NAU Solar Thermal Capstone

Preliminary Proposal

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1 BACKGROUND

1.1 Introduction

Our team has been tasked with developing a solar thermal heater of a hydronic loop running through the engineering building on NAU's campus. The solar panels will be utilized alongside a boiler's HTHW line to provide heating to the engineering building. Upon completion, the carbon footprint of NAU's campus will be reduced, working in accordance with the goals of the project's sponsor: NAU's Green Fund. These solar panels have the potential to not only reduce the carbon footprint of the campus, but also lower the cost required to run the natural gas boilers, thus lowering the long-term costs of natural gas. Assuming this solar system works to our anticipated standards, similar systems will be implemented on multiple other buildings on campus, overall reducing the carbon footprint significantly, aiding in the prevention of the current global warming crisis.

1.2 Project Description

As designated by the sponsors of this project, the team is tasked with the following.

> "NAU is committed to lowering our impact on the local and global environment. The University community is currently undergoing a process to create an updated Climate Action Plan, with the primary goal of becoming carbon neutral while remaining financially sustainable as an institution. While our electricity loads could be met with renewable grid electricity, renewable heating is a bigger challenge. Most campus operations use centralized natural gas boilers to generate steam (North Campus) or high temperature hot water (South Campus). This high thermal energy fluid is then pumped to different buildings around campus where it passes through heat exchangers to transfer the thermal energy to secondary building hot water loops (hydronic loops)."

In summary, in accordance with NAU's goal of becoming carbon neutral and initiating their Climate Action Plan, the team must attempt to solve renewable heating, in this case through solar panels to offset the load to the central boilers.

1.3 Original System

The team's design will be implemented supplementally to the existing hydronic loop in the engineering building. The current heating for the engineering building utilizes a series of heat exchangers and water lines. Initially, a high temperature hot water (HTHW) line runs into the basement of the engineering building from external boilers. This HTHW line runs through a heat exchanger to heat the internal hot water line which runs through the school. This internal line runs through each floor via a pump in the basement, and is pumped to other heat exchangers in each room which transfer this heat to the air through another coil.

1.3.1 Original System Operation

The existing boiler system and HTHW line offsets an overall load of approximately 1.3 MMBTUs and a temperature change of 10℉, producing a supply temperature of 140℉ with a return of 130℉. The pump in place already utilizes a flow rate of 150 gallons per minute (GPM) and 50 feet of head. The energy consumption by the building follows the trend depicted below in figure 1; spiking to around 2 MMBTUs at 5AM, then stabilizing at around 1.3 MMBTUs between 8AM and 11PM before dropping down to zero at the end of the day.

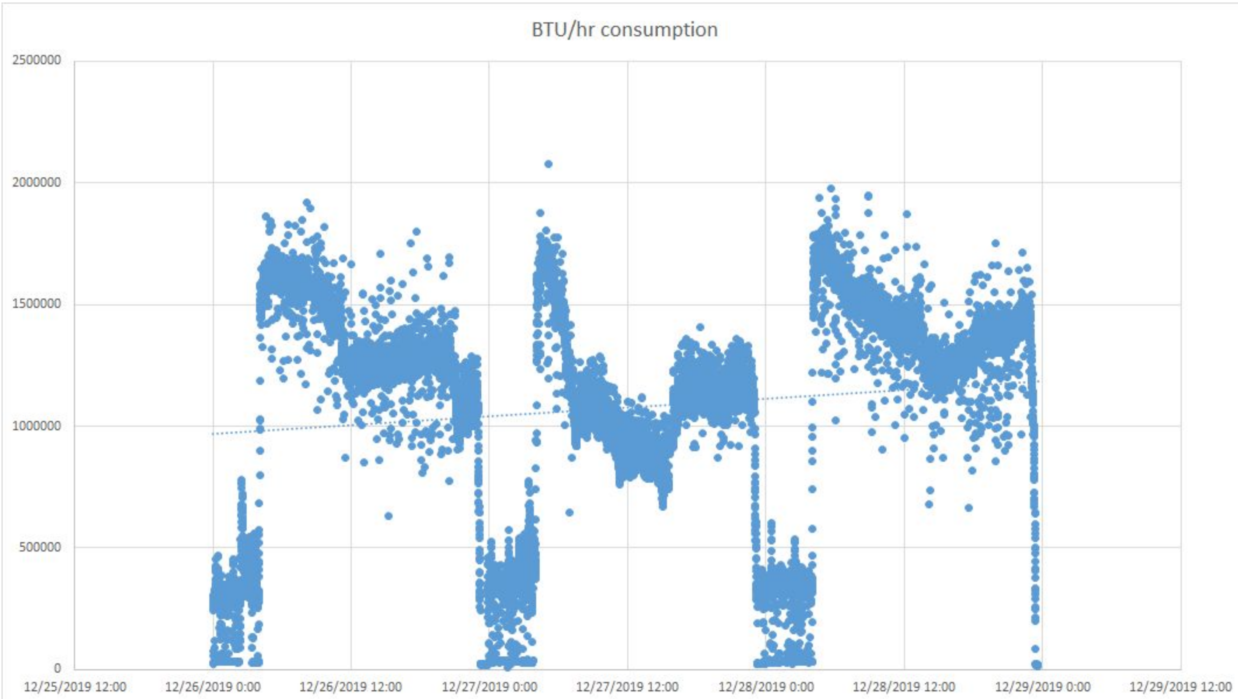

Figure 1: Demand by the engineering building in BTUs/hr

2 REQUIREMENTS

2.1 Customer Requirements (CRs)

The requirements denoted in the project statement include lowering the overall carbon emissions by the university, cost effectiveness, current-system integration, and self-sustainability. NAU's GreenFund and Climate Action Plan strive to lower the university's effect on global carbon emissions, and as such our team has been tasked with aiding this goal. As such, we must design a solar thermal heating system to reduce the demand for the boiler systems currently in place without completely redesigning the hydronic loop of the building. Finally, the solar panels must offset enough of the building's energy demand to run throughout the day using only heat generated by the solar panels.

2.2 Engineering Requirements (ERs)

In order to offset the demand by the central boiler system, our team had to analyze the current demand and consumption trends. Throughout the daytime of the year's lowest solar irradiance, an average of 1.4 MMBTUs/hr is required, and as such this is the target for the solar system being designed. Similarly, in accordance with the current pumps and hydronic loop, a temperature change of 40℉ must be designed for with a return of 100℉ and a supply of 140℉. The pumps operate at 150 GPM which must be matched and achieved through the solar panels to be designed for without reducing the head by the pumps in place.

3 DESIGN SPACE RESEARCH

Research was conducted by the NAU Solar team to understand the current approaches used for similar heating systems. The following chapter details the findings of the research conducted by each member of the team as well as a State of the Art review regarding similar heating projects the group has seen.

3.1 Literature Review

3.1.1 Student 1 - Cole Jennings

For this project, Cole is focusing on developing a system of solar panels that will heat a mixture of water and glycol, which will be distributed to the heat exchanger then to the heating system within the building. To properly configure this system, it is necessary to obtain information regarding what types of panels are sufficient for the given situation, what aspects of solar panels contribute to their flow rate and the temperature of the heating liquid, and the potential cost of the panels along with their installation and maintenance costs. The following section details the sources used to obtain the needed information.

The first source used to develop an understanding of solar panel functions was the Plumbing Schedule document for the solar system installed on the Health and Learning Center of NAU's campus. Shown below is a portion of the document that contains information regarding the solar collection by the solar panels installed.

SOLAR COLLECTOR SCHEDULE										
TAG	SERVICE	LOCATION	TYPE	EFFECTIVE SURFACE AREA (SQ. FT.)(EACH)	COLLECTOR OUTPUT BTU DAY	PANEL FLOW RATE (EACH)	SIZE WIDTH/ LENGTH (IN)	MANUFACTURER	MODEL NUMBER	NOTES
SC-1	DOMESTIC HOT WATER	ROOF ZONES C&D	EVACUATED TUBE	58	6,364,800 (102 PANELS)	.84 GPM	88X49	SILICON SOLAR INC.	SUNMAXX-30	1

Figure 2. Solar Collector Schedule, HLC Solar System

This particular schedule within the document was used to develop an understanding of typical production of solar panels as well as to determine the feasibility of using the same panel model as used in this project. Using the given flow rate (0.84 GPM) and size (88" x 49"), the team was able to develop an idea of the feasibility of using these panels for the NAU Solar Capstone project.

The team used an additional source as a guide that is titled Central Solar Hot Water Systems Design Guide. This document details many different aspects of solar heating systems. For the investigation regarding panels and their functions, section 3.2 "Types of hot water solar systems" outlines different potential solar collector designs.

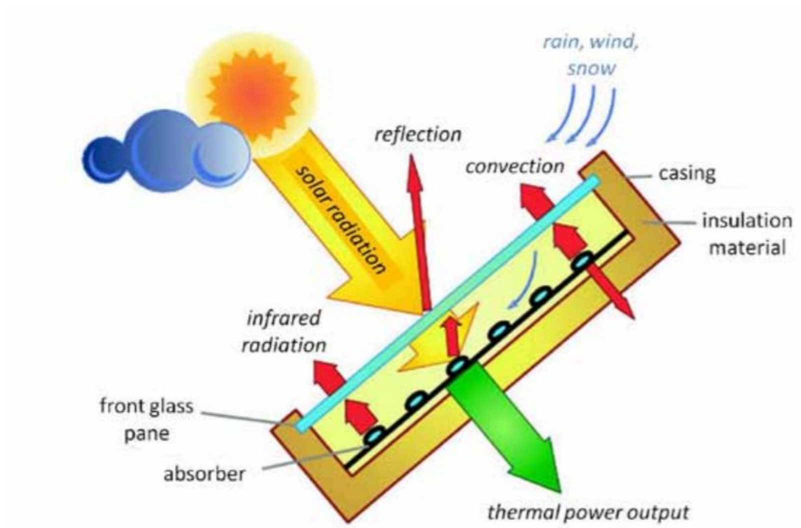

Figure 3. Schematic of Flat Plate Collector

The team selected a flat plate design due to its fit within the given situation. In this design, the team will install these flat plate panels and connect them within a configuration of pipes which contains the water glycol mix.

An additional source used is in the form of a patent for a system of parallel and virtual parallel connections of solar panels. The team was looking to develop an understanding of how flow rate and temperature can be most efficiently maximized via the connections of the solar panels.

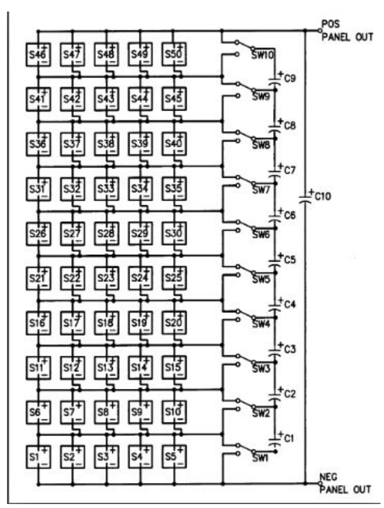

Figure 4. Panel Configuration in Patent US7521630B2

This specific patent is applicable to the project due to its detailing of how parallel connections can impact the performance of the system. The team plans to use patent US7521630B2 in its configuring of the solar panel system. Figure 4 above is an example of one configuration and the basic connections used in the system.

The fourth source for the investigation of solar panels is focused on the optimal slant angle for solar flat plate collectors with respect to the sun in attempt to capture the most sunlight. The team was previously aware of some factors that would affect the optimal angle, however, this case study provides specific examples of what aspects need to be analyzed. This case study is relevant to this project because the team needs to account for the surrounding environments of the engineering building, which include other buildings and taller trees that could obstruct the panels' amount of sunlight. The team plans to use the calculations conducted by the case study to optimize the angle of tilt for the panels.

The team found another source that analyzes the heat transfer throughout a particular type of solar panel. This is relevant because the team will need to understand the heat transfer of the system to ensure the flow rate of the mixture is sufficient to heat the building. The team will use this source as a guideline for heat transfer calculations and for understanding how the temperature and flow rate will be affected by the type of panel that will be used

3.1.2 Student 2 - Drew Bandhauer

Drew's main focus for this project involves the piping, pumping, and layout of the design. First, Drew must understand how the current piping system is laid out and where the best places to tap into the piping are. The first source used to do this are the mechanical piping plans for the entire building. These show where every supply and return line is and how they run. The first floor mechanical piping plans are depicted below in figure 5.

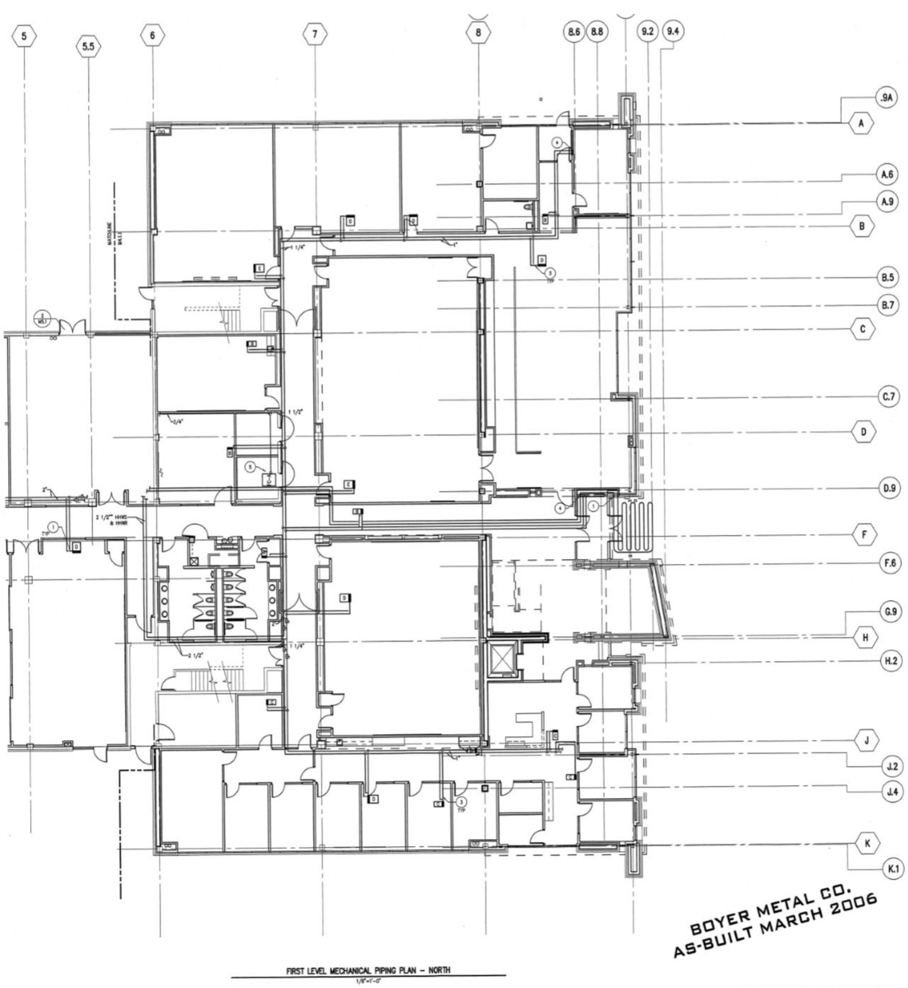

Figure 5: First Floor Mechanical Piping Plans

Second, the flow rate readings for the pump in place currently needed to be found, as this would dictate how many solar panels in parallel and series would be needed. Similarly, the supply and return temperatures are necessary information. These allow the team to determine how many panels are needed to provide the same temperatures in order to run the solar system and boilers in parallel. This information came from the second source used, the pump schedules, as depicted below in figure 6.

PUMP SCHEDULE

TAG	SERVICE	LOCATION	TYPE	FLUID	TEMP F.	GPM	TOTAL HEAD FT. WG.	NOMINAL PUMP INLET/OUTLET SIZE (IN.)	MIN. PUMP EFF.	MAX. NPSH REQUIRED BY PUMP	MOTOR				MANUFACTURER	MODEL NO.
											MAX. BHP	HP	RPM	VOLT/ PHASE		
HHWP-1	HEATING WATER	BASEMENT	CLOSE COUPLED	WATER/ GLYCOL	180	190	60	2.5/2	67%	7.1	4.16	5	1750	480/3	BELL & GOSSETT	1531 – 2-1/2BB
HHWP-2	HEATING WATER	BASEMENT	CLOSE COUPLED	WATER/ GLYCOL	180	190	60	2.5/2	67%	7.1	4.16	5	1750	480/3	BELL & GOSSETT	1531 – 2-1/2BB
SM-1	SNOW MELT SYSTEM	BASEMENT	CLOSE COUPLED	WATER/ GLYCOL	100	1.3	35	–	3%	5.21	.26	1	1750	120/1	BELL & GOSSETT	–

NOTES: 1. PUMPS HHWP-1 & HHWP-2 HAVE BEEN SELECTED FOR FUTURE CAPACITY. INITIALLY BALANCE PUMPS FOR 150 GPM AT 50 FEET OF HEAD.
2. COMPONENTS HAVE BEEN SELECTED FOR 50% BY WEIGHT GLYCOL SOLUTION.

Figure 6: Pump Schedule

This source not only describes a flow rate of 150 GPM, it describes a head of 50 feet which will also be discussed throughout the design.

The third source to be used is Fox and Macdonald's Introduction to Fluid Mechanics (9th Edition). It will provide all necessary calculations and tables needed for calculating head loss within the pump and through the solar panels. The current pump is rated for 50 feet of head, so depending on the current head loss to be calculated through the piping, we will also calculate the head loss through the piping of the solar system to determine if the pump needs to be changed or if we can continue using it.

In conjunction with the third source, the Hazen-Williams Equation, found on EngineeringToolbox.com will be used as a fourth source to cross-reference all calculations. This site provides details as to what constants will be used based on different materials and what each variable for each equation is.

3.1.3 Student 3 - Drake Cleveland

Drake's main task has been to determine the amount of heat the solar thermal collectors are likely to supply on an hourly, monthly and yearly basis. This has required research into solar thermal collectors and the efficiencies associated with them, the amount of solar radiation we can expect the collectors to be exposed to using collected data, gaining experience with programs such as the System Advisor Model to turn gathered information into something the team can work with, and finally, the certifications that would be required for the solar panel system to put in place.

Perhaps the cornerstone of the project is selecting the right solar panel. Since the team is unlikely to be able to offset the entire load of natural gas using just solar thermal panels, selecting the right solar panel is important to maximize the investment. From the research I have conducted, the solar panel we are going to use is going to be a non-concentrating solar collector as opposed to a concentrating solar collector. The details of this are discussed at length in the Benchmarking section of the report.

As far as the radiation we can expect, I referenced multiple sources that compiled data over multiple years to determine an average amount of radiation normalized by surface area(m^2). The first was solar red book. This data was compiled over a 30 year span from 1961-1990. The table for data collected in Flagstaff can be shown in Appendix D. The data shows that the ideal angle of tilt for a solar panel for a year would be at latitude. In Flagstaff, this is at about 35 degrees. Looking closer at the data, a tilt of about 50 degrees would be ideal for winter and an angle of 20 degrees would be ideal for summer. Since the team isn't as concerned with meeting demands in the summer, the design should move forward with an angle of tilt of 50 degrees. This will ensure that the most heating is supplied in the winter as possible. The second source was NREL solar data for a typical meteorological year. These irradiance measurements were taken hourly for a year over a number of years. This data was used in conjunction with the System Advisor Model to show the amount of radiation we can expect at each hour the data was recorded. Since the data being measured was Irradiance at the top of the atmosphere, the System Advisor Model converted this data into usable radiation data for Flagstaff.

Converting irradiance data into usable is no easy task, so the System Advisor Model is a necessary tool. The System Advisor Model(SAM) can also determine the rise in temperature a given solar panel will supply in water given the irradiance data and flow rate. Once the solar panels have been chosen, the SAM will determine exactly the amount of heat the solar panels will be able to supply the rooms at any given time using the NREL data. This is an incredibly useful feature that the team will definitely capitalize on and use the calculated data to propose the design to the GreenFund.

The last bit of research relevant to this report is the certifications that we would need to see in the solar panels we propose. The Solar Rating and Certification Corporation (SRCC) allows any solar panel to be searched and the list of certifications associated with the solar panel appear. Once we have a list of potential solar panels that will work with our design, we can research the certifications of each to determine which will accomplish the goals of the team and the university.

3.2 State of the Art - Benchmarking

If the team is to propose a competent design, building on the research of past and current solar thermal projects will be entirely necessary. Using this information to the team's advantage is called benchmarking, and is a tool commonly used by practicing engineers and researchers in general. Benchmarking for the scope of this project will require an entire system analysis, as well as subsystem analysis. The system analysis will consist of an analysis of a design as a whole in order to get a better idea of what to expect from the team's proposed design and what it should accomplish. A subsystem analysis looks at the components of the system and the roles each component plays. The results from the benchmarking was that the ideal design will include a non-concentrating solar panel, piping that is in series with the heat exchanger, and a control valve to be used to regulate the amount of hot water that flows to each levels heat exchanger.

3.2.1 System Level State of the Art - Benchmarking

From this benchmarking analysis, the team looked at multiple examples of existing Solar Water Heating designs in the real world. The first system analyzed took place on NAU's own campus and has already been a huge point of reference for the project thus far: the HLC Solar Thermal System. While the project was unsuccessful, the team still has plenty to take away from it, especially where the project went wrong. Using the stepping stones and data collected from this system has been crucial to the team's success thus far and will continue to be going forward. Another

3.2.1.1 Existing Design #1: HLC Solar Thermal System

The NAU HLC Solar Thermal system has been the biggest point of reference so far, as the design was implemented less than a mile away from the engineering building. Much of the data accumulated for the HLC can be directly applied to this project because they are so similar overall. The designs are so similar that the team has actually been using the specifications of the HLC panels to determine base calculations until the proposed solar panels can be decided on. The only real difference is that the HLC planned to use the water domestically instead of for heating. The target amount of water for the HLC project is admittedly lower than the amount the team plans for the engineering building. However, the HLC design failed due to an excess of hot water that essentially fried the system. What our team can learn from this project is that even though we don't expect to be able to fulfill the entire demand of hot water for the building, it is crucial to consider that the design may still fail from an overload at any time. While the team will be able to determine the highest amount of heat the system can provide based on past data, the future is unknown and the design should be able to handle a variety of different circumstances. Because of this, the team will include a heat exchanger to air that is connected to the control and balance valves in the proposal to ensure that this does not happen. With this in the proposal, the design will not fail due to overload.

3.2.2 Subsystem Level State of the Art Benchmarking

A subsystem analysis involves researching the different components within a system and determining all reasonable alternatives. The entire Solar Thermal system can be broken down into three main components: solar panels to collect the radiation from the sun, piping to deliver water to and from the solar collectors, and the valves required to control the flow rate of hot water into areas of need. The best possible combination of these components will be proposed at the team's design to offset the most amount of natural gas possible.

3.2.2.1 Subsystem #1: Solar Panels

Solar Panels are the bread and butter of the project. The team's entire proposal revolves around the specs and orientation of the panels. Per the customer requirements, a sufficient amount of hot water needs to be supplied to offset the natural gas demand from the engineering building. Solar Thermal panels are how this will be achieved. The team researched 3 variations of solar thermal panels in order to determine the best fit for the proposed system. These variations include: flat solar collectors, parabolic solar collectors and 3D solar collectors. Each variation is discussed at length below.

3.2.2.1.1 Existing Design #1: Non-concentrating Collectors

Non-Concentrating collectors are collectors that are able to collect both direct and diffuse radiation. They are essentially a rectangle surface area that collects radiation from the sun. In Solar Thermal systems, these panels capture heat into an insulated area where the heat is transferred into the water. These are the most common type of large system solar panel because they don't require direct angle radiation. These panels can be tracking or untracking around any axis.

Due to the fact that non-concentrating collectors capture both direct and diffuse radiation, this design seems ideal to satisfy the customer and engineering requirements. The team will consider other options, but non-concentrating collectors seem to be an ideal fit.

3.2.2.1.2 Existing Design #2: Concentrating Collectors

Concentrating Collectors capture the heat from the sun and direct it to the focus point of the curve. These designs are often tracking and are excellent when trying to raise the temperature of a small area drastically. These designs don't capture heat, but instead redirects all the heat captured to a single point, the focus.

While this design will likely handle the team's target change in temperature of 40 degrees celsius easily, the design would have to be tracking because the design can only capture direct radiation. This would lead to a significantly lower amount of heat compared to a non-tracking non-concentrating collector. Because of this, the concentrating solar collector will be insufficient for the proposed design and the team will no longer be able to consider it because the customer has required that the design be a fixed design.

3.2.2.2 Subsystem #2: Building Piping

One of the last major issues that the team faces is determining whether or not the amount of heat the system can provide is worth heating rooms on its own. If the solar panels can't provide enough heat for the building during the day, the system may run more efficiently as a pre-heating option for the heat exchanger to take off some of the load from the natural gas plant. If the building can be completely heated during the day from the panels, the efficiency will be greatest if the piping runs in series with the heat exchanger as one big hydronic loop. Each of the options will be discussed further below.

3.2.2.2.1 Existing Design #1: In-Series with Heat Exchanger

If the solar panels can heat the water enough to provide sufficient heat throughout the day, then the piping should be run in-series with the heat exchanger. This will be the cheapest and most efficient option for the proposal so this is definitely what the team is hoping for. Running the piping in series with the heat exchanger could shut off the demand for high temperature hot water from the natural gas plant during the day. On top of this, the cost for implementing the pipe needed would be much cheaper as the existing pipe could just be added onto to include the solar panel loop.

3.2.2.2.2 Existing Design #2: Pre-Heat for Heat Exchanger

If the design will not provide sufficient heat during the day, the team may have to implement the solar panels a different way. Instead of the water from the solar panels heating the building directly, a separate loop may need to be put in place to act as a preheat for the building's return water supply. In this case, the water from the solar panels would need to be piped down to the basement and heat the return water supply before it enters the heat exchanger. This will still take a lot of the load off of the natural gas plant, but the piping will be an issue. The team will have to determine how to fit an entire new loop of piping alongside the existing piping. This will be both difficult and much more expensive. If the team needed to move forward with this design, the cost would skyrocket when considering materials and labor. This would not be an ideal case for the team, but it is a solid backup plan for the project to move forward with.

3.2.2.3 Subsystem #3: Valves

Control and Balancing valves are used to determine the amount of hot water delivered to certain areas once the water has been heated from the solar panels or heat exchanger. These devices are often overlooked in the design process, but are perhaps the most important component of the design. If the needs for each room continues to change, it might be worth implementing both valves into the design.

3.2.2.3.1 Existing Design #1: Balance Valve

A balancing valve is a valve that is often used in hydronic loops to ensure optimum flow rate. It does this by creating a consistent output pressure from an inconsistent input pressure. This will be useful in our design because the flow rate changes variably, so having a valve such as this would create a consistent output pressure.

3.2.2.3.2 Existing Design #2: Control Valve

The purpose of a control valve is to regulate flow based on a set input. These are very common in hydronic loops because they will continue a certain flow rate until room conditions have been met. This is perfect for what the design requires because this will regulate the flow rate of hot water automatically until the room conditions are met.

4 CONCEPT GENERATION

4.1 Full System Concepts

The following sections include designs developed by the team. The system must be careful not to be over-designed and must be easily installed in conjunction with the existing system.

4.1.1 Full System Design #1: Solar System in Parallel

The first concept under consideration is our ideal circumstance. This involves running the solar panels and boilers in parallel, allowing the water to be sent from the return line directly to the solar panels then back through the building with a similar set-up to the boilers and heat exchanger. Doing this would allow the full daytime load of the boilers to be offset by the solar panels, reducing the carbon footprint and natural gas cost by the boilers to the best of our ability.

4.1.2 Full System Design #2: Solar System in Series

The second concept involves running the solar panels in series with the boilers rather than in parallel. Under this circumstance, the solar panels serve as preheaters for the boilers. This keeps the boilers running throughout the day, but lowers the amount of heat needed by these boilers, still lowering the carbon footprint and cost of natural gas but not to the same extent as running them in parallel.

4.2 Subsystem Concepts

4.2.1 Subsystem #1: Solar System

Design #1: Panels in Parallel

This subsystem regarding the solar system deals with the solar panels used and analyzed by the existing project atop NAU's Health and Learning Center (HLC). These panels can handle a flow rate of 0.84 GPM with a temperature change of 20℉. As such, this design features 180 solar panels in parallel with 1 in series - accommodating our required 150 GPM flow rate. While this design works well with the flow rate, it does not adhere to the 40℉ temperature change we need to design around.

Design #2: Panels in Parallel and Series

This subsystem is dependent on our team's ability to find alternative solar panels to those used in the HLC design. Assuming we find some panels with a flow rate of 2 GPM and a similar temperature change of 20℉, it would be possible to use 75 panels in parallel with 2 in series, for a total of 150 panels. This option would be cheaper and more effective, however it has proven very difficult to find vendors willing to work with the team.

4.2.2 Subsystem #2: Piping System, Pumps

4.2.2.1 Design #1: Design Integration

The first design regarding the piping system and pumps involves retaining the same pump already in place while tapping into the third-floor piping. This system serves as the easiest install, however we must first analyze the pump's head and ensure the head loss through the panels won't be too much for the pump.

4.2.2.2 Design #2: Pump Redesign

This design retains the piping through the building with a T-tap on the third floor. This case assumes the piping through the solar panels will increase the head loss past what the current pumps are capable of, and a new pump will need to be integrated to the system.

5 DESIGNS SELECTED – First Semester

After developing potential options for each component of the solar heating system, the team is able to analyze each selection based on criteria, including customer and engineering requirements. The following sections describes each selection criteria and justifies their uses within the team's project.

5.1 Technical Selection Criteria

When comparing the different choices for each component of the solar thermal heating system, the team focused on the feasibility in terms of cost, maintenance, installation, and efficiency of each item. The following sections details the selection criteria and describes the rationale behind the team's decisions.

The most important criteria for the design process is the performance of each part. The team is in the process of finding solar panels that can account for the load necessary and produce a flow rate and temperature for the liquid mixture that will ensure that the building will be heated properly. The team is in search of panels that will support liquid flow rates of at least 1 GPM and can support a change in temperature of 40 degrees Fahrenheit through the pipes. By accomplishing this, the team will be able to support the heat requirements and reduce the use of natural gas heating.

Another necessary criteria is demonstrating a potential to save money in the future with savings in natural gas heating. This can be accomplished by minimizing costs and taking on as much load as possible from the natural gas heating that is currently being utilized. The team is aiming to account for approximately 1.3 MMBTU/hr in the system, which takes the majority of the load. By doing so, the team is demonstrating that the proposed system has the potential to reduce the natural gas heating substantially and to save money for the school.

Safety is another important aspect of the design process. However, because the team will not be tasked with the task of installation or maintenance, the level of safety is considered to be equal among each panel configuration designed by the team. The team will take necessary measures when working with outside vendors and distributors to ensure that the project is safely installed and operated.

5.2 Rationale for Design Selection

Based upon the described criteria, the team has determined a basic configuration for the solar panel system. The team determined that the most effective configuration demands a mixture of panels in series as well as in parallel. Putting panels in series allows the liquid mixture to increase its temperature, and the goal is to obtain a temperature change of at least 40 degrees in order to maximize the efficiency of the heat distribution throughout the building. Additionally, by putting the rows of panels into a system in series, the flow rate will be increased and the team can obtain the goal of 150 GPM. The configuration will be ultimately dependent on which model of solar panels will be in use, which will be determined in the next stage of the project.

A Pugh chart was utilized to demonstrate the effectiveness of the theoretical configurations, shown in Figure 6 below.

Problem/Situation: NAU Solar Capstone

	Criteria	Baseline	Alternatives 1: Panel System- 180 in Parallel	2: Panel System- 75 Parallel, 2 Series	3: Panel System- 50 parallel, 3 series	4	5	Totals	Rank
1	Safety	0	0	0	0			0	
2	Cost	0	–	0	0			-1	8
3	Temperature	0	–	+	+			1	1
4	Flow Rate	0	+	0	–			0	7
5	Installation	0	–	0	0			-1	8
6		0						0	
7		0						0	
8		0						0	
9		0						0	
		Totals	-2	1	0				
		Rank	3	1	2				

Figure 6. Pugh Chart

The Pugh chart demonstrates the different criteria being analyzed for each potential system. Based on the criteria of performance (flow rate, temperature), safety, and installation, it was found that minimizing the number of panels on the roof is the most effective way to design a configuration. Once the team decided to use both panels in series as well as in parallel, the team created a rough design with SolidWorks to demonstrate how the configuration will be set up. The team utilized the approximate surface area of the roof of approximately 16,000 square feet to demonstrate how the system will be set up. Figure 7 shows the final configuration set up.

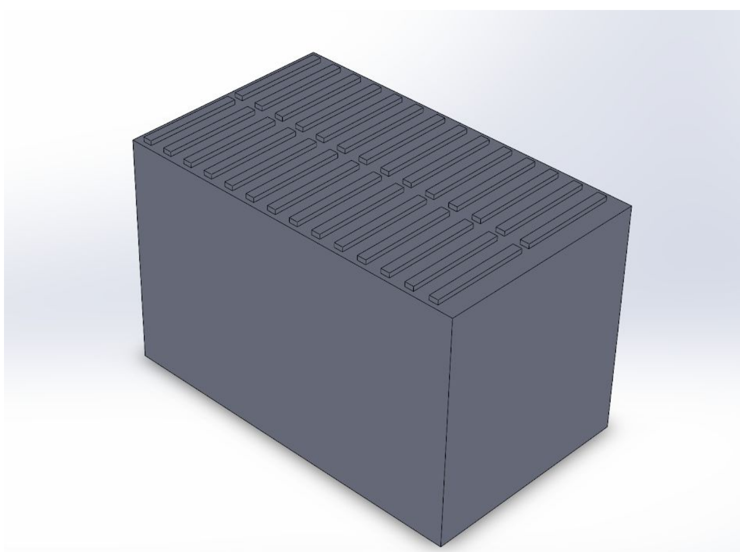

Figure 7. Solidworks model of series and parallel configuration

As shown, the model uses 28 separate rows of panels in parallel, each row having 10 panels in series. The calculations for this figure as well as the two other proposed configurations are shown in appendices A-C. This configuration uses the same model panels as the HLC, the SUNMAXX-30 model from Silicon Solar Inc. The team is currently in talks with this vendor among others in order to find the model of panels that will optimize the design.

The next steps for the NAU Solar team include speaking with vendors to find solar panels, finishing calculations with regards to irradiance to figure out the final configuration, and finalizing the overall plan with regards to installation, budget, and maintenance.

6 REFERENCES

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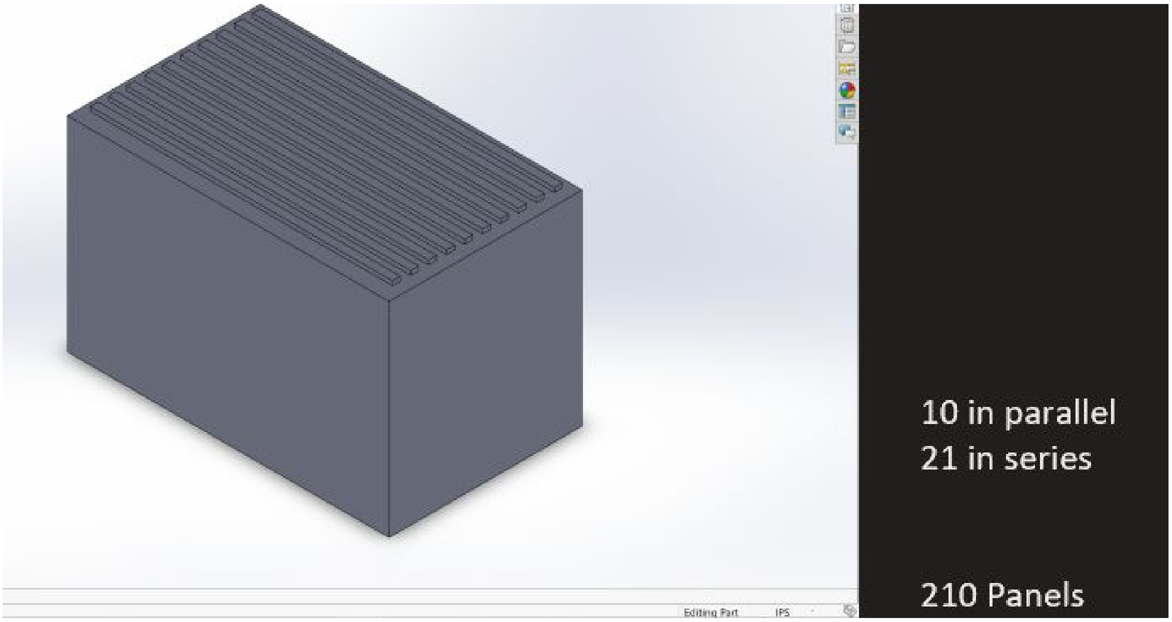
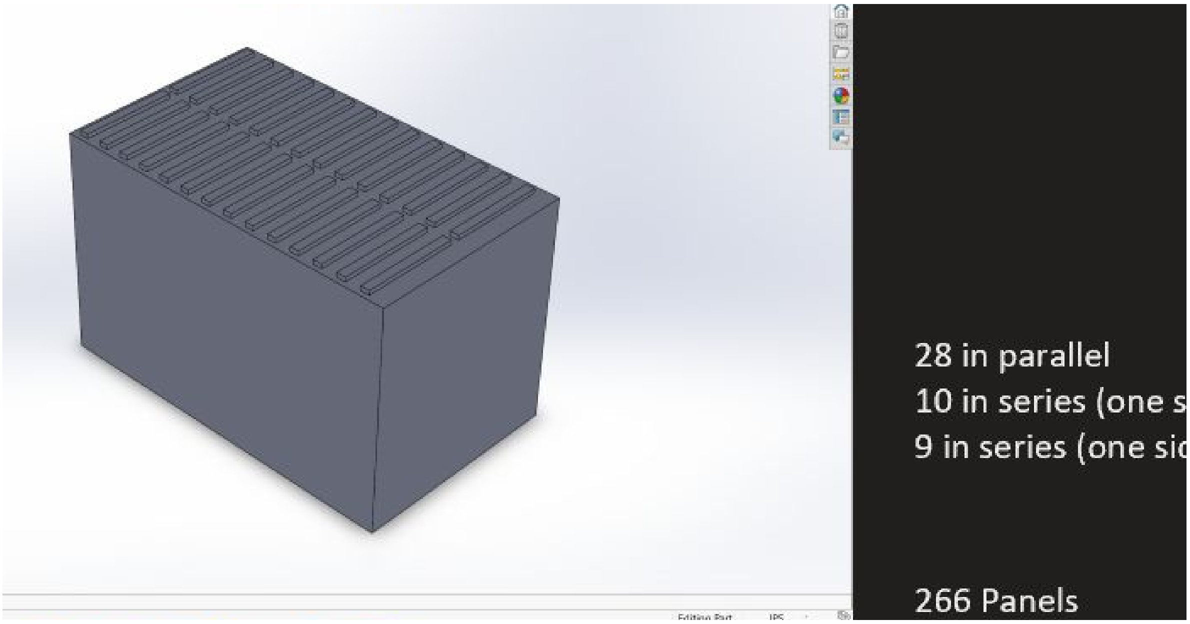
7 APPENDICES

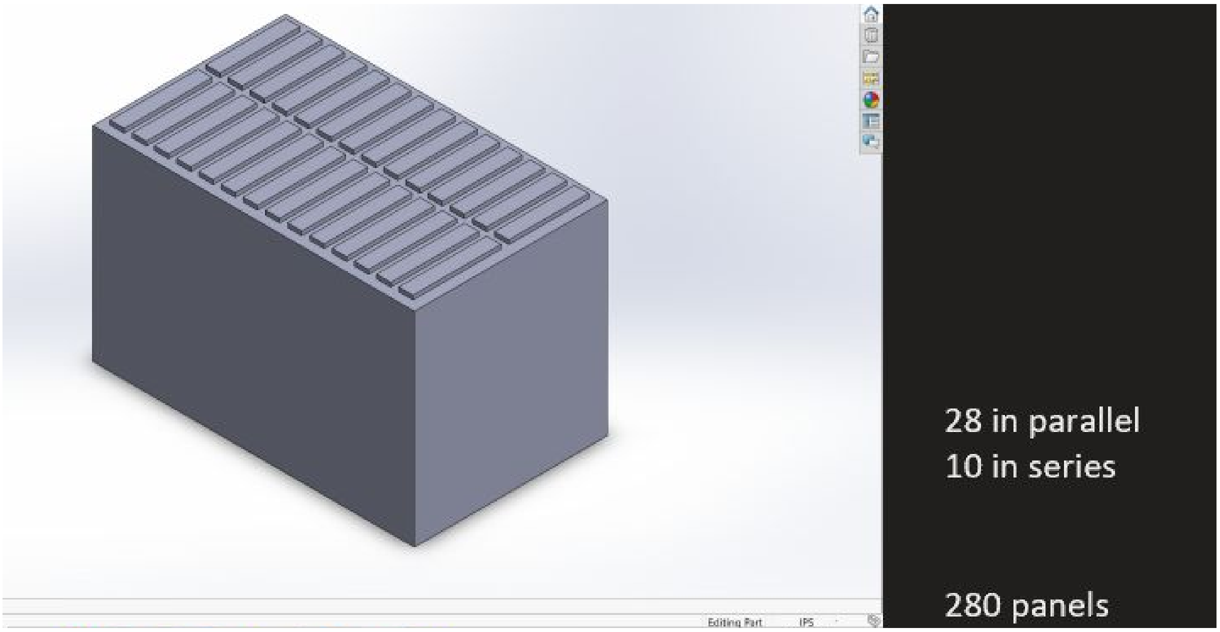
7.1 Appendix A: Design 1- SolidWorks Model



7.2 Appendix B: Design 2- SolidWorks Model



7.3 Appendix C: Design 3- SolidWorks Model



7.4 Appendix D: Solar Red Book Data (1961-1990)

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	3.1	4.0	5.1	6.3	7.2	7.7	6.4	5.9	5.4	4.4	3.3	2.8	5.1
	Min/Max	2.7/3.5	3.5/4.5	4.3/6.0	5.4/6.8	6.2/7.8	6.6/8.4	5.2/7.4	4.4/6.8	4.6/6.4	3.4/5.0	2.6/3.7	2.2/3.2	4.8/5.4
Latitude -15	Average	4.4	5.2	5.9	6.8	7.2	7.4	6.2	6.1	6.1	5.6	4.7	4.2	5.8
	Min/Max	3.5/5.3	4.4/6.0	5.0/7.1	5.8/7.3	6.2/7.8	6.4/8.1	5.2/7.2	4.5/7.1	5.1/7.4	4.0/6.5	3.4/5.4	3.0/4.9	5.4/6.1
Latitude	Average	5.2	5.8	6.2	6.7	6.7	6.7	5.8	5.9	6.3	6.1	5.4	4.9	6.0
	Min/Max	4.0/6.3	4.9/6.8	5.2/7.5	5.7/7.2	5.8/7.3	5.8/7.3	4.8/6.6	4.3/6.8	5.2/7.6	4.3/7.1	3.8/6.3	3.5/5.9	5.5/6.2
Latitude +15	Average	5.6	6.1	6.2	6.2	5.9	5.7	5.0	5.4	6.0	6.3	5.8	5.4	5.8
	Min/Max	4.3/6.9	5.1/7.1	5.2/7.5	5.3/6.8	5.1/6.4	5.0/6.2	4.2/5.8	3.9/6.2	5.0/7.3	4.3/7.3	4.0/6.8	3.7/6.5	5.3/6.1
90	Average	5.3	5.3	4.6	3.6	2.6	2.2	2.2	2.8	3.9	4.9	5.1	5.1	4.0
	Min/Max	4.1/6.5	4.3/6.2	3.8/5.4	3.0/4.6	2.4/2.8	2.1/2.3	2.0/2.4	2.1/3.1	3.2/4.6	3.3/5.8	3.4/6.1	3.5/6.4	3.6/4.3