Solar Thermal Collector Design of Experiments for the NAU Renewable Energy Laboratory

Northern Arizona University Engineering Fest

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Team

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Background: Renewable Energy

- 173,000 terawatts of solar energy strikes the Earth continuously. More than 10000 times the worlds energy usage
- Replenishable sources of energy
- NAU Renewable Energy lab
  - Wind
  - Solar
- Solar thermal

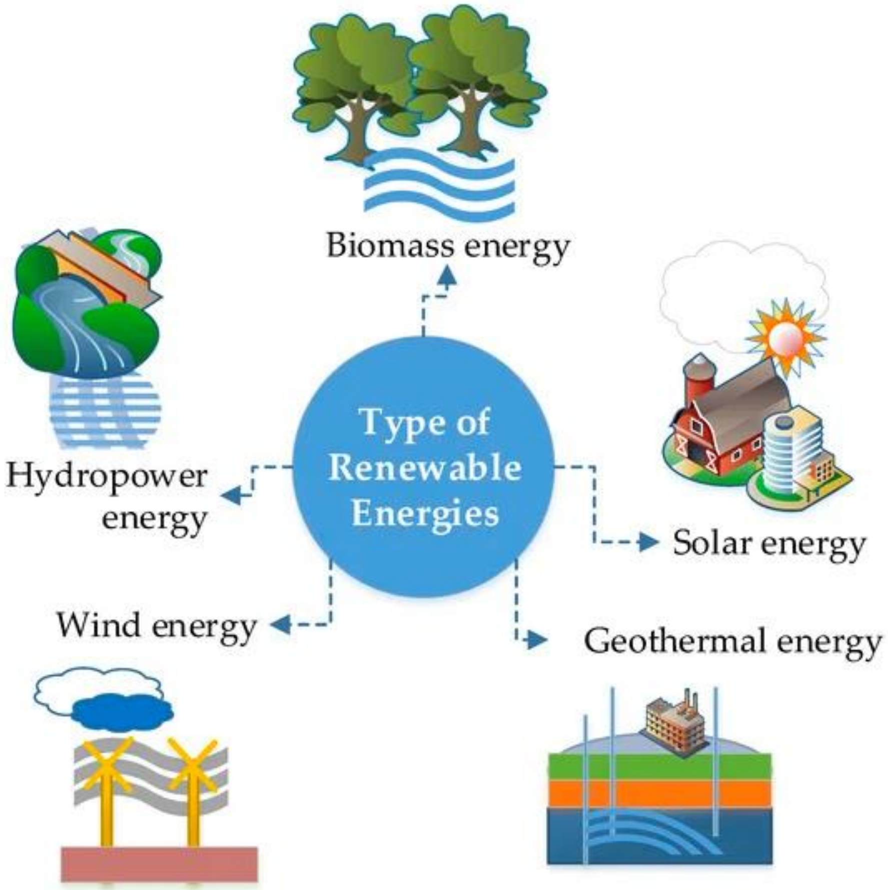

Figure 1: Types of Renewable Energies

Background: Solar Thermal

Collector Anatomy

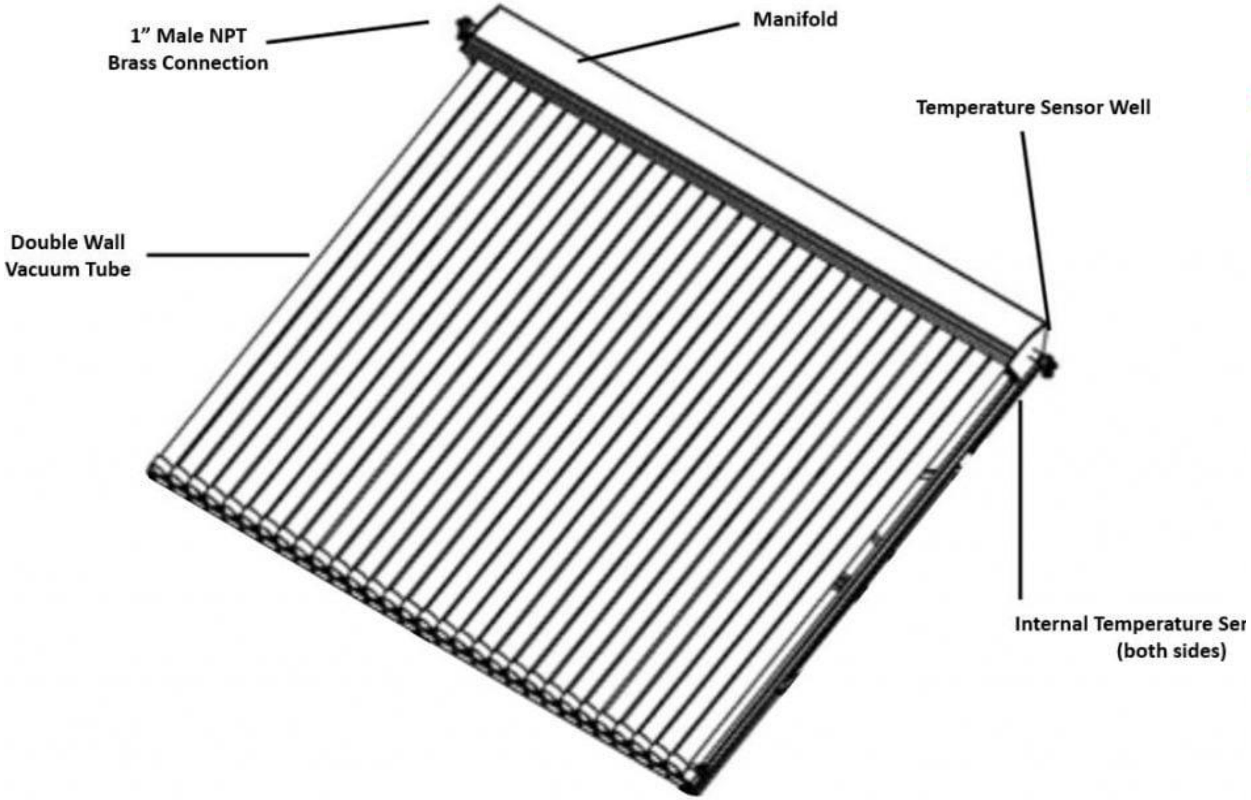

Figure 2: Collector Schematic

Evacuated Tube Mechanics

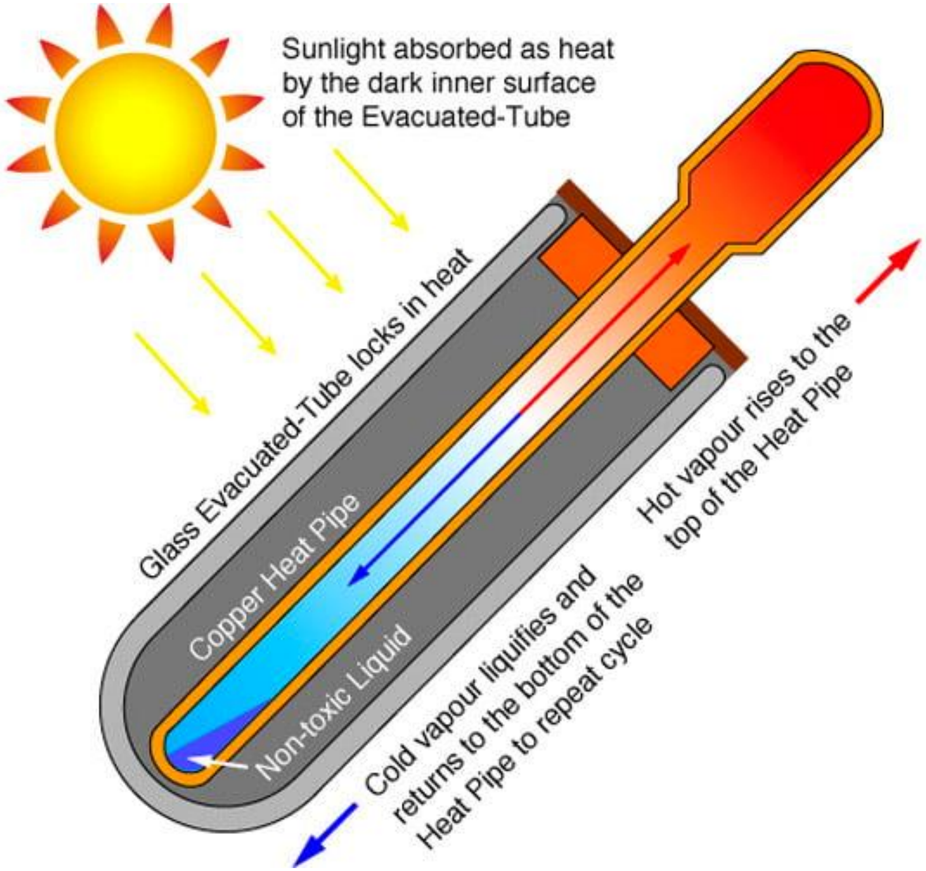

Figure 3: Evacuated Tube Schematic

Project Description

- Design an experiment to calculate the efficiency of the collector
- Build testbed for the experiment
- Compare expected and measured results
- Create a lab manual for the experiment
- Expose students to solar thermal concepts
  - Convective Heat Transfer
  - Efficiency Calculations
  - Economic Implication

Figure 4: Renewable Energy Lab Space

Design Requirements

Customer Requirements

- Design and create an experimental test bed housing an evacuated tube solar collector
- Write lab procedure for a new ME 451 lab
- Design an experiment to compare Reported v. Experimental Data from evacuated tube system
- Utilize Existing Evacuated Solar Thermal Collector
- Run the system as described in the lab procedure to have master set of data

Engineering Requirements

- System Failure Prevention
  - Freeze Protection (x2 Methods)
  - Steam Protection (x2 Methods)
  - No system leaks or fluid discharge
- Cost
  - Solar Thermal Capstone Budget target of $3083.55
- System Longevity
  - Contain system in covering, protected against weather and wildlife
  - Lifespan Target of 10 years
- Data Collection
  - Temp In, Temp Out, Flow Rate, Insolation
- Simplicity of Operation
  - Safe, general operation by 1 person.

Decision Making

- Types of Systems
  - Passive
    - Internal Storage
    - Thermosyphon
  - Active
    - Open Loop
      - Direct
      - Drain Down
    - Closed Loop
      - Drain Back
      - Antifreeze
- Consider…
  - Low Maintenance
  - Student Engagement
  - Seasonal Protection
  - Appropriate use of materials

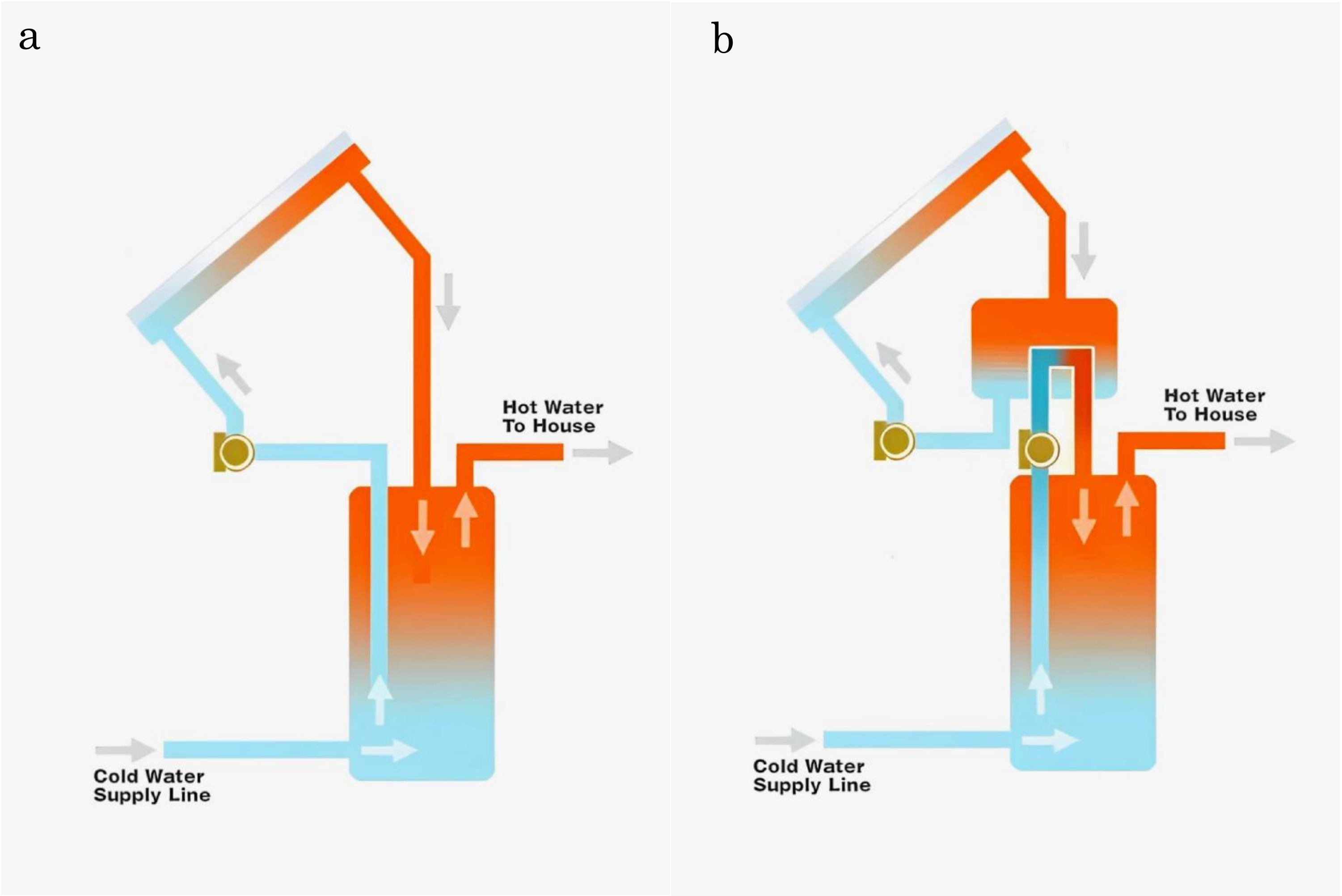

Figure 5: a) Direct Solar Thermal System b) Indirect Solar Thermal System

Preliminary Designs

Freeze Plug System

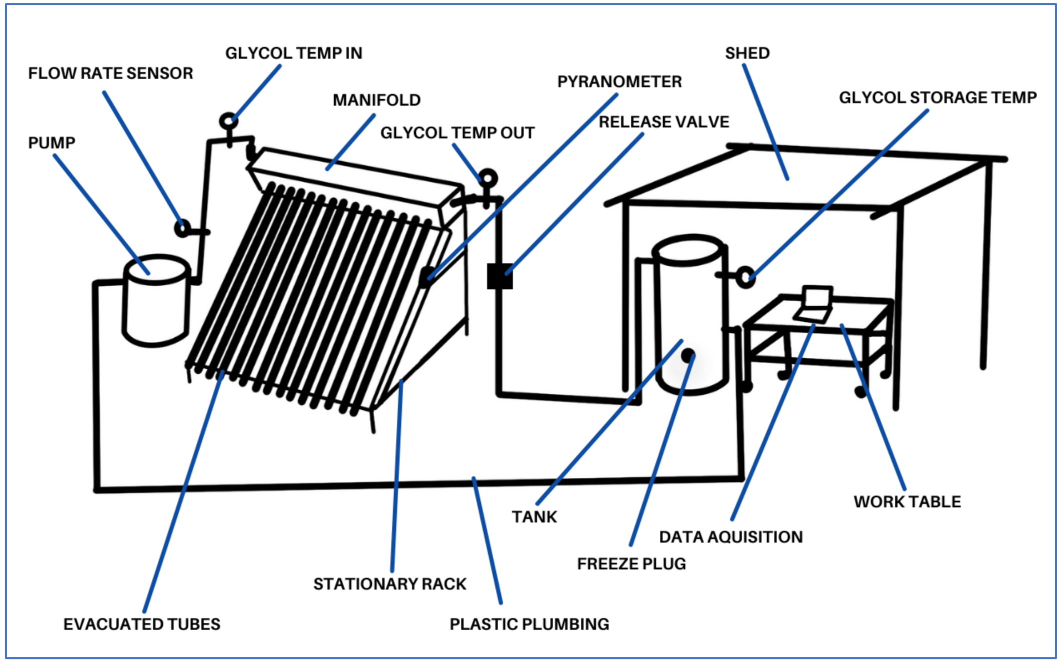

Figure 6: Freeze Plug System Sketch

Drain-Back System

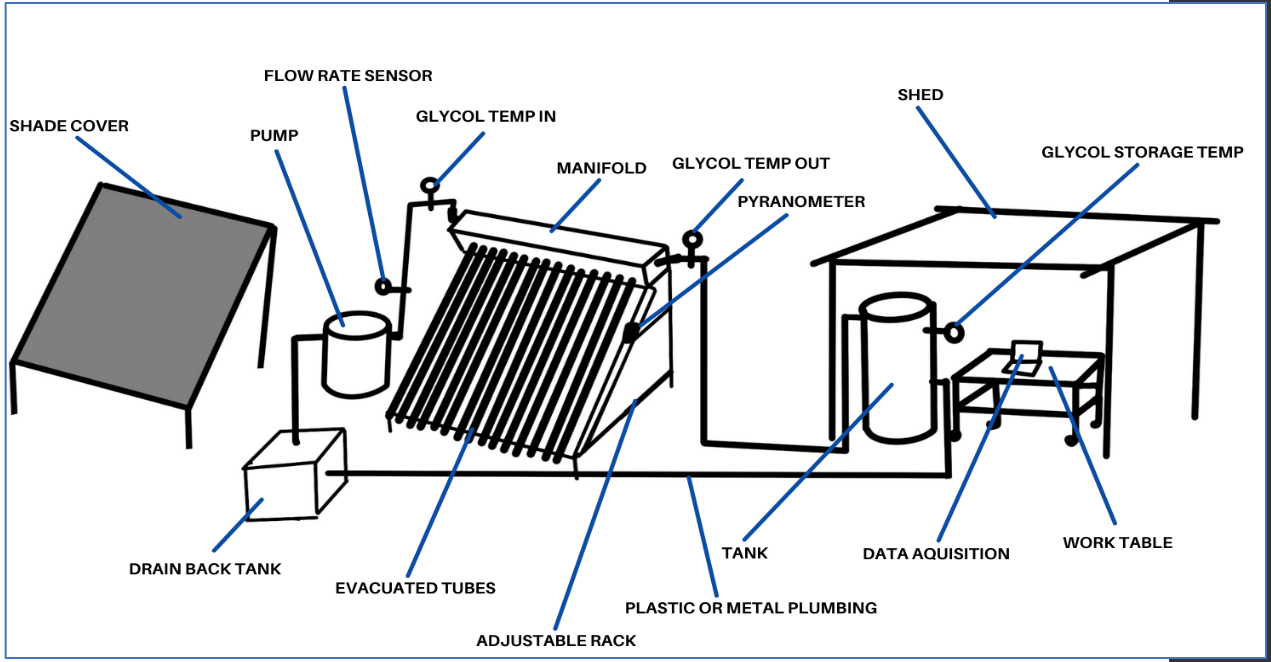

Figure 7: Drain-Back System Sketch

- Advantages
  - Inexpensive
  - Simple
- Disadvantages
  - Not adjustable
  - Less durable

- Highlights
  - Freeze Plug
  - Pressure Release Valve
  - All plastic plumbing

- Advantages
  - Adjustable
  - Durable
- Disadvantages
  - Costly
  - More complicated

- Highlights
  - Shade Cover
  - Drain-back System
  - Combination Plumbing

Design Iteration Semester 1

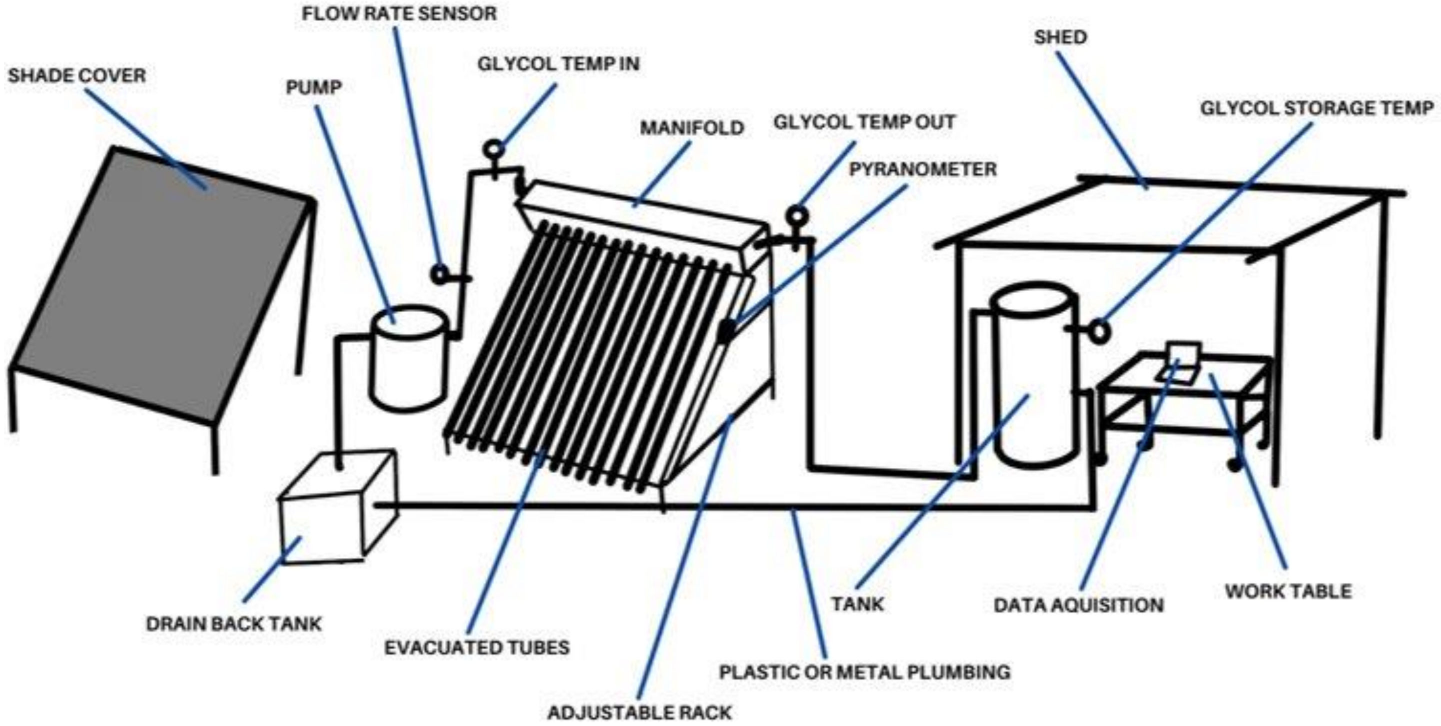

Figure 8: Semester 1 Design Layout

- Implementation
  - Drain back System
  - 2 methods of Freeze Protection
- Fluid is stored in a reservoir
- Pumped Through the Collector
- Manifold Heat Transfer Occurs
- Fluid Returns to Reservoir
- Temperature is tracked for analysis
- Need to measure Insolation (I), and Flow Rate (Q)

Design Iteration Semester 2

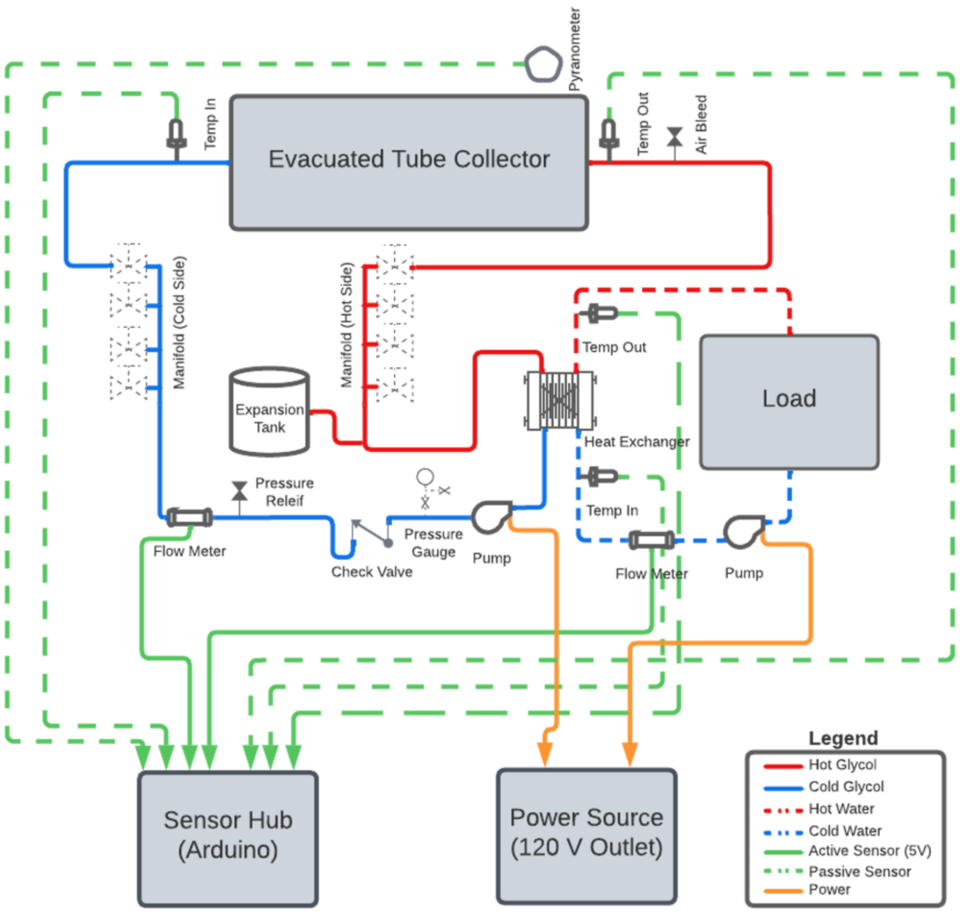

Figure 9: System Diagram

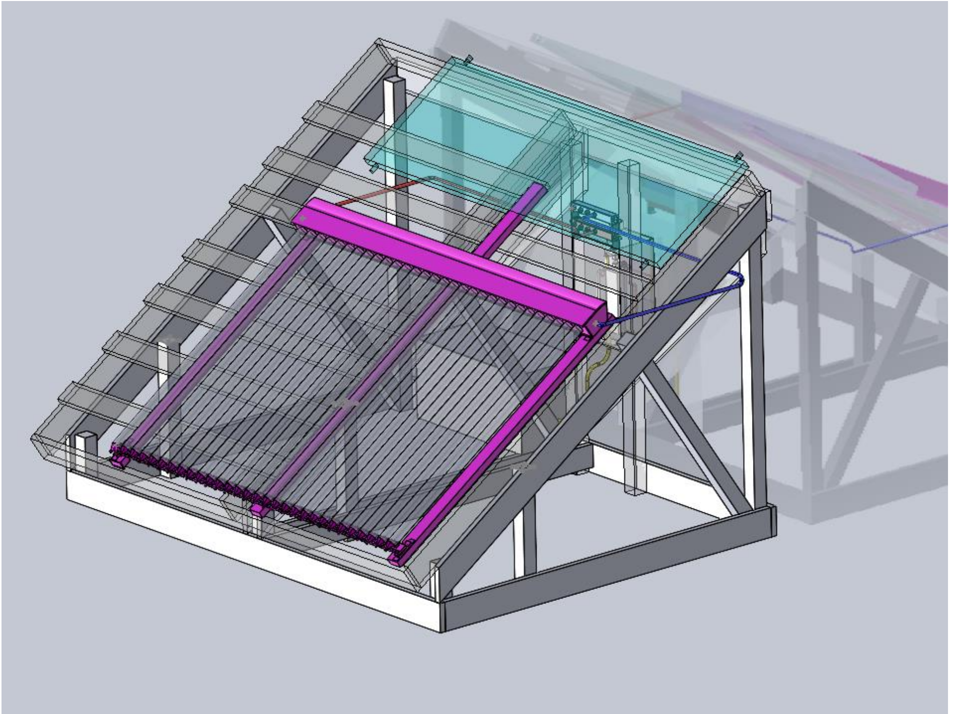

Figure 10: CAD Assembly

Manufacturing

Figure 11: Testbed Rack

Figure 12: Primary Components

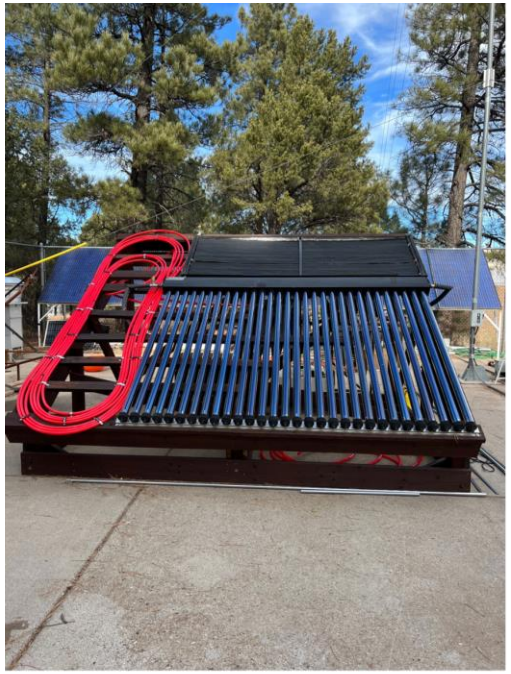

Figure 13: Full System

- Stage 1
- Rack Redesign and Assembly
- Aided by Prof. Carson Pete

- Stage 2
- Primary Component Layout and Installation

- Stage 3
- Final System Set-up and Testing
- Plumbing and Electrical

Top Level Testing Summary

- Leak Down and Pressure Test
  - Verifies System Operation
- Data Collection Check
  - Necessary Parameters are Measured and Accurate
- Efficiency Analysis and Comparison
  - Analysis can be performed, and Results can be validated

Table 1: Top Level Testing Summary

Test Number	Test Name	Relevant DR
T1	Flow Meter Calibration	CR3 ER4
T2	Thermocouple Calibration	CR3 ER4
T3	Leak Test	ER1
T4	Lab Run	CR1 CR2 CR5 ER4
T5	Verify Budget Constraints	CR4 ER2
T6	Confirm Primary Component Protection	ER3

Demonstration

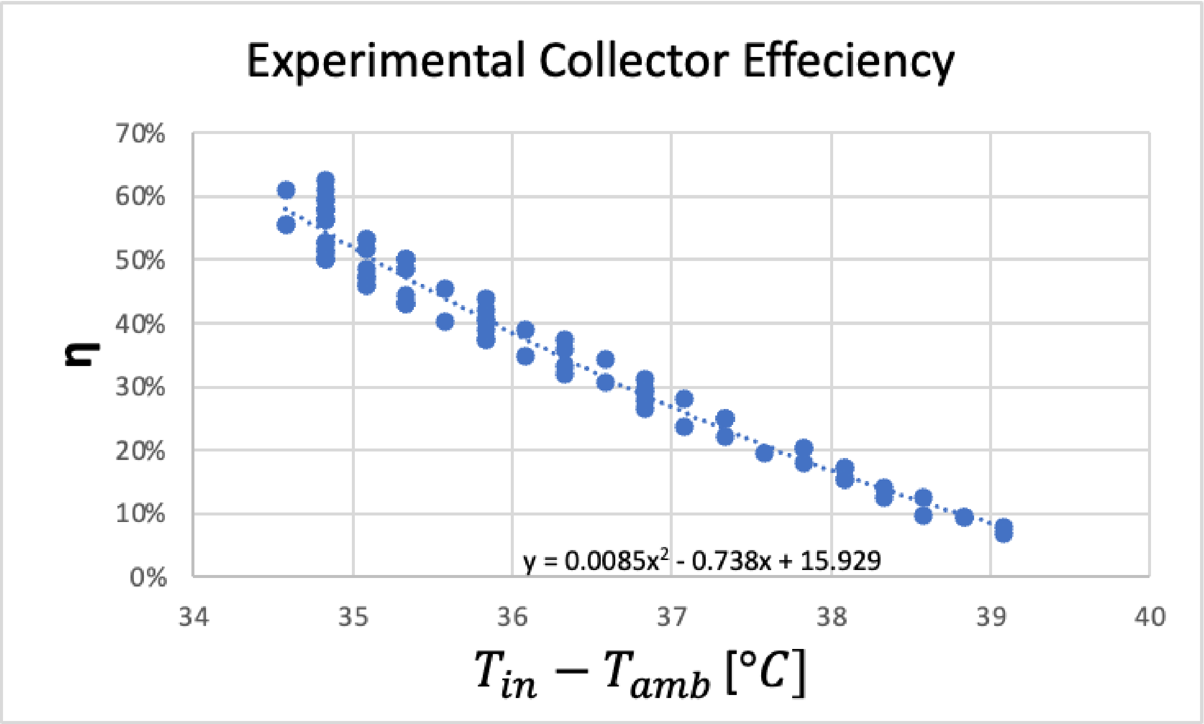

Figure 14: Experimental Efficiency Curve

Measured Efficiency Equation

$$\eta = 0.0085x^2 - 0.738x + 15.929$$

Manufacturer Efficiency Equation

$$\eta = 0.01611x^2 - 0.622x + 0.398$$

Results

- Test Data vs SRCC Data
- Sub optimal Test Conditions
  - Winter
  - Small Direct Sunlight Window

Specification Sheet

Table 2: Customer Requirements

Customer Requirement	CR met?	Client Acceptable
CR1 – Test Bed	✓	✓
CR2 – New Lab	✓	✓
CR3 – Efficiency Comparison	✓	✓
CR4 – Utilize Pre-owned Solar Thermal Collectors	✓	✓
CR5 – Base Data set	✓	✓

Table 3: Engineering Requirements

Engineering Requirement	Target	Tolerance	Measured/Calculated/Observed	Met	Customer Acceptable
ER1 - System Failure Prevention	2 Freeze, and Pressure protection methods	-26.1°F (50yr low) 40psi+/-10psi (half of maximum expected pressure	-30 °F 25psi	✓	✓
ER2 - Cost	$3083	+800*	$3109	✓	✓
ER3 - Lifespan	10years	+/-2years	25	✓	✓
ER4 - Data Collection	Uncertainty <10%	+/-5%	12%	✓	✓
ER5- Simplicity of Operation	1 Person Operable	+3 people	1	✓	✓

Andrés

Budget

Total Budget -

$ 3200

Cost Before Taxes and Shipping –

$ 2717.63

Cost After Taxes and Shipping -

$ 3109.30

Table 4: Budget Summary

Category	Cost
Data	$ 148.78
Electrical	$ 552.13
Fluid	$ 1,454.74
Rack	$ 480.85
Supplies	$ 81.13
Total	$ 2,717.63

Future Work

- Lab Variety Expansion
  - Collector Comparison
  - Angular Adjustment
- Analysis of Additional Collector Types
- System Performance Improvement
  - Reduce Thermal Losses
- Usage of Collected Energy
  - Expand to use heated water for other projects
- Adjustability Refinement
  - Improve Lifting and Support Mechanism
- Collect More Sets of Data
  - Spring, Summer, Fall

References

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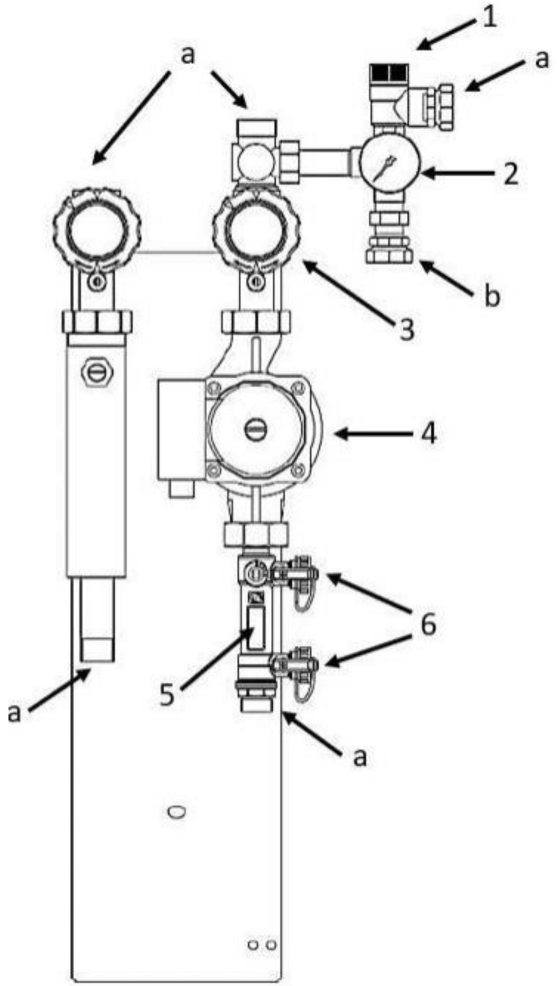
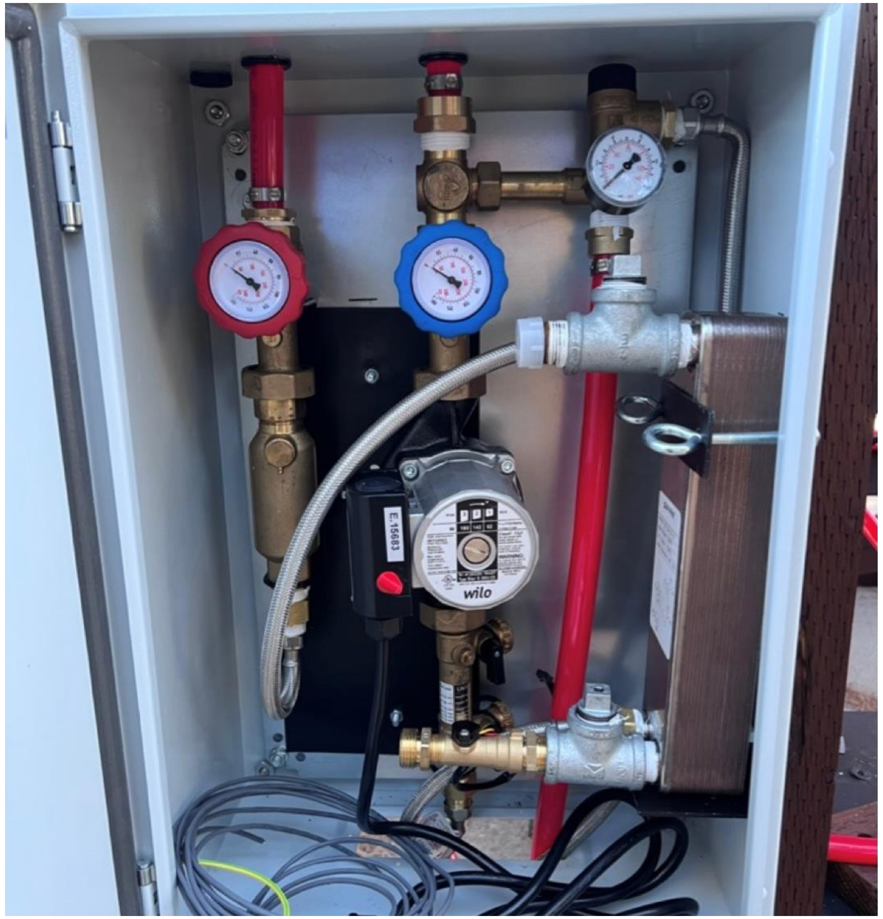
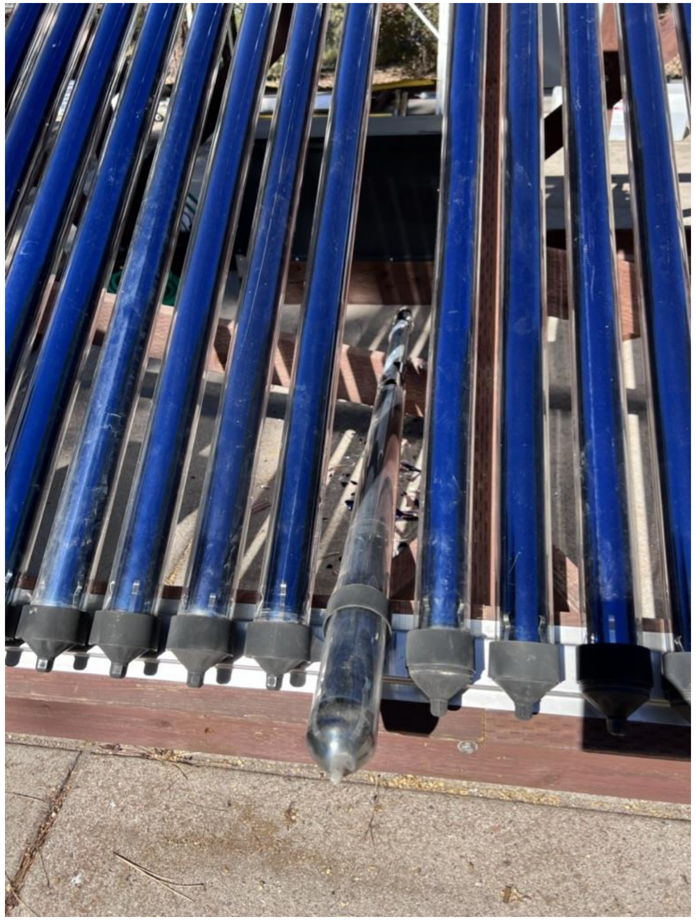
Pump Station

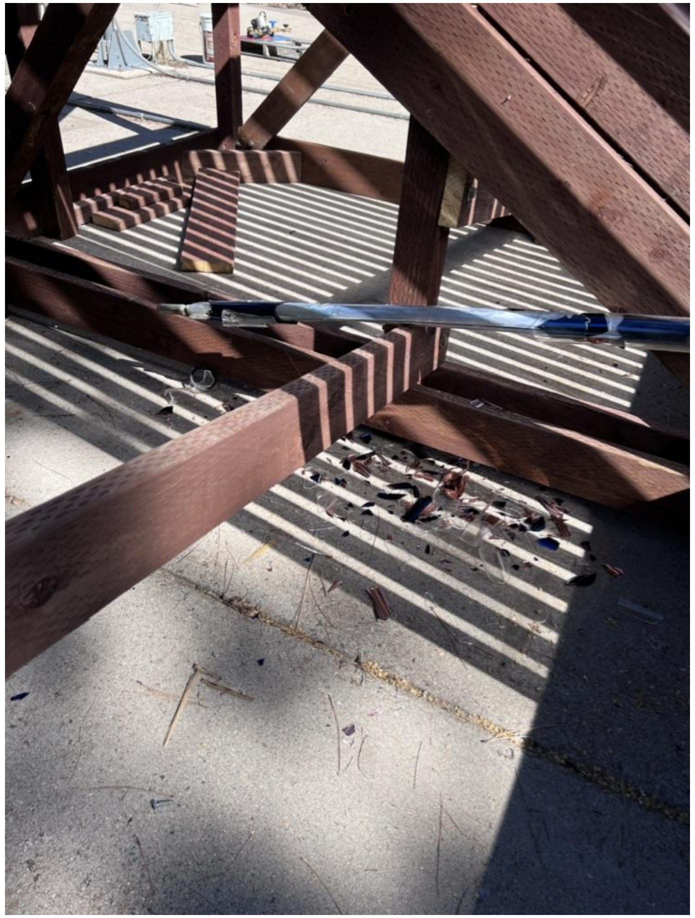




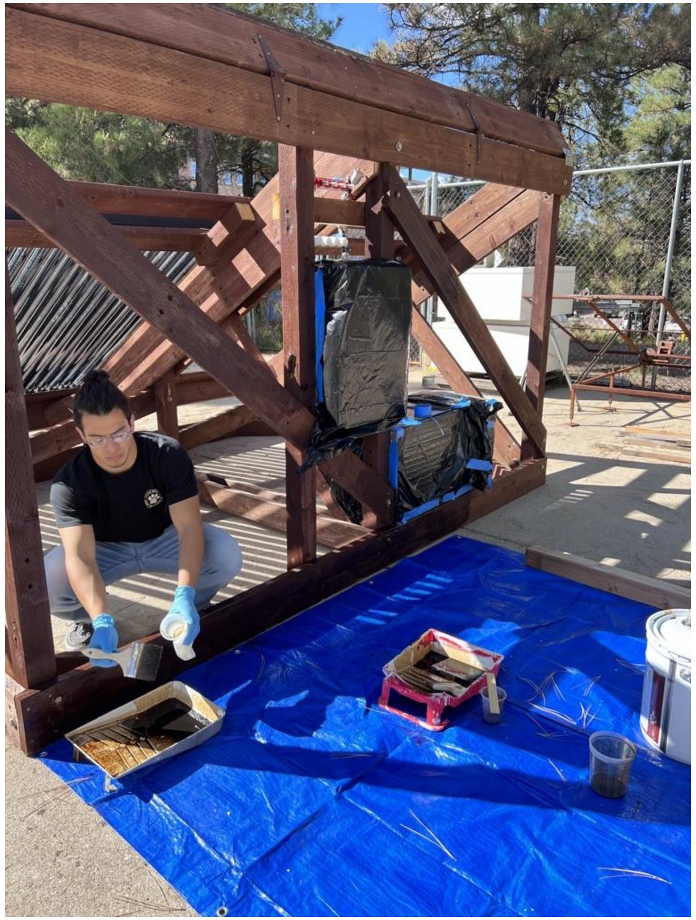
List of components
1) **Pressure relief valve**
2) Pressure gauge (145 psi / 10 bar)
3) Ball valve with temperature gauge in the return (320°F / 160°C)
4) Solar pump - UNIMAXX-PLUS-SC-S30-R
5) Flowmeter
6) Drain Valves
7) Ball valve with temperature gauge in the supply (320°F / 160°C)
List of connections
a) UniMaxx Quick Connect fittings: UNIMAXX-PLUS-SC-500-ADPT-3/4IN-CF (or 1IN-CF
b) Expansion tank fittings 3/4in GxNPT - XMAXX-HW-3/4IN-3/4IN-G-NPT

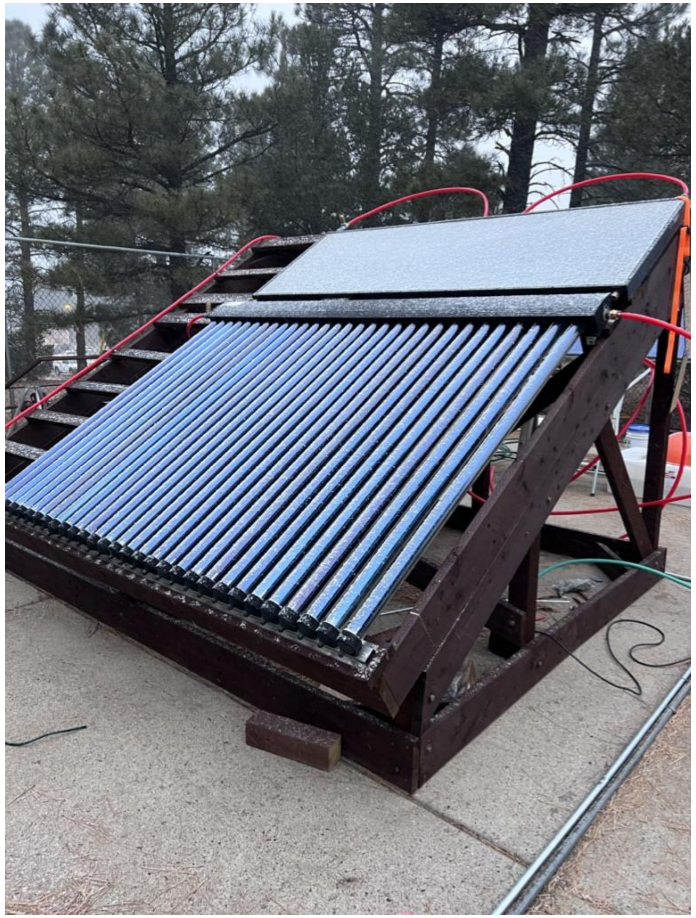
Mishaps





Staining





Efficiency Calculation

$$\eta = \frac{q''_{conv}}{q''_{rad}} = \frac{\dot{m} \cdot C_p \cdot \Delta T}{A_c \cdot I_c}$$

$\dot{m}$ = mass flow rate
C_p = specific heat capacity
ΔT = temperature difference cross collector inlet and outlet
A_c = gross area of collector
I_c = solar irradiance

Electrical Conduit