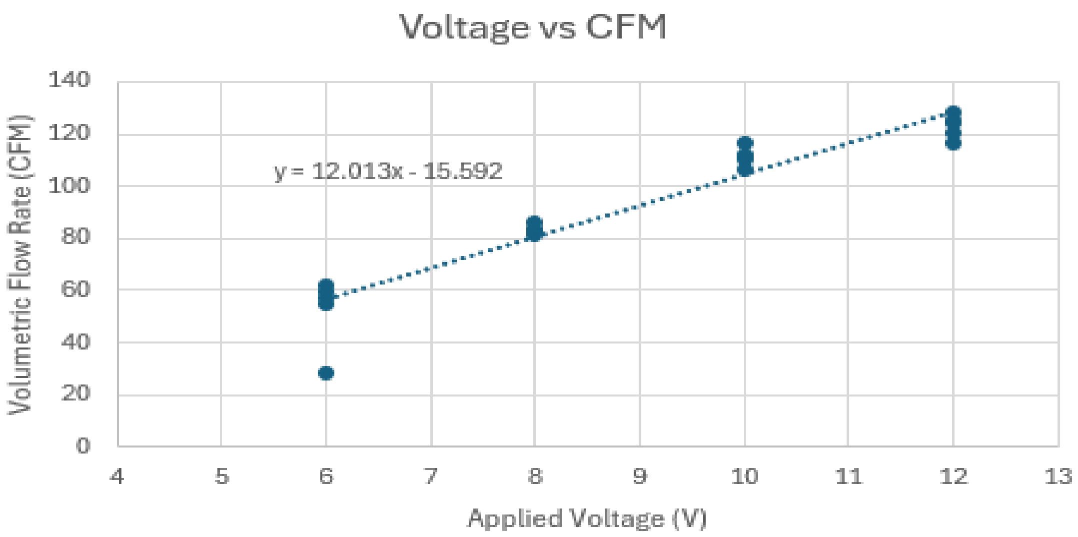

Figure 1: CFM Based on Applied Voltage

Energy Calculation: Dynamic Output

```
for k = 1:length(winter_months)
    month = winter_months(k);
    T_amb = T_K_amb(month);
    G_month = G(month);

    q_net_total = 0;
    q_net_array = zeros(1, length(theta_sequence));

    for i = 1:length(theta_sequence)
        theta = theta_sequence(i);
        G_tilted = G_month * sin(theta);
        if G_tilted < 0, G_tilted = 0; end  % prevent negative irradiance

        q_abs = alpha * G_tilted * A_proj;

        % Iterative calculation for T_plate_est
        T_plate_est = T_K + 20;
        error = 1;
        while error > 0.01
            q_loss = U_loss * A_proj * (T_plate_est - T_amb);
            q_net = q_abs - q_loss;
            T_plate_new = T_K + q_net / h;
            error = abs(T_plate_new - T_plate_est);
            T_plate_est = T_plate_new;
        end

        T_out = T_K + q_net / (m_dot * cp);
        T_out = min(T_out, T_plate_est);  % Clamp outlet temp

        deltaT = T_out - T_K;
        q_interval = m_dot * cp * deltaT * 1800;  % J over 30-min interval

        q_net_array(i) = q_interval;
        q_net_total = q_net_total + q_interval;
    end

    energy_kWh = q_net_total / 3.6e6;
    energy_BTU = q_net_total / 1055.06;
    q_net_avg = q_net_total / (length(theta_sequence) * 1800);

    T_plate_final = T_K + q_net_avg / h;
    T_out_final = T_K + q_net_avg / (m_dot * cp);
    T_out_final = min(T_out_final, T_plate_final);

    fprintf('\nMonth: %s\n', datestr(datetime(2000, month, 1), 'mmmm'));
    fprintf(' Tilted Irradiance (peak): %.2f W/m^2\n', G_month * sin(theta_max));
    fprintf(' Absorber Plate Temp (est.): %.2f °C\n', T_plate_final - 273.15);
    fprintf(' Outlet Temperature (est.): %.2f °C\n', T_out_final - 273.15);
    fprintf(' Energy Input: %.2f kWh or %.2f BTU\n', energy_kWh, energy_BTU);

    % Plot 30-min interval kWh for this month
    energy_interval_kWh = q_net_array / 3.6e6;
    plot(time_vec, energy_interval_kWh, 'DisplayName', month_names{k}, 'Color', colors(k,:));
end
```

Figure 2: Energy MATLAB Code

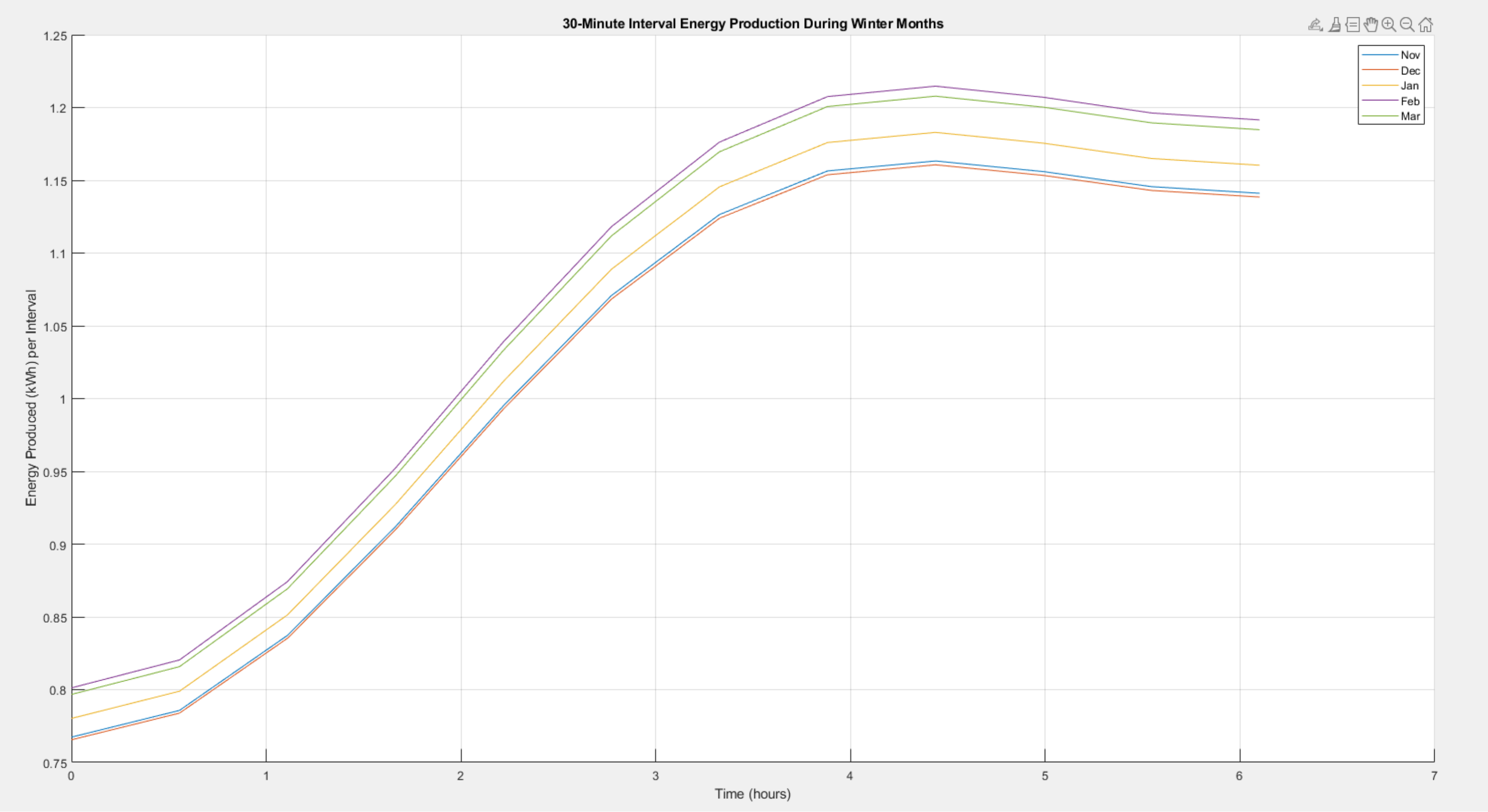

Figure 3: Dynamic Angle Energy Output

NORTHERN ARIZONA UNIVERSITY

Brendan Frazier

SolidWorks Flow Simulation

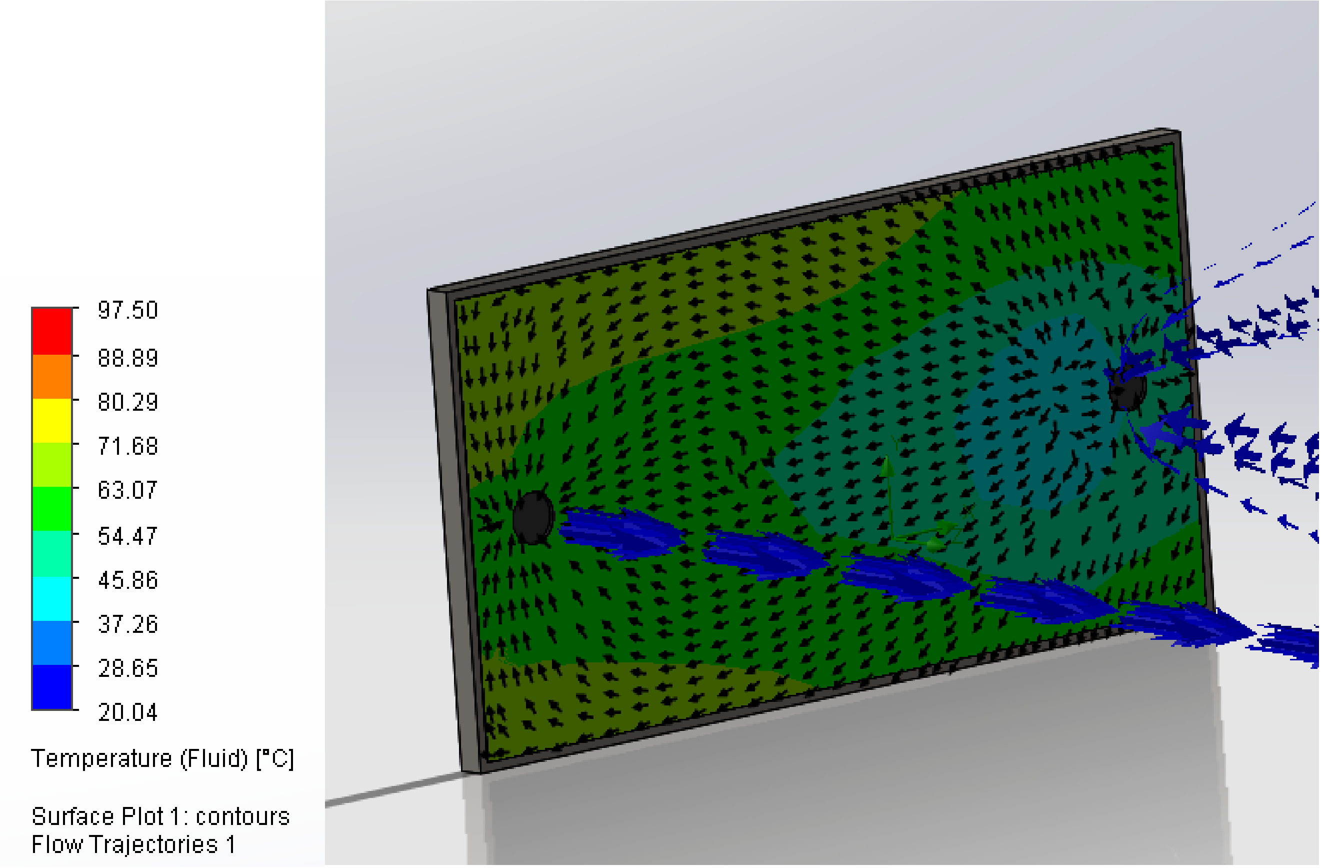

Figure 4: Air Collector Flow Simulation

Jacob Apodaca