# RE Lab Solar Heater

# Finalized Testing Plan


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**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 [1].

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 a sufficient amount of 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 has a tight budget, provided with $500 by the client and requesting to raise another $500, bringing us to $1000. While $2000 was donated to fix the roof, this added budget does not reflect the cost of the system itself.

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.

**<u>Testing Summary</u>**

*Table 1: Test Summary Table*

| Experiment / Test | Relevant DRs |
|---|---|
| EX1 - Output Temperature | CR1, CR3, CR9, CR10, ER1, ER2, ER3 |
| EX2 - Output Flow Rate | CR1, ER4, CR9, CR8 |
| EX3 - Wind Loading | ER7, ER5, ER6, CR9 |
| EX4 - Continuity Test | CR8, CR9, ER3 |
| EX5 – Air Leak Test | ER6, CR9, ER2, CR4 |
| EX6 – Water Leak Test | ER7, ER5, CR4 |
| EX7 – Data Collection (for irradiance, wind speed, etc.) due to annual weather changes | ER7, ER5 |
| EX8 – Performance Test (building heat load) (ok not to beat cr) | CR1, CR10, ER5, CR8, ER6 |

**<u>Testing Plans</u>**

<u>EX1 – Output Temperature</u>

From our initial testing over the summer, we know that the solar panels can output sufficiently high temperatures (up to 170° F), however it is yet to be seen whether high enough temperatures can be maintained after the air is pumped through the long lengths of ductwork in the winter. This experiment aims to answer that question by measuring the output temperature of the indoor vents, rather than the panels themselves. This result of this experiment can be used to calculate the supplied heat load (CR1), and the experimental setup would require us to have a means of monitoring temperature (CR9) as well as confirming that the system can monitor itself and shut off before overheating (CR10).

To perform this test, we will need a Type T thermocouple (TC) and the equipment required to calibrate one (ice bath, hot plate for boiling water, RTD), as well as DAQ software and the hardware to run it. Although our finalized system will include a thermostat that can measure and report temperature, we do not have the means to calibrate it. Therefore, we need the TC simply to confirm that the thermostat is reporting accurate data.

In this experiment, temperature (°F) will be the isolated variable. From this result and the result of EX2 (below) we will calculate heat load (BTU/h) using the sensible heat formula, (BTU/hr)=CFM×ΔT×1.08.

The steps for EX1 are as follows:

1) Calibrate the TC using the RTD as the reference standard over three points of data (ice bath, room temperature, boiling water)
2) Securely place the calibrated TC at the output vent of the entryway to the RE Lab.
3) Using the DAQ software, record temperature data for all assumed daylight hours (9 am – 2pm)
4) Calculate results

EX2 – Output Flow Rate

During initial tests over the summer, the fans that were used were recycled and supposedly had a CFM of 190. However, they had spent an unknown amount of time outdoors and likely did not operate at the stated flowrate. The new fans that will be used are also rated at 190 CFM, but due to the many branching paths of our ductwork system, it is likely that this flowrate will drop significantly before reaching the output vents. Using a handheld digital anemometer provided by Dr. Willy will allow us to determine the output flowrates (ER4), as well as calculate the supplied heat load when combined with the result from EX1 using the sensible heat formula, (BTU/hr)=CFM×ΔT×1.08.

To perform this test, we will only need a handheld digital anemometer, supplied by Dr. Willy.

Air speed (ft/s) will be the isolated variable in this experiment. The calculated variables will be flow rate (CFM) heat load (BTU/hr).

The steps for EX2 are as follows:

1) While the fans are blowing air, hold the digital anemometer at the output vent
2) Record data for all 3 fans
3) Calculate flow rate using the speed and the cross sectional area of the ducts

EX3 – Wind Loading

Using the Weather Station Team's anemometers, we will be able to determine the maximum wind speeds at the RE Lab, which could differ from those we used in our calculations because of obstructions like surrounding buildings funneling the wind to more aggressive speeds. Determining the actual wind speeds at the RE Lab will allow us to determine the amount of wind loads the solar collectors will be experiencing. By comparing the peak gust speed measured by the Weather Station Team to the 120mph used to calculate the mounting system requirements, we can validate our mounting system's ability to withstand said speeds. The backup plan in case the weather station team does not have working instruments by the time of testing is to base an assumption and use the flagstaff airport's weather data. The isolated variable that will be measured is wind speed. The results that will be calculated are the wind loads on the solar air collectors on the roof.

To perform this test, the Weather Stations data or Flagstaff airports data will be utilized, and the variables will be plugged into our existing equations to determine wind load. The results we are looking for should be in the ballpark of our existing wind load calculations which is around 1,000 lbf of wind load that the solar air collectors will experience if the wind speed is 120mph. The equations that will be used is $F_n = Q \cdot s \cdot C_n$, $F_d = Q \cdot s \cdot C_d$, and $F_l = Q \cdot s \cdot C_l$. The data collected for wind speed will alter the dynamic pressure and using these equations and taking the root sum of squares allows us to calculate the wind load. Where Q is dynamic pressure, S is the module height (height of solar collector), Cn is normal force coefficient, Cd is the drag coefficient, and Cl is the lift coefficient.

<u>EX4 – Continuity Test</u>

A multimeter will be utilized by performing a continuity test on the circuits parallel network. This will be done with the system unplugged to find out if the circuit is complete or if it's open. The isolated variable will be voltage, and the expected result is that the circuit will be complete. To test that the circuit is complete, the 12V power supply from the PV solar panels will first be disconnected. Then the multimeter will be in continuity mode, and its leads will be connected to the output wires that run to both solar air collectors on the roof. The multimeter will signal us if the circuit is complete with a beep and will not signal if the circuit is broken. Diagnostics will be performed if the wiring circuit has a break in it to find out where the circuit is not fully connected. This will be done by visual inspection at the connection ports which include j-boxes and lug terminal blocks.

Steps for EX4:

1. Use multimeter to verify that the circuit is complete
2. If the circuit is not complete, troubleshoot the source of the break

<u>EX5 – Air Leak Test</u>

The purpose of this test is to determine whether air leaks are present within the solar air heating ducting and collector system. This will reveal if the system meets the standards of being sealed tight all around. The tools required will be a fog machine, air blower, and visual inspections. This is important because if there is air leakage then the system's efficiency will be affected. The primary variable measured will be air leakage visibility, identified by fog escaping from joints, seams, or fittings. From these observations, the leakage rate and potential loss in system efficiency will be estimated to evaluate how well the system meets design requirements for airtightness and thermal performance.

Steps for EX5:

1. Use nontoxic smoke at the inlet of the system
2. Monitor ducting and solar panel inlet and outlet for any smoke leakage

<u>EX6 – Water Leak Test</u>

Buckets of water will be moved to the roof and dumped across the mounting system and solar panels. During the process, points of possible leakage will be monitored to check for any water leaks. This includes lag screw mounting points, boot flashing, and solar panel cover plates. For this experiment, no calculations are required as this is a test of installation and refurbishing of solar panels. The primary question being answered for this is are there any leaks? Where are the leaks if there are any present? How will any possible leaks be fixed?

Steps for EX6:

1. Pour water over the entire external system
2. Monitor any points of possible leakage

<u>EX7 – Data Collection</u>

For this test, the team will reach out to the Weather Station capstone team to collect data for certain parameters such as solar irradiance, wind speed, and so forth due to annual weather change. This is important because the team aims to ensure that the product will last for a minimum of 10 years and no obstacles will obstruct its performance due to the environment. The team will also use Flagstaff Airport's weather website to obtain data collected for annual weather changes. Variables that need to be calculated are the amount of solar radiation the solar panels will absorb due to both annual solar irradiance and the angle the solar panels will be at. This will be calculated by using the equation $G_{abs}=\alpha G\cos(90-\theta)$. Other variables are wind load, weight of snow, and environmental factors that could pose a challenge for the project. Variables that can be ignored are convection from the surrounding air for the solar energy absorbed by the solar panels, the weight of snow is non-uniform, and wind speeds won't be random.

<u>EX8 – Performance Test</u>

Performance testing will establish energy input into the building. This will be done using a hot wire anemometer at the outlet of the ducting and using the time rate calculation based on the temperature input to gather the energy supplied. This will be done over the possible working period of the solar panels (i.e. when radiation is incident on the solar panels). The results will be in units of kW or Btu/h and be compared with the building heat load simulation completed earlier in the project. Based on the established customer requirements, the comparison should indicate that 30% of the total building heat load requirements are equal to that of the energy supplied from the solar panels. The following equation indicates how to gather the energy supplied in Btu/h. $(BTU/hr)=CFM\times\Delta T\times1.08$.

The data collection for this test will be the temperature output which will also be gathered from EX1 but will be collected over a selected period and noted to complete the calculation over however much time the system was operable.

Steps for EX8:

1. Take temperature data at the outlet using a hotwire anemometer
2. Temperature data collection done over constant interval
3. Perform calculation to gather energy supply
4. Compare with building heat load simulation

**Specification Sheet Preparation**

*Table 2: CR Summary Table*

| Customer Requirement | CR met? (Y or N) | Client acceptable (Y or N) |
|---|---|---|
| CR1: Reduce heat load by 30% | TBD | TBD |
| CR2: Must function during winter | TBD | TBD |
| CR3: RE energy as primary source | Y | Y |
| CR4: No major mods. To building | Y | Y |
| CR5: Safe and compliant with codes | Y | Y |
| CR6: Minimal Maintenance | N | N |
| CR7: 10yr payback period | Y | Y |
| CR8: Visual indicator for operating status | Y | Y |
| CR9: Monitoring system for temperature | Y | Y |
| CR10: Cannot overheat sys. or building | Y | Y |

*Table 3: ER Summary Table*

| Engineering Requirement | Target | Units | Tolerance | Measured / Calculated Value | ER met? (Y or N) | Client acceptable? (Y or N) |
|---|---|---|---|---|---|---|
| ER1: Energy Stored | 30 | kWh | +/- 5 | TBD | TBD | TBD |
| ER2: Efficient Insulation | 10 | R-Value | +/- 2 | 8-10 | Y | Y |
| ER3: Thermostat | TBD | W | +/- | TBD | TBD | TBD |
| ER4: Flow Rate | 180 | CFM | +/- 5 | TBD | TBD | TBD |
| ER5: Life Expectancy | 10 | Years | +/- 1 | 10-15 | Y | Y |
| ER6: Cost | 1000 | $ | +/- 200 | ~3000 | Y | Y |
| ER7: Mounting System | 20 | kg | +/- 10 | 11.4 | Y | Y |

**Results**

After conducting the eight experiments, the team expects the results to help guide the team's decision-making in the design of our product. By understanding certain circumstances such as the annual solar irradiance, wind load, snow fall, and so forth, the team can design the solar air system in such a way that weather conditions will not affect its performance in any way. Since the team plans to mount the solar panels on the roof, we want to ensure that it can remain stable and that environmental factors such as wind loads and snow fall won't render the system useless. And since the system involves two solar panels, the team needs to analyze the data for the annual solar irradiance so that the solar panels can collect enough solar energy, especially during shorter days of the year. We also want to consider other factors such as how much heat the fans will be supplying to the building, ensuring that there is no water and air leakage, and that the fans are working properly and operating at a steady flow rate.

**Conclusion**

The solar air heater project is aimed at designing and implementing a renewable heating system that uses refurbished solar air collectors to reduce the RE lab's reliance on non-renewable energy sources during the winter. Throughout this project, multiple experiments have been conducted to verify the system's performance, safety, and efficiency. We will continue to do testing for output temperature and flowrate to determine heat delivery, a wind loading test to ensure the mounting system can withstand Flagstaff's weather, and a fog test to confirm the system is airtight. Additional tests include water leakage, data collection with the weather station, and overall performance will show the efficiency and reliability of the systems' durability and energy output under environmental conditions. These experiments are designed to ensure the system meets the design requirements, airflow, insulation, cost effectiveness, and safe conditions. Overall, this project provides a model that is looking to meet its requirements of maintaining efficient heat over the winter months.

**References**

[1] Standards and guidelines, https://www.ashrae.org/technical-resources/standards-and-guidelines (accessed Oct. 26, 2025).