To: Dr. Sarah Oman

From: Drew Bandhauer, Drake Cleveland, Cole Jennings

Date: 9/25/20

Subject: Implementation Memo

The NAU Solar Thermal capstone team has been working to implement a solar thermal heating system on the Engineering building in order to reduce campus's natural gas demand. The building is currently heated from using high temperature hot water, which is supplied from the south campus heating plant. Because the building is already heated by water, the team is looking to find a way to utilize solar thermal energy to heat the buildings water and reduce the natural gas demand.

The team started by reviewing the Customer Requirements and developed a list of Engineering Requirements. The team was very optimistic about fully achieving these requirements early in the project, but there was a lot more to consider than originally thought. The team began gathering more information, such as determining the parameters by which the building currently operates and specifications of potential solar thermal panels. Using the building's natural gas consumption charts, the team was able to figure out the amount of heat the building required for each day of the 2019 year. The team's goal was to be able to provide the building with the highest heat demand from the 2019 year, which was 1.4MMBTU/hr. The charts show a spike around 5am when the building is turned on and then decreased during the sunny parts of the day until late at night when the building shuts down.

Looking at previous projects similar to this one, the team took away the need to implement a security device in the case of too much heat. The HLC project failed due to this, so the team was sure to include an exterior heat exchanger in the design to dissipate excess heat. The initial heat generation calculations made the team optimistic about the design's potential. The team even considered possible ways to store extra heat, looking at a basement heat tank that would help with the morning surge.

The team used solar irradiance resources such as the Solar Redbook and System Advisory Model to get a better idea of heat generation we can expect. Both resources use collected irradiance data from the past. The Solar Redbook gives the measured solar irradiance at the edge of the atmosphere. This was initially used in the back of the envelope calculations. The results of these calculations gave the team a false sense of optimism, as this method turned out to be incorrect. The team then switched to the System Advisory Model to develop an estimate of the return. The System Advisory Model is an NREL program that approximates the return of different forms of renewable energy systems specific to that location. This program includes many different parameters to give the most accurate approximation of the return. This program estimated a significantly smaller return.

If the return given by the System Advisory Model is correct, the design is simply not feasible with the current price of natural gas. The design will not pay itself back within 20 years, let alone 5 years. The team's current experiment was designed to show exactly what the return will be. Proposing a design to the GreenFund without concrete evidence of the returns would be extremely shortsighted with the expected price of implementation. The experiment will show the true return we can expect from the design and give the team factual evidence to propose to the GreenFund. The team is currently finishing up the experimental setup and will run the test as soon as possible.

1 Customer Requirements (CRs)

Implementing a system of this magnitude to the engineering building is going to be costly. The NAU GreenFund has conditionally agreed to provide the funding for this project as long as the design pays itself back within 5 years. This will be tricky because the cost of natural gas is so low and the expected cost of implementing this system is likely to approach $1 million. As the cost of natural gas increases, the impact of the design will increase as well. This cost may also consider the social cost of carbon footprint which accounts for the overall cost of harmful carbon emissions by an entity such as the university. This cost is estimated to be nearly $50.00 per ton of carbon emissions, and will be calculated in comparison between current carbon emissions by the building and the offset after implementation.

Carbon neutrality is essentially the driving factor of the project and relates to every other customer requirement as this is likely to be the largest contributor to paying the project back in the desired 5 year span. It also provides reasoning for interrupting the current system as the current system does not have any significant problems aside from carbon emissions. In attaining this goal, the building must also be heated by the new system year-round to offset carbon emissions by any allowable amount.

2 Engineering Requirements (ERs)

The engineering requirements depicted below provide information pertaining to numerical and designable criteria for each customer requirement. They allow the team to clearly identify the criteria for which they need to design around and by how much they may miss the desired amount. These requirements include the energy output through the solar system, the temperature change though the solar system, and the flowrate through the solar system, along with tolerancing for each requirement.

2.1 ER #1: System must provide 150GPM flow rate

2.1.1 ER #1: Provide 150GPM flow rate - Target = 150GPM

A flow rate of 150GPM is what the building currently runs, so keeping near that would be ideal. However, changing the flow rate may be necessary with varying levels of sun. A range between 135GPM and 165GPM will keep the system in check. The relationship between flow rate, temperature change and heat generation is shown below:

$$Q_{Generation} = \dot{m} C_p (T_{out} - T_{in}) \qquad (1)$$

This is a governing equation for this project and will be used to calculate any unknown variable given initial parameters.

2.1.2 ER #1: Provide 150GPM flow rate - Tolerance = +/- 15GPM

A tolerance of 15GPM allows for the system to reach its full potential of 150GPM, while having a worst case scenario of 135GPM. 135GPM would still cut the natural gas demand of the engineering building by 80%, compared to the current system. The flow rate is best kept constant, as changing the building flow rate so that the design can catch up will likely result in more problems than answers. Keeping a sufficient flow rate is imperative to the success of the design. It is much easier to call for more heated water from the heating plant than it is to slow the flow rate of the whole system.

2.2 ER #2: Temperature change of 40℉ through system

2.2.1 ER #2: Temperature change of 45℉ - Target = 45℉

The building is currently heated by an internal hydronic loop with an inlet water temperature of 100℉. The water passes through a heat exchanger in the basement, where heat is transferred from the high temperature hot water supply to the building's water supply. The water leaves the heat exchanger at 140℉ and a flow rate of 150GPM. This flow rate is changed to provide more or less heating throughout the building. Varying flow rate will result in a higher or lower temperature change.

2.2.2 ER #2: Temperature change of 45℉ - Tolerance = +/- 5℉

The Engineering building's heated water supply needs to be at least 140℉ to heat the building with a flow rate of 150 GPM. The tolerance exists to keep the flow rate within an acceptable range. Slowing down the flow rate will result in a higher temperature change, and vise versa. A temperature change between 40 and 50 will keep the flow rate in an acceptable range.

2.3 ER #3: System must provide .8MMBTU/hr

2.3.1 ER #3: Provide .8MMBTU/hr - Target = 1MMBTU/hr

This requirement was created by examining the natural gas demand of the Engineering building. The building had a peak daytime demand of 1.4MMBTU/hr in 2019. If the design can provide this amount of heat, this is the best case scenario for this project. The heating plant will need to jumpstart the building in the morning when there is no sun, and the design should supply the rest.

Covering the entire amount would be perfect in the winter, but will make the building unbearable in the summer. Aiming for 1MMBTU/hr would drastically decrease the natural gas demand yearly, and is in the sweet spot for an acceptable amount of heat for both winter and summer. The remaining required heat can be supplied by the heating plant during the winter months, and the excess heat can dissipate through an exterior heat exchanger during the summer months.

2.3.2 ER #3: Provide .8MMBTU/hr - Tolerance = +/- .2MMBTU/hr

While the team would've liked to completely heat the building with the design, the calculations don't back up the teams aspirations. It has become necessary to face the fact that the design can't possibly work as well as the team wanted it to. Lowering the target to this value will also change the layout of the design, as .8MMBTU/hr will not be enough to heat the building by itself and will require a change in design.

3 Design Changes

From the beginning of the project, the design was going to go one of two ways: work in series with the building heating or in parallel with the building heating. A design in parallel was the ideal option as the water heated from the design would directly heat the building. If the design could produce close to the building's required heating, the team would move forward with implementing it in parallel. However, with lower heating projections from solar irradiance models than expected, the team is likely going to move forward with a design in series with the building heating. Instead of heating the building directly, the design will act as a preheater to the heat exchanger and lower the natural gas demand that way. This design is subject to change after testing of the attained test panel to determine temperature change and energy output through one panel with Flagstaff's conditions. Figure 1 below depicts the panels in our ideal parallel output, while figure 2 below depicts the panels in our anticipated series output.

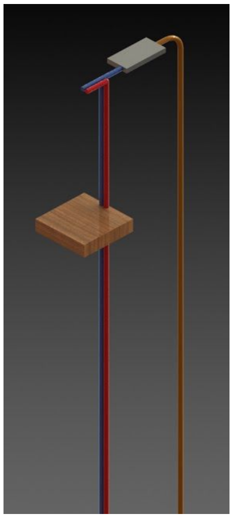


Figure 1: Parallel Design

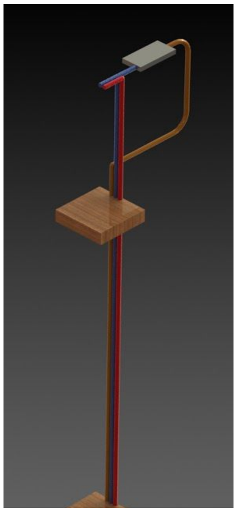


Figure 2: Series Design

The design has not encountered much alteration as implementation for the design is already functional, the team simply has to wait for test results to determine how many panels are needed in the array for functionality. This testing has been halted multiple times by external sources but will likely provide necessary information in the coming weeks and as such allow the team to complete design and await implementation. The testing mount has not changed in design much other than reinforcements in joints (not pictured) and a central beam to attach a pyranometer above the panel to achieve irradiance measurements at the panel. The design of the panel is pictured below in figure 3.

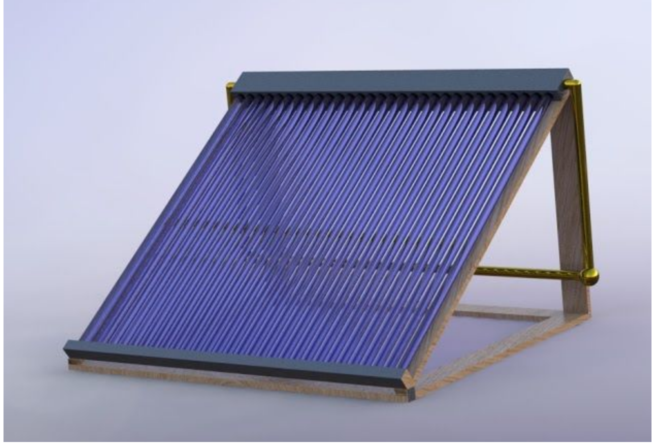


Figure 3: Testing Mount

4 Future Work

Throughout the remainder of the design process, the team will establish the amount of panels needed in series and parallel based on the testing results. Once this configuration has been determined, the solar system will easily be integrated into the current design to act in series or parallel with the existing heating system. All accommodations for this implementation are already designed.

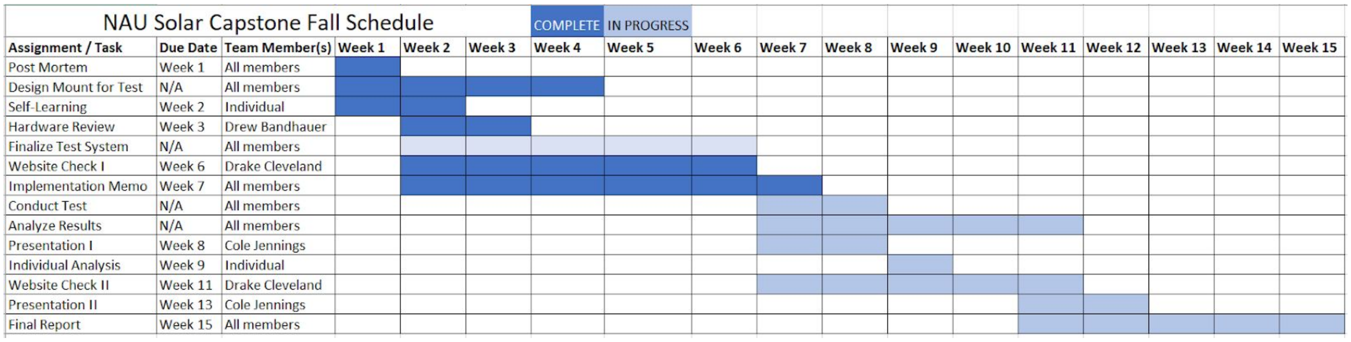
4.1 Further Design

Implementing this system will not be completed by the team due to liability issues with the school and solar panel manufacturers. Once financial feasibility has been determined, the school will determine whether the system will be integrated at a later date and does not include the team's input. It is likely the design will not meet the school's financial requirements, and will not be integrated until the financial requirements are met when natural gas prices and carbon emissions prices rise..

4.2 Schedule Breakdown

The team has been closely following the Capstone schedule for the Fall semester. A Gantt chart, shown in Figure 4 below, has allowed the team to keep track of the tasks at hand and their completion. The team has mainly been working on the project and its assignments collectively with equal contribution to avoid any members not contributing, while some assignments were assigned to one person, with the other two being able to contribute and finalize the assignment.

The Gantt chart gets updated regularly to indicate the completion of each assignment and task the team has to complete. Currently, the team is in the process of finalizing the testing system so the test can be conducted. In trying to conduct the test, the team found small problems with fittings for the panel as well as issues with water supply in the Engineering building. This is the current task the team is working on and it will allow them to proceed with the analysis of the data from the test, which will result in the final proposal for the solar system being implemented on the building. While the team's goals have had to change over the course of the last two semesters, the team is optimistic that the results of the test will lead to a successful proposal that can complete the original objectives of the Capstone project.



NAU Solar Capstone Fall Schedule

■ COMPLETE ▨ IN PROGRESS

Assignment / Task	Due Date	Team Member(s)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Post Mortem	Week 1	All members	■														
Design Mount for Test	N/A	All members	■	■	■	■											
Self-Learning	Week 2	Individual	■	■													
Hardware Review	Week 3	Drew Bandhauer		■	■												
Finalize Test System	N/A	All members		░	░	░	░	░									
Website Check I	Week 6	Drake Cleveland		■	■	■	■	■									
Implementation Memo	Week 7	All members		■	■	■	■	■	■								
Conduct Test	N/A	All members							▨	▨							
Analyze Results	N/A	All members							▨	▨	▨	▨	▨				
Presentation I	Week 8	Cole Jennings							▨	▨							
Individual Analysis	Week 9	Individual									▨						
Website Check II	Week 11	Drake Cleveland							▨	▨	▨	▨	▨				
Presentation II	Week 13	Cole Jennings											▨	▨			
Final Report	Week 15	All members											▨	▨	▨	▨	▨

Figure 4. Gantt Chart