Proposal to Implement the Solar Ventilation System to SBS West at NAU

Northern Arizona University

May 6, 2018

Energy Efficiency 1

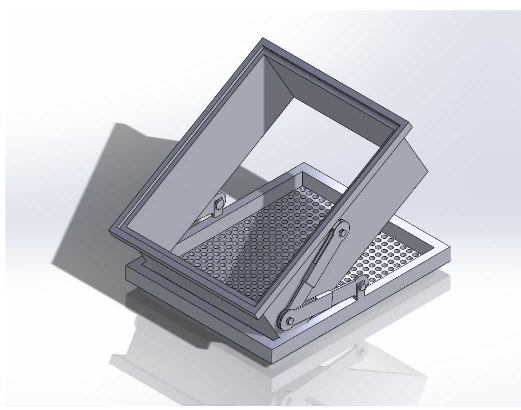
Dan Galindo

Kyle Matsuoka

Taylor Mellon

Talon Mills

Dreighton Nakama



Executive Summary

The Social Behavioral Sciences (SBS) West building at the Northern Arizona University (NAU) mountain campus is inefficient with its annual energy usage, with heating and cooling being a major factor of consumption. Dr. Wade tasked the Energy Efficiency team to come up with a mechanical system to reduce energy consumption in the building.This proposal describes how the team selected the Solar Ventilation for the final design to implement into the SBS West building. The design will be paired with the current HVAC system to improve efficiency of the system as a whole. This system involves using solar panels to generate electricity from sunlight. For ventilation, the system utilizes motors to expand and contract the panel based on the temperature of the building. The outcome of the system is to ease the use of the current HVAC system and generate addition electricity to aid the current system and help pay of the systems implementation. The process of determining this final design included preliminary research, project management, understanding the issue presented, concept generation, analytical calculation, cost analysis, resolving potential ethical issues, and future work.

1.0 Introduction

In this section Background information, motivation for the project, and details on the process the team took to come up with the final design is laid out.

1.1 Background Information

Many HVAC (Heating, Ventilation, and Air Conditioning) systems contained in buildings are proven to be energy inefficient. Buildings in the United States (U.S) are responsible for over 70% of electricity consumption and approximately 40% of carbon emissions, with HVAC systems being the main contributor [1]. A boiler is a common HVAC system, which wastes fuel (diesel or oil) and at low temperatures, wastes productive energy (exergy) [2]. This waste results in a loss of money and produces harmful emissions. Although some buildings have been using natural gas as an alternative fuel, natural gas still emits significant amounts of carbon dioxide (CO2), which is a greenhouse gas, and energy (exergy) is also lost [2]. These inefficiencies create the need for the redesign and optimization of HVAC systems in buildings.

1.2 Motivation

Universities have a substantial amount of buildings, which makes HVAC systems a vital factor when analyzing a University's energy consumption and efficiency. With Northern Arizona University (NAU) mountain campus being located at 7,000 feet and experiencing all seasons, HVAC systems are important and necessary. Through studying the effects of equipment size, surrounding environment, and fiscal impacts using thermodynamics, kinetics, and economics, an innovative design with efficient power and heating can be produced. Outdated HVAC systems are costing NAU financially and environmentally. By improving or redesigning current HVAC systems in older buildings, such as SBS west, through modern concepts and designs, NAU can resolve these costs by reducing annual expenses and their carbon footprint. Dr. Wade has tasked our team with designing a mechanical HVAC system by using state of the art (SOTA) concepts that will reduce the overall energy consumption of SBS west.

1.3 Process to Reach the Final Design

The process of determining this final design included preliminary research, project management, understanding the issue presented, concept generation, analytical calculation, cost analysis, and resolving potential ethical issues. Our preliminary research was conducted by selecting State of the Art (SOTA) systems currently on the market and analyzing their impact on HVAC efficiency. The two main systems that were researched were Solar Radiative systems and Data Furnaces. From this we were able to take the customer requirements and analyze them against engineering characteristic in a QFD. During this process the criteria and weighting for the decision matrix was generated as well as benchmarking against current systems on the market. Once this was completed, the team was then able to start brainstorming and generating concepts. To complete this we used the 6-3-5 method to generate over 50 designs and then narrowed it down to 3 concepts. Form there a decision matrix was created to weight different aspects and requirements of the project to decide on a final design. Once the final design was created analytical calculation were conducted to determine final aspects of sub systems for the project. Once all subsystems were finalized a cost and ethical analysis was conducted to determine the feasibility of the project for the university.

2.0 Problem statement, SOTA, and Project Management

To begin the project the Problem statement must be understood and broken down to useful information for the team. The list of criteria was created and the quantified through the use of the QFD. Once the project was understood SOTA systems were analyzed to give a better understanding of how other engineers approached similar problems in the past. At this point in time, the team was able to set up a structure of project management based on the use of the Gantt chart and the Work Breakdown Structure (WBS).

2.1 Problem Statements

In this section, an updated problem statement is provided. The team was tasked to find ways to increase the energy efficiency at Northern Arizona University (NAU) who is the main stakeholder for the project. The problem statement can be divided up into three sections: needs statement, problem definition, and constraints.

2.1.1 Needs Statement

The NAU Mountain Campus is inefficient with its energy consumption.

Northern Arizona University has buildings on campus that are over 100 years old. Some of these buildings still have systems from the mid-1900s, which have been deemed energy inefficient, compared to modern technology. Dr. Wade, our client and a stakeholder, has tasked the team with reducing the energy consumption across campus, without compromising the energy services NAU provides (Heating, lighting, etc.) to its faculty and students. She assigned the team to construct a mechanical solution and not a solution based solely on energy conservation.

2.1.2 Problem Definition

The problem definition can be split up into three different sections: the goal statement, objectives and constraints. The goal statement is a response to how the team will solve the problem given. The objectives are the expectations and conditions from the client. Lastly, the constraints are certain conditions that the team has to satisfy for the design of the system.

2.1.3 Goal Statement

As a team we started with a broad scope that fit the problem definition and then kept narrowing it down until we got we got a final statement that is more specific and was selected by Dr. Wade.

1. Improve the heating efficiency of SBS west.
2. Reduce the amount of energy used by Social and Behavioral Sciences building (SBS west) for heating the building.
3. Increase energy efficiency on campus by targeting Social and Behavioral Sciences building's (SBS west) heating system.
4. Design a system to reduce the energy used by the Social and Behavioral Sciences building's (SBS west) heating system.

2.1.4 Objectives

The table below (Table 1) displays the overall objectives of the project with the measurements, criteria, and the units of measurement to quantify the objectives.

Table 1: Objectives

Objective	Basis for Measurement	Criteria	Units
1. Cost effective	Annual cost savings	Cost	US dollars
2. Reduce amount of energy used	Annual kWh	Energy	kWh

3. Safety for users	Electrical current	System shutdown	Amps
4. Provide same service as current heating system	Building temperature	Temperature	℉
5. System savings pay-off	System pays itself off in 4 years or less	Cost/efficiency	US dollars/annual kWh

Objectives 2-4 should comply with the 2014 NEC (National Electric Code) and the NFPA code 1 (National Fire Protection Association).

2.1.5 Constraints

A list of constraints were collected to give a clear understanding what the system must or must not be able to do.

1. All services that are provided now must be provided in the solution.
2. The system must pay for itself in 4 years.
3. Size of system must fit in the space provided.
4. Must be able to increase or decrease the temperature of the building.
5. The system must not increase NAU's carbon footprint.

2.2 Quality Function Display (QFD)

A QFD, as seen in Appendix A.1, is an organized table that relates the customer needs to engineering characteristics. The QFD development consists of three sections: customer requirements, benchmarking, and engineering characteristics. Lastly, rankings of the customer requirements and engineering characteristics are provided based on importance.

2.2.1 Customer Requirements

Customer requirements are a list of wants and needs that the customer required for the design.

1. System pays for itself: The system must save enough money that it will pay itself off in a certain number of years depending on how much it costs. If the system costs under $500,000, then the system must pay itself off in less than five years. If the system cost over $500,000, then the system must pay itself off in less than ten years.

2. Same heating and cooling as previous system: The system must provide the same services that the current system provides. This means that the system must use the same energy inputs and outputs as the current system.

3. Less energy use: The system must reduce the energy consumption of heating, while not increasing the greenhouse gas emissions.

4. Easy maintenance: The system must be easy to repair and maintain if there is an event where the system shuts down or there is something wrong with the system.

5. Occupies the same space: The system must be easily integrated into the same space provided. It can either be smaller or larger than the current system as long as it fits in the same space provided.

6. Less noise: The system must not make a lot of noise while running. This is to ensure that staff and students are not disturbed by the noise.

7. Adjustable timing: The system must be able to turn on and off depending on the times of demand.

2.2.2 Benchmarking

Benchmarking is a list of current products that are used by companies that are closely related to the design system.

1. Active Solar Heating: SolarDuct is a Rooftop Solar Air Heating System that collects thermal energy from the sun to heat air. SolarDuct is a black metallic heating system that heats ventilation air before entering air-handling units. SolarDuct is nearly 80% efficient with low cost for sizing and installation [3].

2. Boiler heating: Model Buderus SB625WS is a commercial condensing boiler heater designed for flexibility for retrofitting and new construction projects. Model Buderus's efficiency nearly up to 98%. Multiple fuel options consist of natural gas, ultra low sulfur oil and heating oil type 2[4].

3. Electric Heating: RQNL-B is a commercial Electric Heater/Heat Pump that utilizes Scroll Compressor Technology. Scroll Compressor Technology are more advanced than traditional compressors. The compressor is hermetically sealed and incorporates fewer moving parts, quieter, more efficient and longer lasting[5] .

2.2.3 Engineering Characteristics

The engineering characteristics are quantifiable statements that are derived from the customer requirements.

1. 5 year payoff estimate: The updated system must save enough energy so that the money saved on reduced energy pays off the cost of the system in four years.

2. New Thermal output = Old thermal output: The thermal output of the new system must be equal to the thermal output of the old system. The use of energy will be reduced but the amount of heat produced must not be compromised.

3.Energy efficient: The system must increase energy efficiency of the building. Reducing energy use will reduce cost and lower the carbon footprint of the SBS West building.

4. Size <= Current size: The updated size of the system must be less than or equal to the current size of the system. When updating or replacing the system the size can't exceed the size of the previous system.

5. Easy to repair/ replace parts and check systems: After manufacturing the system, the parts must be easily accessible to complete repairs and to conduct normal checks to ensure proper functioning of the system.

6. Temperature Management: The temperature the system produces must be easily managed. The temperature felt inside of the building must be adjustable and cooperative.

7. System runtime (turn on and off): The system must have a specific runtime that pertains to the part of the day it is running and not running. Energy must not be wasted at times when heating/cooling is not needed.

8. Selective heating/cooling: The heating and cooling of the system must be punctual and selective. At times when no one is in the building, such as overnight, the system must preserve energy and not waste it.

9. Display usage: The system has a way to display temperatures, power output, efficiency, and trends of the system. This display can be used to gather information on how well the system is running.

10. Mechanical system: The system must be mechanically engineered with different technologies. It shouldn't focus on conservation to save energy, but the technology.

11. Noise pollution (Reduce): The system must not produce too much noise pollution. The noise output of the updated system should be reduced from the current noise output.

2.2.4 Simple QFD
The QFD's, seen in Appendix A figure 1, main job is to show the relationships between the customer requirements and the engineering characteristics by using a 9-3-1 scale, nine being most and one being the lowest significant impact. Each of the customer requirements has a weighted score from 1-5, one being the least important and five being the most important, which are then multiplied by the designated relationship scale. This is to show the overall importance of each engineering requirement. Along with creating these weightings, the QFD compares how the engineering characteristics compare against each other by showing positive and negative impact (-- largest negative impact and ++ largest positive impact). Finally benchmarking takes products on the market and compares them with the customer requirements showing how well they work. The QFD is a useful tool in any design project because it gives the team an idea on what they should and should not do.

2.3 SOTA and Lit Review
By improving or redesigning current HVAC systems in older buildings like SBS west with modern concepts/ designs, NAU can resolve these costs by reducing annual expenses and their carbon footprint. Before any improvements can be made, research about SOTA designs have been done and conveyed through this section.

2.3.1 Data Furnace
Passive HVAC systems use nature or pre-existing systems to cool and/or heat a building to replace current HVAC systems. A current leading passive system is the Data Furnace [6]. These systems use subsystems to redirect airflow. This allows for the passive system to displace thermal energy throughout a room or building. Passive systems are known to be environmentally friendly and cost-effective. These systems do not have to generate additional thermal energy, however this system can be unreliable and may struggle keeping a room or building at a consistent temperature.

2.3.1a Utilizing Pre Existing systems
This design is a unique way to utilize a pre-existing system in a building to provide heating. Most commercial buildings have some sort of data center, which wastes a large amount of thermal energy. Although the exact design is still being designed, the way the design works is by redirecting the heat generated by data centers [6]. This concept has been interpreted in many ways, from single-room heating to building heating [6]. This design will overall reduce the waste of a data center and pre-existing HVAC systems.

2.3.2 Radiative Systems
Radiative system design uses thermal energy generated by the sun. However, a Radiative System explores the uses of the sun further. Additionally, the Radiative system fulfills the functions of an HVAC system.

2.3.2a Beyond Solar Panels
By using the circulation of heated fluid along with additional sub functions and ventilation the Radiative system can heat and cool to a user's specification. This design heats and cools off buildings by using radiative panels (seen in Figure 2), which are panels that collects and amplifies solar energy to heat and pump fluid (e.g. water) throughout the building [7]. The pipes circulate the fluid through the floor, walls, and/ or the ceiling (depending on a customer's need or price range). Moreover, this design has a function, which cools down the fluid in the pipes, cooling both the building and the existing air conditioning (AC)

unit [7]. Although this design is efficient and has radiative panels that can allow for lower airflow, this design does not meet the air ventilation and air quality standards [8]. Therefore, it should be accompanied by an all air AC unit. This design will optimize the ACs functionality resulting in an increased efficiency of the unit.

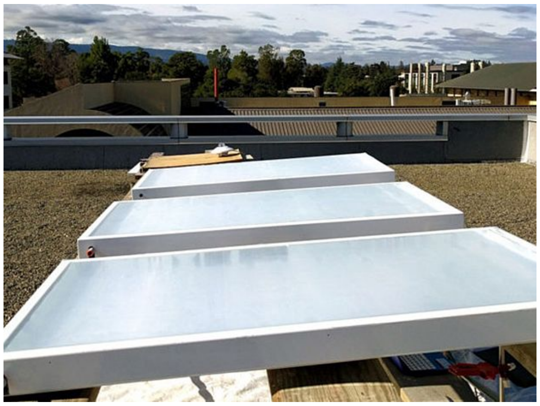


Figure 2: Radiative Panel with Ventilation Example [4]

2.4 Project Management

When working on a project with a set deadline, the management of tasks and anyone involved is vital. This section contains how the Energy Efficiency Team's plans to manage their project through the use of two methods: a Work Breakdown Structure (WBS) and a Gantt chart. These allow the team to identify and organize, by duration, due date, and those in charge of each task. With the WBS the project will be broken down into tasks based on work needed to complete the team's design proposal. From there, the Gantt chart will organize the tasks created in the WBS and tasks assigned by Professor Moghaddam and Dr. Wade using their completion dates. Additionally, each task will contain their duration and the members in charge.

2.4.1 WBS Documentation

The WBS is a table that identifies and organizes tasks that have been completed and tasks to be completed, shown in Table B.1 of Appendix B. This table includes a corresponding number, estimated hours spent, who is assigned, different resources needed, and material cost of each task.

The first major task of the project is to research and analyze different components of the designed system. This includes potential designs for the retractable arms, window panels, and piping. Additionally, research on pricing, installation, location, safety codes, and the roof material of the desired building will be done. Each team member is assigned to research a specific area of the design, seen in Table 1 in Appendix B from WBS # 1-1.6. This process has an estimated duration of 19 hours and involves the use of the Internet and engineering books.

The second major task of the project is to design and plan the system that will be integrated into the Social and Behavioral (SBS) west building on the Northern Arizona University (NAU) mountain campus. This includes performing engineering calculations on the different components of the design and creating a model of each part of the system, will be done using SolidWorks or AutoCAD. The process of designing the solar ventilation system is estimated to take around 19 hours. This can be seen in Table 1 in Appendix B from WBS # 2-2.24.

The last major task of the project is to integrate the solar ventilation system design into the SBS West building. This includes building the system, removing the old system, installing the new system, and updating the system components. The costs of this project are still subject to change based off of the integration of the solar ventilation system design. The process of integrating the system into the SBS west building is estimated to take around 48 hours, seen in Table 1 in Appendix B from WBS # 3-3.5.

2.4.2 Gantt Chart

The Gantt chart, as seen in Figure 1,2 Appendix C., was created based off of the tasked creating in the WBS above. The Gantt chart visually represents the assigned tasks, who is performing them, when they will be preformed, what must be completed before a new task is begun, and resources will be used for them. The purpose of the chat is to provide a clear and concise project timeline that incompeses all parts of the project. The subtasks have tentative deadlines although the main tasks have set deadlines.

2.5 Conclusion

The project began with the Problem statement that must be understood and broken down to useful information for the team. The list of criteria was created and the quantified through the use of the QFD. Once the project was understood SOTA systems such as Ratative Systems and Data Furnaces were analysed to give a better understanding of systems that could be implemented. Finally, the team was able to set up a structure of project management based on the use of the Gantt chart and the Work Breakdown Structure (WBS).

3.0 Concept Generation and Final Design

To generate concepts and the final design multiple steps were taken. The first step was to break down the problem is the Problem Decomposition. Then concepts were generated off of the problem decomposition using the 5-3-4 method. Once the ideas were generated they could be further analyzed using the Decision matrix to generate a final design.

3.1 Problem Decomposition

Problem Decomposition is where you decompose a complex problem into smaller solvable problems. There are two main types of Problem Decomposition, Functional and Physical (the Problem Decomposition for the team is represented in figure 3 below). Our complex problem is to design an efficient HVAC System for Northern Arizona University (NAU) SBS West building. This complex problem can be broken down into smaller solvable problems such as provide heating/cooling, Protect user and operator, Reduce energy consumption and Pays off in the long-term. One of the major functions of the proposed system is to reduce energy usage, which means to reduce emissions, reduce electricity and reduce the amount of fuel used for energy production. Providing heat/cooling requires that our system must provide the same services, controlled with ease, ventilated throughout the entire building and is able to maintain the desire temperature. Safety plays a large role in the decision making process. The proposed system must be able to control the temperature, provide and maintain safe air quality and must be easily accessible. The system must be able to pay itself off within a four-year time span, efficient with energy consumption and continues to save for NAU in the future.

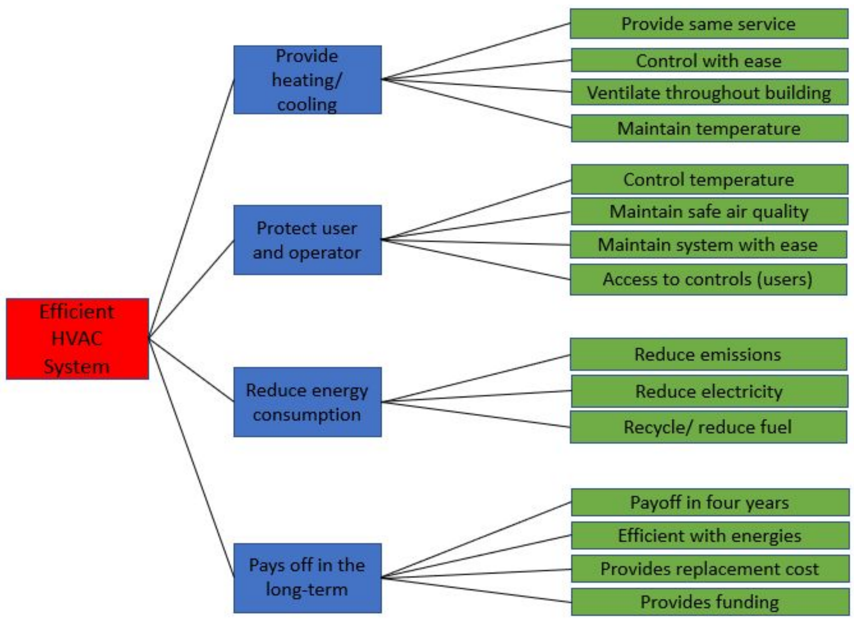


Figure 3: Problem Decomposition

3.2 Concept Generation

The concept generation is a process used to generate numerous concepts to be considered for the final design. The Energy Efficiency team used two methods for the concept generation: the 5-3-4 method and a silent brainstorm. Both the 5-3-4 and the brainstorming method are shown in the subsections along with a few concept drawings.

3.2.1 5-3-4 Method

The first method the team used was the 5-3-4 method, which allowed each member of the team to come up with three different concepts based on five different categories. These five categories are based on the smaller problems from the problem decomposition: provide heating/cooling, protect user and operator, reduce energy consumption, pays off in the long-term, and a mechanical system. Below a example of the 5-3-4 method the team generated based on the mechanical system category.

Table 2: Mechanical Systems

5-3-4 Method Mechanical Systems

Air filter from regular heat produced in building	Black material on building to absorb heat	Use outside temperature to cool inside (run pipes to slowly let air in building)
Taking heat from computers to heat building	Upgrade current heating system to modern heating system	Radiant floor heating. Running hot water on the base level so heat rises up in building
Have cold air enter the building from the top floor and move down	Have hot air enter the bottom floor and move up	Run pipes under ground to cool to around 50 degrees Fahrenheit but keep them from freezing
Pump either hot or cold water or air throughout building	Rotating panels -White to reflect light to improve cooling -Black to absorb heat	Mirrors on roofs to reduce heat absorption
Two sets of doors to enter building so heat doesn't escape	Control heating for different zones in building	Solar panels that is hooked up to a water heater that is hooked up to a heat pump

Table 2 shows the 5-3-4 method the team generated for the long-term effectiveness category. A top design concept for this category is the system optimizes the efficiency of other systems. For example, the system helps heat and/or cool other systems within its building. Another top design is the system will have a storage tank that stores unused energy, which allows energy to be consumed without a constant supply. Table 2 shows the 5-3-4 method the team generated for the mechanical system category. A top design from this category is the system takes heat produced by computers in the building and distributing that heat to the rest of the building. Another top design is having a radiant floor heating system. This design uses pipes that run underground on the first floor to allow heat to travel up into the building.

3.3 Concept Selection

Concept Selection is the process used to analyze and determine our final designs based off of specified criteria from the QFD. As a team we scored and weighed our designs to determine which design best suits our needs. Figures 4-6 shows the top concepts the team generated. Figure 4 shows a data furnace, which takes heat being generated from a data center and distributes that heat throughout the building. Figure 5 shows the solar ventilation system that utilizes a vent on top a roof to allow air to leave and/or enter the building ultimately cooling it down. The system also has a solar panel on the window panel in order to produce energy from the sun. Figure 6 shows a radiant floor heating system, which includes panels that are installed under the floors of the buildings that pumps hot water throughout the system allowing for heat to travel up and heating the building.

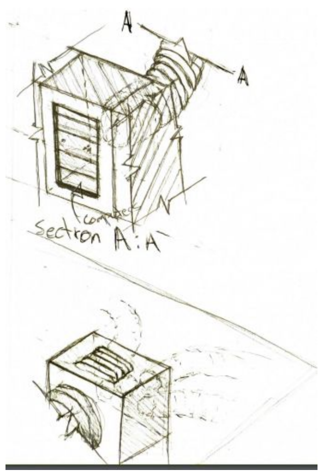


Figure 4: Data Furnace

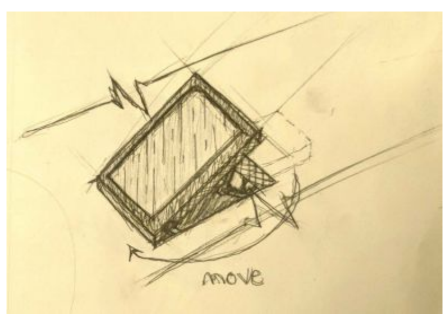


Figure 5: Solar Ventilation

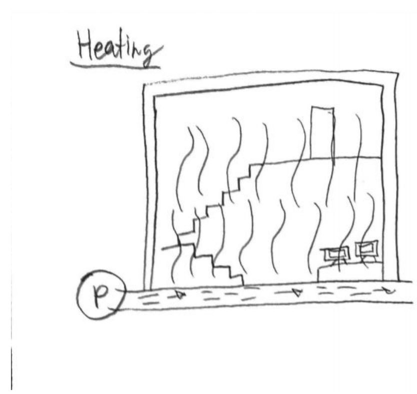


Figure 6: Radiant Floor Heating

3.3.1 Concept Selection Requirements and Calculations

Each concept was evaluated fairly under the same criteria as the rest of the concepts. The criteria were Systems Pays for itself, Same Heating and Cooling as Current System, Reduce energy usage, Easy to fix system problems, Uses the same space, Less noise and Adjustable Times. Each criteria is weighted differently based off of the QFD on a scale from 0-100%. Each system is scored within this criteria on a scale from 1-10 with 1 being 100%+ worse than current system, 5 being equal to current system and 10 being 100%+ better than current system. To determine the overall score multiply the weight% by the score and sum up all the weighted score to get overall score. This can be seen in table 3.

Table 3:Concept Selection Chart

For Main Components							
		Figure 6:		**Figure 7:**		**Figure 8:**	
Criteria	**Weight (%)**	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
System Pays for itself	15	8	120	9	135	7.5	112.5
Same Heating and Cooling as Current System	20	7.5	150	7.5	150	7	140
Reduce energy usage	25	8.5	212.5	9.5	237.5	8	200
Easy to fix system problems	15	9	135	9	135	6	90
uses the same space	10	9.5	95	9	90	9	90
less noise	5	9	45	9	45	8.5	42.5
adjustable times	10	7	70	8	80	9	90
Total	100		827.5		872.5		765

3.3.2 Hypothesized Final Design

The final design with an overall score of 872.5 weight score points is the Solar Radiation and Ventilation. This system meets the desired criteria to be effective and successful. This can be seen in table 4 under figure 7. The Solar Radiation and Ventilation system works by using solar to generate electricity and the sun to radiate heat. This system also allows for different levels of ventilation depending on the outside climate. The ventilation is controlled by a set of arms that is controlled by motors, and they will extend or contract depending on user defined temperature of building. This system excels in the two main criteria, which are Reduce Energy Usage and System Pays for itself.

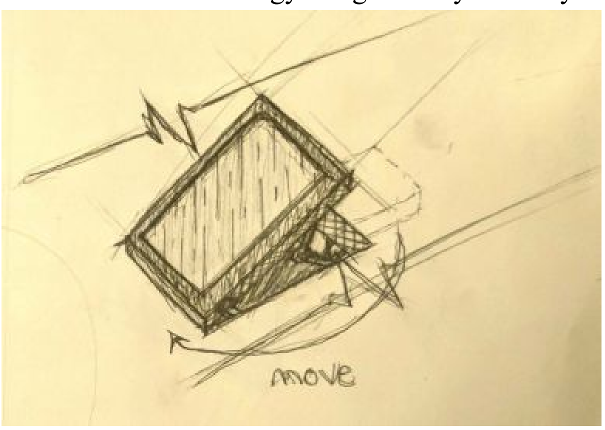


Figure 7: Solar Radiation and Ventilation

3.4 Conclusion

The Final Design was chosen based on how well the system ranked in the specified criteria from the QFD. The main criteria are Reduce Energy Usage and Provide Same Heating/Cooling Services. As a team we scored and weighed our designs to determine the design that best meet the specified criteria. The design that best met those criteria is Solar Radiation and Ventilation, which scored a total of 872.5 out of 1000 points. Solar Radiation and Ventilation works by using solar energy to generate electricity and the sun to radiate heat. This system will be interconnected with the existing electric grid and fit to meet Flagstaff's climate. Solar Radiation and Ventilation can be implemented on nearly any roof. After planning our design to meet all national and local Arizona Safety Code, as a team we will find a company with the necessary skills to properly and successfully install our final design.

4.0 CAD Model of Final Design

In this section the computer-aided design (CAD) Model for the final design will be discussed. The CAD model was produced in Solidworks. From the 3D model, drawing sheets in 3rd Angle Projection were produced.

4.1 CAD Model

Figure 8 seen below depicts the final CAD model of the Solar Ventilation System. Figure 1 in Appendix D depicts the Drawing Sheet created off the model with dimension in mm that was used to 3D print the CAD part for the in class presentation. Actual dimensions are subject to change based off of building installation and can be changed easily if the system were to be implemented.

The main body of the system will hold the solar panel and will have wires running from it to the power grid of the building. The base plate vent of the system will be mounted to the roof of the building and has a built in grate to prevent large object from falling in the building from the roof when open. The arms for the vent allow for the main body of the vent to completely extend off of the base plate and allow for ventilation to occur. The arms that attach the main body to the base plate can extend and maneuver to allow for the solar panel to track the sun while acting as the vents manipulation system to open and close as building temperatures fluctuate.

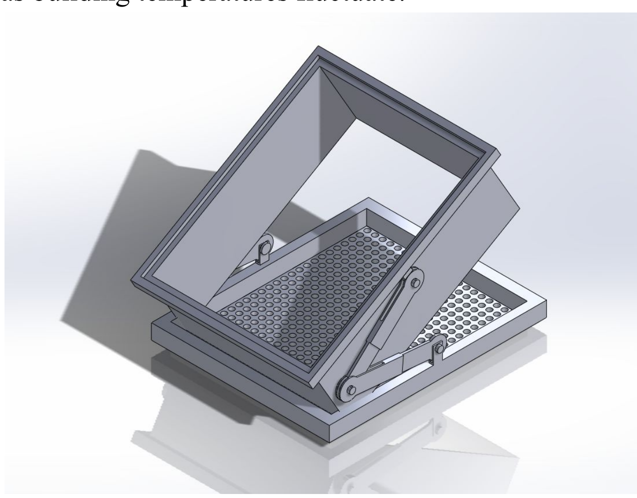


Figure 8: Solar Ventilation CAD Model

5.0 Design Evaluation

In this section the design will be evaluated for material selection, type of panel used, and optimal array set up.

5.1 Analytical Calculations of Design

In order to clearly understand and make crucial decisions, each aspect of the design the system was broken down into important subsystem to be analyzed. From the information collected during this process the final design could be solidified further into a function system to be implemented in SBS West.

5.1.1 Solar Radiative vs. Solar Photovoltaic Panels

In designing a system to add on to the existing HVAC system in the Social and Behavioral science building, our team finalized a design to add ventilation system on the roof the building that can be opened and closed to better monitor and control the temperature in the building. These vents are comprised of panels that open and close based on the desired temperature in the building. The main body of the panels was proposed to either be a Solar Thermal or Photovoltaic radiation capturing system.

5.1.1a Background Information

Solar thermal (ST) radiation capture is where the radiation energy from the sun is collected and stored in a working fluid often water. The panels have room temperature water entering that is heated up by solar radiation as it passes through. The hot water then exits the panels and is stored in a hot water storage container, which is a non-mixing heat exchanger, with air being circulated throughout the building. The cool air passes through the heat exchanger extracting the heat out of the working fluid and then dispersed into the building providing heat. The Thermal panels on average have an efficiency of 70% [10]. To implement this system pumps, water lines, storage tanks, and flood control devices are necessary to safely and properly install. Due to the extra infrastructure needed to implement the system after the initial build, it becomes a larger scale project and takes more money and time than just implementing the panels. Finally, this system would be used during the colder months of the year because the system can only generate heat, which in Flagstaff is about four months of the year [10]. Photovoltaic (PV) panels are the "solar panels" that are used on homes, businesses, and in solar farms. The sun's radiation energy comes into the panel and is converted into electric energy that is then connected into the building electrical grid and provides additional electricity to the building. These panels have an efficiency of approximately 15% and cost roughly five times that of solar thermal panels [9,10]. To implement these panels all that is required is to install the panels is to connect the electrical output up the electrical grid of the building. These two types of systems were chosen to be analyzed based on their availability on the market to be purchased and that the technology that is implemented into building is reliable.

5.1.1b Assumptions

In comparing these two systems a few assumptions must be made. First, both panels types would be subject to the same amount of radiation which in Flagstaff Arizona ranges from 5-7 (kWh/m^2)/day year round [11]. This allows the panels performance and efficiencies to be compared directly to one another. The second assumption is that both systems at hand are available to be purchased from large production companies insuring the lowest cost possible. The third assumption that was made is that both panels at hand are the same size which is approximately 2ft x 3ft resulting in a collection area of 6ft^2. The final assumption made is that all transmissions lines (the working fluid lines or electrical lines) are ran through the end of the panel that will be hinged on surface of the roof. Not all assumptions can be directly linked to the performance of the panels but rather the overall implementation of the final design.

5.1.1c Calculations

Basic relative panel comparison:

A quick look at numbers that are presented in the open statements begin to point that the basic performance of the solar thermal panels seems to higher than the Photovoltaic panels.

Solar thermal is 4.66 time more efficient than PV solar and 5 times more cost effective per panel.

4.66*5 = **~23.5 times "better" performance per dollar spent**

With this number of the solar thermal panels being 23.5 times "better" than Photovoltaic per dollar, more calculations are needed really understand the true impact of each system.

Basic radiation collection for one panel:

5-7 (kWh/m^2)/day * (2ft*3ft/3.28ft/m) = 2.78 – 3.90 kWh/day

ST: 70% * (2.78- 3.90) = **1.95 – 2.73 kWh/day**

PV: 15% * (2.78- 3.90) = **.418 - .585 kWh/day**

Yearly radiation collection for one panel:

ST: 1.95 – 2.73 kWh/day * (365 days * (4 months/ 12 months)) = **237.25 – 332.15 kWh / year**

PV: 0.418 – 0.585 kWh/day * 365 days = **152.57 – 213.52 kWh/ year**

The yearly total of the solar thermal panels collects more energy than that of the Photovoltaic panels but this still does not adequately produce a solution to this problem. Implementing a proper Solar thermal system into the building would have major cost implication with installing the working fluid holding tanks/ non-mixing heat exchangers, pumps, piping, rerouting the ventilation and air handlers to the non-mixing heating exchangers, added a risk of flooding the building, and the need of extra electricity to run the system. Having to use electricity to run the system poses more efficiency questions based on how the building electricity is being produced. If the building is being powered from a coal power plant the energy needed to run the thermal system might drop its overall efficiency close to that of the Photovoltaic system. These factors can drastically change the cost and practicality of the project as well as longevity of the system where as the Photovoltaic system might have a higher initial cost of the panels but provides a more reliable system that has less maintenance cost and will produce year-round instead of only for a third of the year.

Even with a potential lower output of energy to the building, the photovoltaic panels seem to be the clear winner from an overall practical solution standpoint to this problem. The PV system offers consistent energy collection year-round, have a lower maintenance cost do to not having moving parts or working fluids, does not require electricity to run the system, and have lower installation costs.

5.2 Optimal Design Array

To optimize the final design array for power output there are many factors that need to be considered. The final design consists of 30 vents each equipped with a Panasonic VBHNSA16 (330W) panel. The final array will produce a total power output of 9.9kW with an Azimuth of 171 degrees which 9 degrees north of the equator. The sun rises in the East and sets in the West, to ensure the photons emitted from the sun strike the panels perpendicularly the panels are oriented horizontally [12-16].

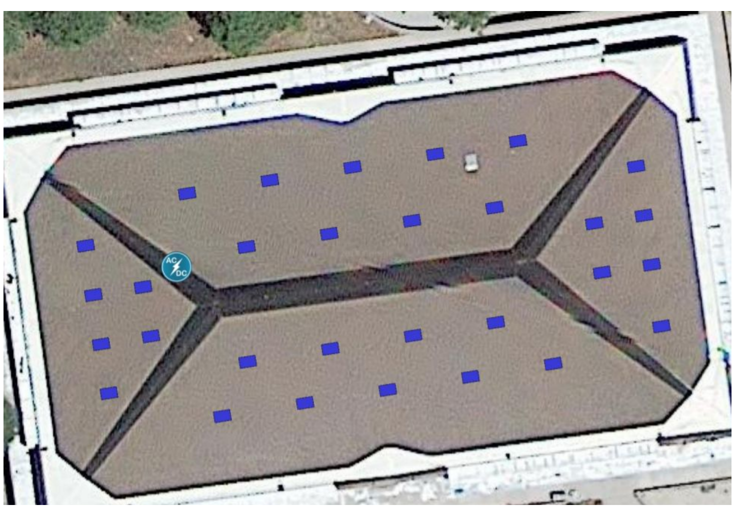


Figure 9: Panel Array

5.3 Window Panel Material

The main component to the solar ventilation system is the panel that is controlled by retractable arms. In the team’s proposed design, a 61” x 40” glass sheet is attached to the bottom of the solar panel in order to retain heat in the building. The type of glass was analyzed in order to find the optimal material for the window panel.

5.3.1 Material Properties

The team looked at two different types of glass: tempered glass and annealed glass. Tempering glass involves heating annealed glass up to a temperature of 700℃ and instantly cooling it. This process strengthens the glass by about four to five times stronger than annealed glass [17]. Table 4 shows some mechanical properties of tempered glass and annealed glass.

Table 4: Mechanical Properties of Tempered Glass and Annealed Glass [17-19]

Glass	**Tensile Strength (MPa)**	**Thermal Resistance (℃)**	**Modulus of Elasticity (MPa)**	**Density (kg/m^3)**
Tempered Glass	65	250	70,000	2,500
Annealed Glass	30	50	70,000	2,500

Table 5 shows the comparison between the tensile strength, thermal resistance, modulus of elasticity, and density of tempered glass and annealed glass. The modulus of elasticity and density for both types of glass are the same, however, the tensile strength and thermal resistance for tempered glass is higher than that of annealed glass. This shows that tempered glass is a lot stronger than annealed glass. Tempered glass is also a safer material to use than annealed glass because when a sheet of tempered glass breaks, it splits into small fragments, where annealed glass would break into sharp fragments [17-18].

When deciding the material to use for the glass sheet that goes under the solar panel, tempered glass has a higher tensile strength and thermal resistance than annealed glass. Also, due to the fact that tempered glass breaks into small fragments and not sharp fragments like annealed glass, it is a safer material to use. As a team, the best material for glass sheet that is attached to the window panel is tempered glass since it is stronger and safer than annealed glass.

5.4 Housing and Arms

When this analysis was done, various concepts were considered. This document will only address a few of these concepts with many assumptions and approximations being made do to the lack of experience. The main aspects analyzed are, “What is the best material and why?”, “How many arms should be used?”, and “Will the arms be able to achieve the optimal angle for energy collection?”. These concepts will allow the team to understand how the arms should be designed for the best product.

5.4.1 Material

When analyzing any sort of mechanical system, the factor that determines the systems amount of deformation, max torsion, yield stress, weather resistance, cost, and many more is the material used. Therefore, materials must be analyzed before any further analysis can take place.

5.4.1a Material Strength

Material Strength is the first thing to look at when selecting a material because the it must withstand the forces it is subjected to with a reasonable factor of safety. Strength incorporates stress and deformation. Meaning both the materials max stress and max deformation needed to be considered, which can be done by looking at the material yield stress (this is this the max amount of stress the material can take without

permanent deformation).
Stress and any related equations are listed below, and calculations made using assumptions are in Appendix E.1.

Variables: F = Force, M = Moment, m = Mass, a = Acceleration , σ = Stress, ε = Strain,ϵ = Modulus of Elasticity

Equations:

$$\sum F_x = F_{Ax} + F_{Bx} + F_{Cx}$$

$$\sum F_y = F_{Ay} + F_{By} + F_{Cy}$$

$$\sum M_A = M_B + M_C$$

$$\vec{F} = m\vec{a}$$

$$\sigma = m/A$$

$$\varepsilon = \Delta L/L$$

$$\epsilon = \sigma/\varepsilon$$

These calculations provided a list of materials, list not provided because the list was to extensive, that need further analysis for further material selection.

5.4.1b Material Weather Resistance

Provided in Appendix E figure E.2 is a chart that displays the melting/ Degradation temperature of the material. This chart allows the team to understand at what temperatures the material becomes a major issue. From this the material selection can be further narrowed down. Although this chart provides data that narrows down possible materials, further charts and analysis are needed to understand the materials weather resistance. This is a direction to head, not the complete analysis. To do a complete analysis more research and expertise is needed. With the general material being selected non-material-based factors can be considered.

5.4.2 Number of Arms

When analyzing the arms and making sure they provide the best performance, the number of arms and where the arms are attached need to be addressed. The number of arms, position, and length of the arms determine how much ventilation can be provided from one radiative solar vent. The quantities we decided to look analyze were two and four arms. These two quantities are examined because they can provide the largest range of movement without overcomplicating the system. The ideas of how these arms would be done are attached as sketches in Appendix E.3 and in a SOLIDWORKS model in Figure 8.

After visually seeing these arms on the system for the maximum ventilation the system should have four arms. The orientations of the arms seen in Appendix E with the sketches created. The max ventilation provided is similar. However, a CAD model was created based on the two arms connected because it would take less motors and, in the end, save money (model can be seen in Figure 8).

5.4.2a Orientation of the Arms

The orientation of the arms was the final thing considered by the team was the angle the arm could set the panels at. With the four-arm design selected the panel will be able to be positioned at 0 to 90 degrees and allows the panel to be completely rotate. This versatility allows for the panel to be used to its complete potential allowing for the panel to be used with a dark window tint and light window tint. This allows for the panel obtain the optimal light and thermal energy for maximum performance. These arms will also allow the panel to be positioned at the angles of 25 for the summer and 55 for the winter for optimal solar collection [20]. As strange as it seems this angle needs to be kept throughout the day which means the sun needs to be tracked while maintaining the proper angle. With this arm design this can be achieved because of the range of positions this device can be oriented. These ideas understood more when looking at the figures in Appendix E.

Although there are many other aspects to be analyzed before committing to a design for the arms of the system, a rough design was drafted based on material, number of arms, and the orientation of the arm. The material was narrowed down to many materials but will likely be made from aluminum # because aluminum can withstand all four seasons and can combat any forces that the panel with be experiencing. Additionally, aluminum will be the cheapest material to use when creating the design although a fiscal report has not yet been done. The number of arms that will be used in the design will be four. These arms will be formed into two main arms but allow for greater movement. Finally, the orientation of the arms will allow for full motion of the panel. Along with the other team members analyses of the design and this analysis a detailed design can begin to be conceptualized.

6.0 Economical Analysis and Justification

When designing a product and creating a proposal, it is crucial to generate a cost analysis based on aspects of the design. Provided in this memo is a cost analysis of our team's generated redesign (seen in Figure 8) of the heating, ventilation, air conditioning (HVAC) system in the Social and Behavioral Science west (SBS west) building at Northern Arizona University (NAU). This building needs an HVAC upgrade because it is energy inefficient and hurts the University in annual costs. As a team we have generated an estimation of the cost to implement our hypothesized design, along with an estimation of the saving our system will provide.

For the cost analysis to be efficiently completed, each member of the team was assigned an aspect of the design to analyze. Taylor was tasked with the cost analysis of the housing and the arms of the system. Kyle oversaw the cost analysis of the window panel. Then Talon and Dreighton did a cost analysis of the solar panel. Talon focused on the total cost of the window panel while Dreighton focused on the pay of period solely based on the panels. The reason the solar panel was split this way was because the solar panel is the only non-fixed cost. Finally, Dan conducted an analysis of the estimated installation cost. An estimated total cost was the generated using the aspects analyzed by the team.

6.1 Estimated Cost of the Body and Arms

A cost of most solar panel designs' that is often overlooked is the cost of the housing. Our team made sure to conduct a cost analysis on the parts of the design, which makes up the housing. Additionally, a cost analysis of the arms that control the angle and ventilation of the panel were considered in this section. This be based on the team's decision to create the housing and arms out of the same material.

6.1.1 Cost the Systems Housing

The team decided that a low carbon steel (4150 steel) would be our best option to use when creating the housing and arms for the design. Then the team decided that each panel will be about 61 in by 40 in (length by width), so the frame needed to be larger than 61 in by 40 in. The team decided to round up to the nearest foot for easy calculation and with plenty of room for size and cost reduction if needed. With the body being designed to be six feet by four feet, the only dimension not decided was the height of the panel. To keep calculations simple and provide an overestimation (again, this provides reduction freedom) the height will be set to one foot. With both the material and dimensions being selected, an estimated cost per panel housing can be calculated using the volume of the panel without the volume subtracted to fit the solar panel and widow. Volume = height*length*width: V= 1ft*6ft*4ft = 24 ft ^3 cu.ft. However, this is not the actual volume of the housing of the design. The actual volume can be better approximated found by; taking the estimated volume of the space the window panel and solar panel will occupy and subtracting that volume from the original volume found (calculated above). With the size of the panel being 61” by 40” (~5ft by ~3ft) and the assumption that the hole must go all the way through the housing (1ft). Estimated hole

Volume = 1ft*(61in*1ft/12in)*(40in*1ft/12in) = 16.94 cu. Ft

Needed volume=Initial volume – estimated hole volume = (24-16.94) cu. ft = 7.06 cu. ft

Then with some research, which it was found that 4150 steel averages approximately $160/cu. ft [21], and the calculated needed volume, an estimated cost can be generated per panel and for 30 panels. Thirty panels because this is the number the team has decided to propose for SBS west.
Cost of housing = $160/cu. ft*7.06 cu. ft = $1,128.89 per panel
Cost of 30 housing units = $1,128.89*30 units = **$33,866.67** for 30 housing units

6.1.2 Cost of the Arms

Without a technical analysis on the ideal shape to make the arms, it is hard to tell the actual cost. However, some basic assumptions can be made to estimate the cost of the arms. If our team assumes that there are four arms per panel, each two feet long, six inches wide, and three inches thick, then a volume can be found. With this calculated volume per arm multiplied by four and then by the approximate cost of 4150 steel of $160 per cu. ft [21] an estimated cost per panel can be found. Finally multiplying this value by 30 will give the estimated total cost of the arms for the system. This approximation is shown below,

Volume of arm = length*width*thickness = 6in*1ft/12in*3in*1ft/12in*2ft = .25 cu. ft

Cost per arm = .25 cu. ft *$160/cu. ft = $4 per arm

Cost of arms per panel = 4 arms * $4 per arm = $16 per panel

Total cost of arms for the system = $16 per panel * 30 panels = $480 for the system

After making some assumptions and approximations, the systems housing and arms are estimated to cost **$34,346.67** for the system. However, this is not a full analysis because exact dimensions are needed along with motor and fastener costs to have a better approximation of the systems cost.

6.1.3 Cost of Window Panel

Aside from the solar panel, there is also a window panel that will be installed on the bottom of the solar panel. This window panel is a 61” by 40” glass sheet, which is made of tempered glass and has a 3/16” thickness. The size of the glass sheet is smaller than the solar panel to provide a better seal of the whole panel in the roof. From One Day Glass, one sheet costs about $100.79 [22]. This window panel also provides insulation when closed. A thermal film can be installed onto the glass sheet to reduce the amount of heat loss from within the building. The thermal film can have an emissivity rating of 0.70 through 0.81 and about 19% through 30% of heat is reflected into the building [23]. The price of the thermal film is around $4 per square footage. If the film is installed on the whole glass sheet, the price of the thermal film it will cost approximately $813.33. With the glass sheet and thermal film, one window panel can cost around $914.12. For 30 vents, the total cost for the window panels can cost around $27,423.70. All pricing of both the glass sheet and the thermal film can be shown in table 5.

Table 5: Window Panel Cost

# of Window Panel	Cost of Glass Sheet (61”x40”)	Cost of film per square foot	Total Cost
1	$100.79	$813.33	$914.12
30	$3023.70	$24,399	**$27,423.70**

6.2 Cost of the panels

The factor that would relate to the cost the most would be the solar panels themselves. When deciding on a panel a few criteria were taken into consideration. The performance of the panel was a crucial factor of the criteria. The panel needed to be as efficient as possible, to aid in the long-term payoff and generate as much power as possible. After some further research, the panel selected was the Panasonic 330 HIT high efficiency solar panel. The panel costs $310/Unit, which allows the tentative materials budget per panel to be roughly $500 [23]. Each vent that is installed will be accompanied with a solar panel. With 30 proposed vents the cost of the solar panels comes to $9,300 seen in table 6.

Table 6: Cost of Solar Array

Option	Quantity (units)	Cost per Unit ($)	Total Cost ($)
Just on Vents	30	$310	**$9,300**

6.3 Photovoltaic System Pay-off Based on Solar Panels

The Photovoltaic (PV) System consists of 30 Panasonic VBHN330SA16 (330W) panels. A single panel costs $310/Unit [24]. The total cost of 30 panels is $9300. The total cost including equipment and installation is approximately $30,000. Each panel produces 330 Watts of electricity an hour. Knowing this information, it is important to calculate when the system will pay itself off.

6.3.1 Calculations

To calculate when the system will pay off, we first multiplied the amount of energy produced by a single panel by the total amount of panels. Then we multiplied Watts produced in one hour by six hours (the most energy produced from 9am to 3pm) for optimal energy production. This provides the value for how many Watts will be produced in one day. Furthermore, we multiplied daily energy production by 365 days to determine the amount of energy it will produce annually. With knowing how much the system produces annually we calculated how much the system is worth to the customer. Take the total number of panels and multiply by the price of purchase to acquire system cost. Then we made sure to divide the system cost by the annual production, to determine how much the system is worth hourly. This value ($0.43/kWh) is the average rate the system will provide throughout the year. With this, the amount saved based on the panels was calculated. Done by finding the difference between the cost of energy produced in an hour, and the price of total energy consumed in an hour. The customer saves approximately $0.343 per hour if this system were to be installed. Now to Calculate when the system will pay itself off, we set up an algebraic expression including total cost, customer saving and an unknown time variable. Then we solved for the number of hours to make this algebraic expression true. Finally, we divided by the number of hours in a year by this estimated value and we got an approximation of how many years it will take for the system to pay itself off based on customer saving. With this calculation we were able to approximate an estimated pay off time of ten year. This may sound like this pay off time but in twice the amount of time (20 years) the savings including the time it takes to pay off the system will have an estimated savings of $30,000. Provided in Appendix E are some figure providing a visual example of the hypothesized array, along with some tables that assisted in calculations, shown below:

330 Watts * 30 panels = 9900 Watts total/ Hour.
9900 W * 6 Hours = 59.4kWh/Day.
59.4kW * 365 Days = 21681 kWh/Year.
30 Panels * $310 = $9300). ($9300/21681 kWh = $0.43/kWh.

$0.43/kWh - $0.087/kWh = $0.343/kWh(Savings).
0 = $30,000-($0.43/kWh)*Hours
87463.6 Hours.
87463.6 Hours/ 8760 Hours(1 Year) = **9.98 Years**

6.4 Installation Costs

A most of the installation costs come from the solar panels, which are included in the initial costs of buying all the panels. With the cost of the solar array being approximately $105,400, the company we decide to purchase these from will include installation in the total initial cost. This is believed to be more cost efficient than hiring a third-party installation team. Purchasing solar panels comes with federal and state tax incentives coming in at 30% and 10% respectively [25]. The average cost of installing vents on to a rooftop in Flagstaff, Arizona is $495 per vent [25]. With 30 vents being coupled with solar panels the cost of installation for the vents would be:

30 vents * $495 Dollars = **14,850 Dollars**

This installation cost is due to the material cost of the vents being independent of their installation cost.

6.5 Conclusion

With knowing these cost analyses done by the team, a rough estimation of the cost of the entire project can be calculated. However, it important to remember that these cost analyses are based on assumptions and approximations. For a more accurate cost analysis to be done on the entire system, more things must be determined and not assumed. The cost analysis has provided the team with a rough number for different components of the system and also provided an insight on where costs can be reduced. Finally, a total cost is not provided due to components not analyzed and the components that were analyzed having such variable costs.

7.0 Ethics of Design

As the solar ventilation system is implemented two present ethical issues arise: The environment impact of batteries compared to the need to store energy, and the aerial impact to aircraft and wildlife compared to the generation of more energy through a larger solar array. Both issues are equality important and present clear arguments for each side. As a team both issues have been evaluated and decisions made off of the results of each situation. There are other issues such as Patenting, Future Consumption and Production and Aerial Impact of Solar Panels.

7.1 Environmental Impact of Batteries vs. Commitments to APS Power Company

Solar collection historically has been implemented with batteries to store the energy collected by the panels. More recently as solar farms are created the electricity has been directly streamlined to the power grid instead of storing the energy that is collected in batteries. As the rate of solar energy collection increases power companies are becoming increasingly strict about what they allow to be implemented into the power grid. NAU has a duty to uphold agreements with and contract made with APS who supplies power to the University and the surrounding city of flagstaff as seen in canon four. If a full-blown solar field was to be installed on the roof of the SBS West building these contracts may be violated which could lead to legal battles between the APS and the university.

If the solar array were to be implemented with a energy storage system large enough to be paired with the array, negative environmental impacts would occur. The production, use, and disposal of batteries all come with a high cost to the atmosphere and to aquatic environments. Batteries, in particular lead acid, release photochemical smog that pollutes the atmosphere and contributes to the rise in average global temperature [26]. This rise in temperature is damaging ecosystems across the world, displacing populations of animals and harming precious resources such as rainforest and glaciers. As batteries are disposed the acid and lead in the batteries are contaminating groundwater supplies as well as aquatic environments such as lakes, rivers, and the ocean. The ecosystems in the environments are experiencing chemical pollution causing a decrease in wildlife populations as well as harming the natural balance of life. When NAU started the Carbon 2020 initiative the university pledge to reduce its impact on the environment. As engineers of the project, the code of ethics canon 1 must be followed: "Hold paramount the safety, health, and welfare of the public." Implementing a new solar array that required batteries to store energy for use in the SBS West building would directly go against their pledge to reduce their impact.

As a team we felt the need for final design of our project to comply with APS contracts while removing the environmental impact that batteries inherently create. The final design reduces the number of solar panels used for nearly 340 down to 30 to allow for the electricity created to be directly inputted into the grid rather than stored in batteries. With the final Solar Thermal Ventilation design NAU will have a slower pay off and generate less green energy but will keep its commitments to APS as a consumer and their pledge to reduce the environmental impact of the campus.

7.2 Aerial Impact of Solar Panels

The team's final design incorporates a glass sheet on the top and bottom of the solar panel and is referred to as the window panel. This allows for both protection and radiating heat back into the building. Due to the fact that the solar panels are placed on the roof, this poses the ethical issue of light being reflected back into the sky depending on the angle of the solar panel. This reflection can potentially affect air traffic since the Flagstaff airport is a few miles away from campus. This reflection can also affect wildlife such as birds. The light that is reflected from the glass sheets may harm the birds during flight. With the team's design of having 30 solar panels on the roof, the sheen of the glass will be an important issue to address.

According to the National Society of Professional Engineers: Code of Ethics, this issue violates the fundamental canon stating "Hold paramount the safety, health, and welfare of the public" [27] . With the panel having glass, it could reflect light that may interfere with air traffic and wildlife. One method to resolve this issue is to sand the top glass sheet. Sanding the glass sheet will get rid of the glare that is produced from the light. Sanding the glass may be an effective solution for light being reflected in the sky, however, it can increase the overall cost of the project since the people installing the panels will have to use special tools in order to sand the glass sheet. By sanding the glass, it will also lengthen the time of installation of the panels since installers would have to individually sand 30 panels before attaching it to the solar panel. Another method to resolve this issue is to get rid of the top glass sheet. This will get rid of the reflection of the light since the solar panel itself does not really reflect any light. However, this gets rid of an extra layer of protection for the solar panel. In the end, the team has decided that the glass sheet should be removed to reduce solar reflection. This can also reduce the overall cost of the project since the team will not be paying for an extra 30 sheets of glass.

7.3 Conclusion

There are many aspects of ethics that affect Solar Ventilation and Radiation. The main problems include Environmental Impacts and Production and Aerial Impacts of Solar Panels. As engineers we must adhere to the National Society of Professional Engineers Code of Ethics. Following these codes of ethics allows for engineers to design quality products that suit the engineers and customers ethical needs.

8.0 Conclusion and Future Work

As the project as a whole appears to be a success, more research needs to be completed from professionals with more knowledge of HVAC systems and system implementation. The motors to run the arms were not even considered due to a lack of time. Likewise the Thermal effects of installing the vents on the roof and its potential to reduce the load on the current HVAC system was not analyzed due to a lack of knowledge among the team. We feel that the design presented is a step in the right direction but not a final solution for the project at this time.

References

[1] A. Mohamed, "Energy Optimization In Existing Buildings", *Engineered Systems*, pp. 1-5, 2015.

[2] *IEEE European Public Policy Initiative*, "Heating and Cooling Future of Europe and Interactions with Electricity", IEEE, Europe, 2018.

[3]"SolarDuct - Modular roof mounted Solar Air Heating System (solar thermal collector) The SolarWall has the fastest ROI of any competing solar technology, and competing transpired solar collector systems", *Solarwall.com*, 2018. [Online].

[4]"Bosch Commercial Buderus SB625WS Boiler with up to 98% Efficiencies", *Bosch-climate.us*, 2018. [Online]. Available: www.bosch-climate.us/products-bosch-thermotechnology/boilers/ ler-sb625ws.html.

[5]"RQNL-B, RQPL-B (2-4 Ton) | Ruud Commercial Package Heat Pumps", *Ruud.com*, 2018. [Online]. Available: https://www.ruud.com/product/

[6] E. Ackerman, "Heat Your House with Someone Else's Computers", I*EEE Spectrum: Technology, Engineering, and Science News*, 2014. [Online]. Available: https://spectrum.ieee.org/energywise/energy/the-smarter-grid/heat-your-house-with-someoneelses -computers. [Accessed: 13- Feb- 2018].

[7] P. Patel, "Efficient Air-Conditioning Beams Heat Into Space", *IEEE Spectrum*, 2017.

[8] Babiak, J., Olesen, B. W., & Petráš, D. (2009). *Low temperature heating and high temperature cooling. Brussels: REHVA - Federation of European Heating, Ventilation and Air Conditioning*

[9]"Don't Be a PV Efficiency Snob | Do the Math", *Dothemath.ucsd.edu*, 2018. [Online].

[10]J. Kinnear, "What's Better, Solar Thermal or Solar PV? | Solar Power Authority", *Solar Power Authority*, 2018. [Online].

[11]"U.S. Solar Radiation Resource Maps", *Rredc.nrel.gov*, 2018. [Online]

[12]"Arizona Latitude and Longitude Map", Mapsofworld.com, 2018. [Online]. Available: https://www.mapsofworld.com/usa/states/arizona/lat-long.html. [Accessed: 02- Apr- 2018].

[13]ftp://ftp.panasonic.com/solar/specsheet/n325330-spec-sheet.pdf

[14]https://usa.krannich-solar.com/fileadmin/content/data_sheets/inverter/usa/STPTL-US12-24EXP-DUS 132533W.pdf

[15]"HelioScope: Advanced Solar Design Software", Helioscope.com, 2018. [Online]. Available: http://www.helioscope.com/projects/701823/reports/1719499. [Accessed: 02- Apr- 2018].

[16]Nec., Nec code book 2008. [Place of publication not identified]: Pearson, 2010.

[17] Glazette.com. (2018). *Annealed Glass characteristics | Glazette.com – The Glass Portal*. [online] Available at: http://www.glazette.com/annealed-glass-characteristics-433.html [Accessed 4 May 2018].

[18] Glazette.com. (2018). *Tempered Glass - Glazette*. [online] Available at: http://www.glazette.com/Glass-Knowledge-Bank-25/tempered-glass.html [Accessed 4 May 2018].

[19] Saint-Gobain Sekurit. (2018). *Glass properties*. [online] Available at: http://www.saint-gobain-sekurit.com/glossary/glass-properties [Accessed 4 May 2018].

[20] "Materials," Materials. [Online]. Available: http://www.pages.drexel.edu/ [Accessed: 20-Apr-2018]

[21] "Materials," *Materials*. [Online]. Available:http://www.pages.drexel.edu/[Accessed: 20-Apr-2018].

[22] "Order Online," *One Day Glass*. [Online]. Available: https://www.onedayglass.com/order-online/. [Accessed: 20-Apr-2018].

[23] "Panasonic HIT High Efficiency Solar Panels," *altEstore.com*. [Online]. Available: https://www.altestore.com[Accessed: 20-Apr-2018].
[24] Rooftopsolar.us. (2018). *Solar For Your Flagstaff Business.* [Online]. Available: http://rooftopsolar.us/flagstaff-solar-installation/?gclid=EAIaIQobChMI1YCPyM_H2gIVDBhpCh0ikQkyEAAYASAAEgIdPPD_BwE
[25] Homewyse.com. (2018). *Cost to Install a Roof Vent.* [Online]. Available: https://www.homewyse.com/services/cost_to_install_roof_vent.html
[26]"Environmental Problems That Batteries Cause", *Sciencing.com*, 2018. [Online]. Available: https://sciencing.com/environmental-problems-batteries-cause-7584347.html. [Accessed: 30-Apr- 2018].
[27] National Society of Professional Engineers: Codes of Ethics. 2018. [Online] Availlable: https://bblearn.nau.edu/bbcswebdav/pid-6325736-dt-content-rid-114466406_1/courses/1181-NAU00-EGR-386W-SEC001-5759.CONTENT/NSPE%20Codes%20of%20Ethics.pdf

Appendices

Appendix A

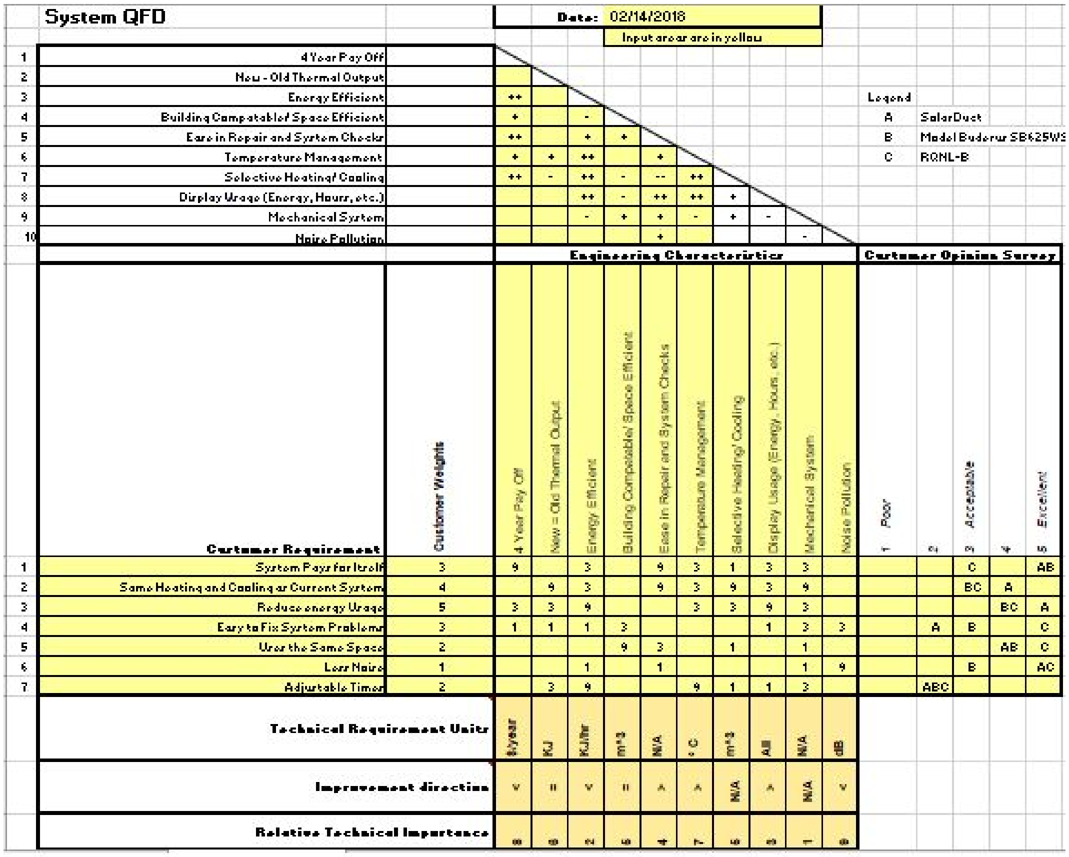


Figure A.1: Simple QFD

Appendix B

Table B.1: WBS

WBS #	Task Description	Est. Hours	Who	R esources	Material Cost
1	**Research**	**~19**	**Team**		
1.1	**Parts**	**5 <**	**Team**	**Internet/ books**	**N/A**
1.1.1	**Arm**	**1**	**Taylor**	**Internet/ books**	**N/A**
1.1.2	**Panel**	**1**	**Team?**	**Internet/ books**	**N/A**
1.1.3	**Piping**	**1**	**Talon**	**Internet/ books**	**N/A**
1.2	**Pricing**	**5**	**Team**	**Internet/ books**	**N/A**

1.3	**Installation**	**1**	**Kyle**	**Internet/ books**	**N/A**
1.3.1	**Codes/Safety**	**1**	**Taylor**	**Internet/ books**	**N/A**
1.3.2	**Installation Team**	**1**	**Talon**	**Internet**	**N/A**
1.4	**Location**	**1**	**Dreighton**	**Internet**	**N/A**
1.5	**Safety Codes**	**1**	**Taylor**	**Internet/ books**	**N/A**
1.6	**Roofing**	**1**	**Dan**	**Internet**	**N/A**
2	**Design/Planning**	**~19**	**Team**		
2.1	**Design**	**4**	**Dreighton and Team**		**N/A**
2.1.1	**Engineering Calculation**	**3**	**Team**	**Internet/ calculator**	**N/A**
2.1.2	**Equipment Design**	**2**	**Team**		**N/A**
2.2	**AutoCAD/ SolidWorks**	**3**	**Dreighton and Team**	**SolidWorks/AutoCAD**	
2.2.1	**Motorized Arm**	**1**	**Taylor**	**SolidWorks/AutoCAD**	**N/A**
2.2.2	**Solar Panel**	**3**	**Talon, Kyle, and Dreighton**	**SolidWorks/AutoCAD**	**N/A**
2.2.3	**Thermal Window**	**2**	**Talon and Kyle**	**SolidWorks/AutoCAD**	**N/A**
2.2.4	**Storage Tank**	**1**	**Talon**	**SolidWorks/AutoCAD**	**N/A**
3	**Integration**	**~48**	**Team**		
3.1	**Build System**	**20**	**Team**	**Arm/Panel/Storage tank/tools**	
3.2	**Removal of Old System**	**1**	**Taylor**	**Vehicle**	
3.3	**Hiring Installation Team**	**1**	**Dan**	**Email/ phone**	
3.4	**Installation**	**24**	**Talon**	**Tools**	
3.5	**System Component Update**	**2**	**Kyle**	**Tools**	

Appendix C

Figure C.1: List of Tasks

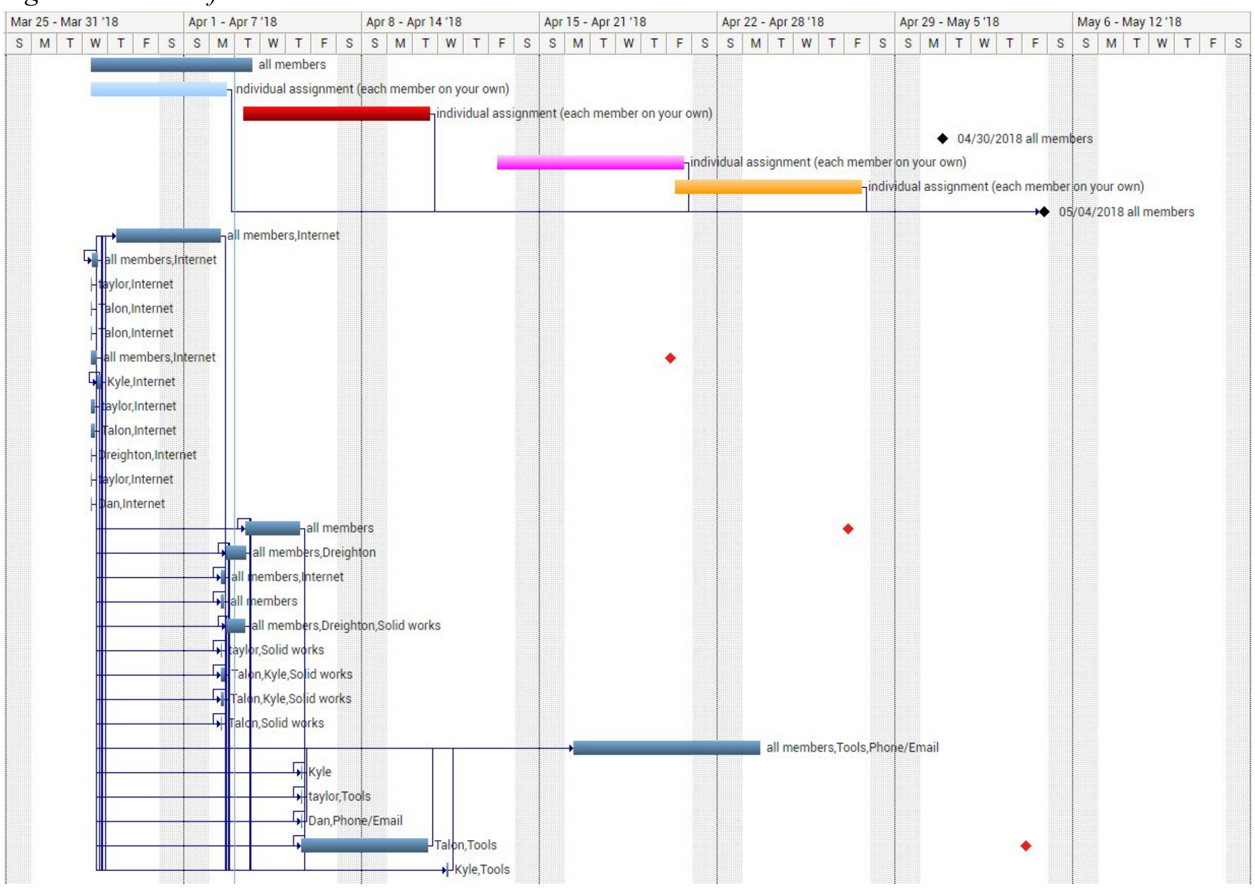


Figure C.2: Gantt Chart Graphical Display

Appendix D

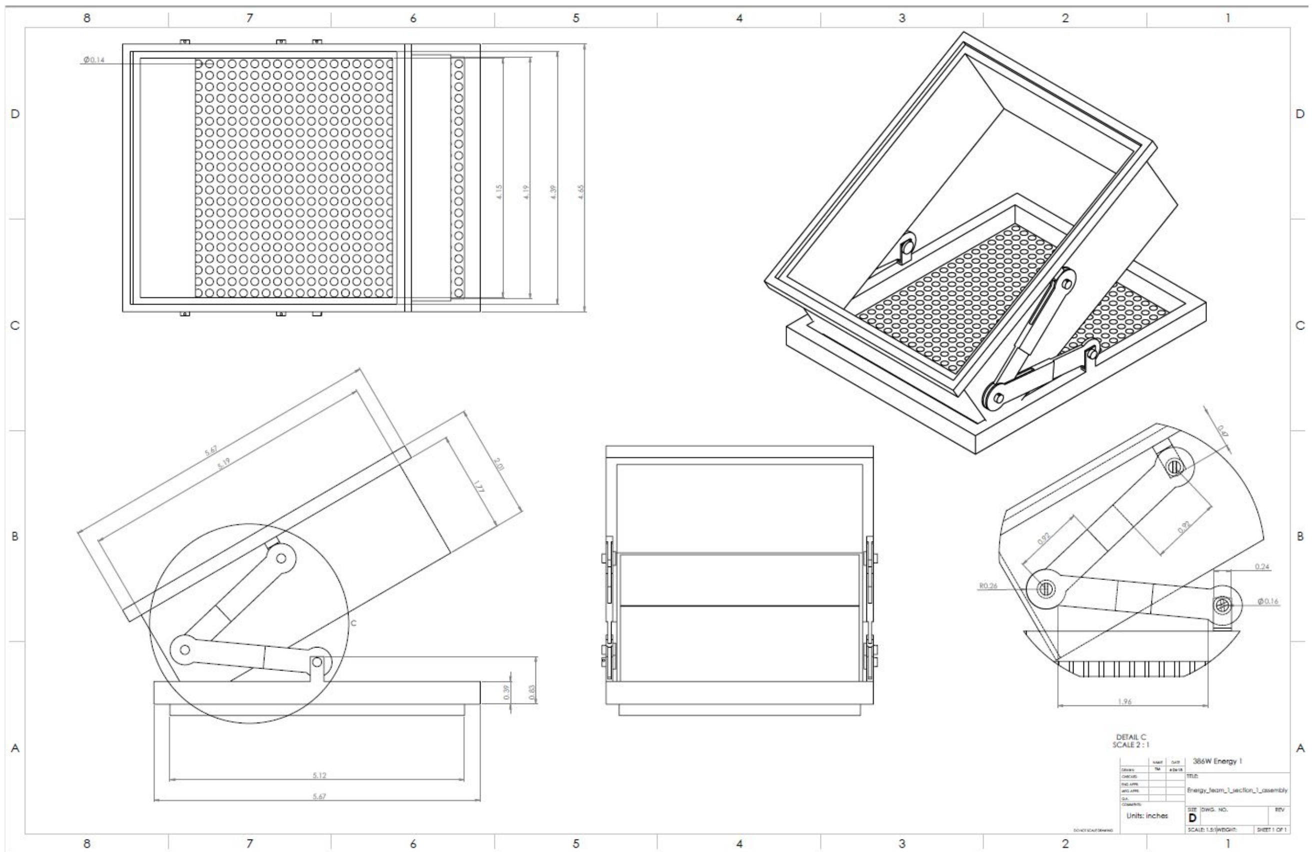


Figure D.1: Drawing Sheet for CAD Model

Appendix E

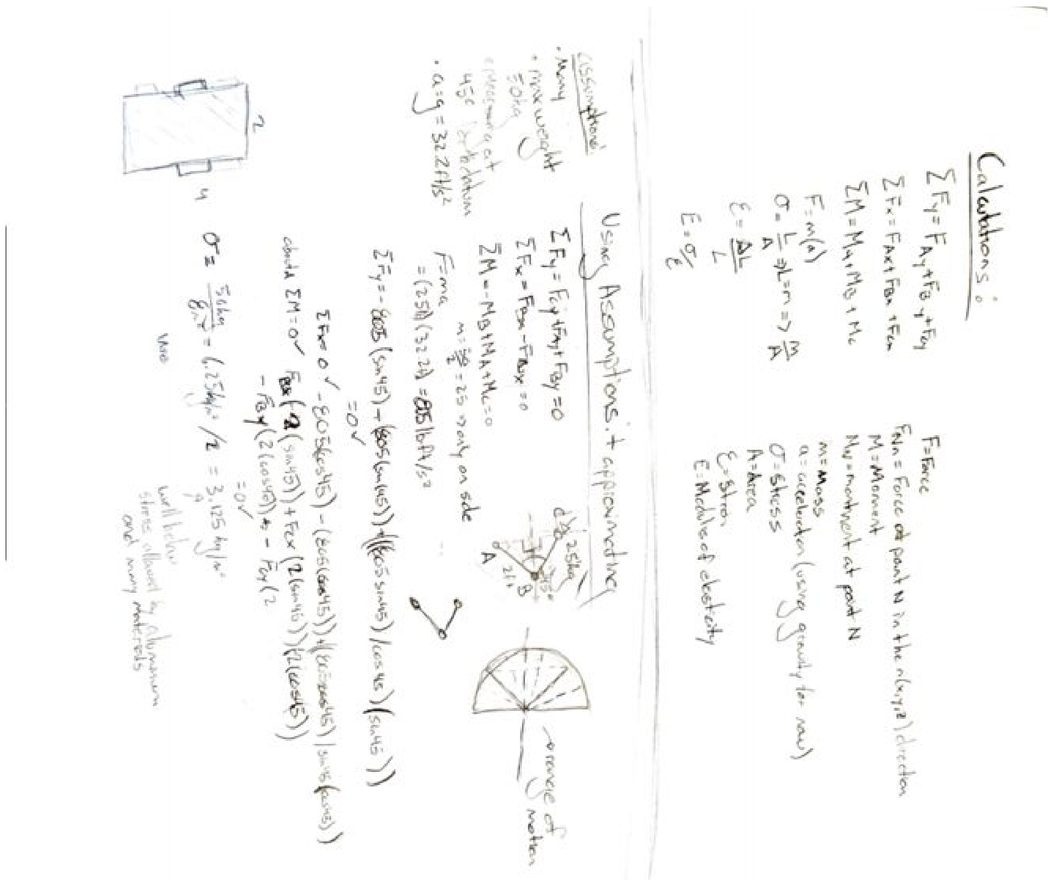


Figure E.1: Calculations Using Assumption

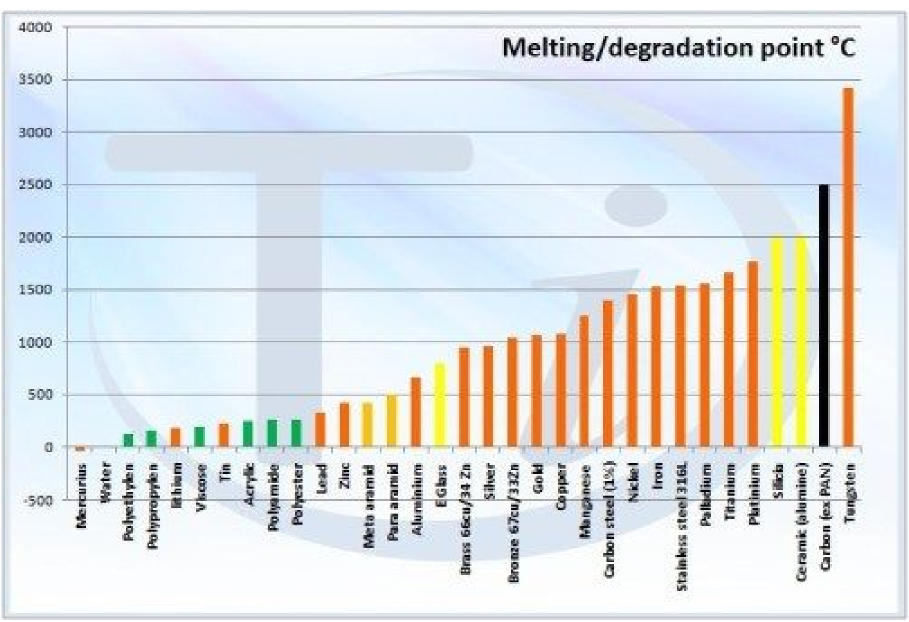


Figure E.2: Melting/Degradation Point of materials [7]

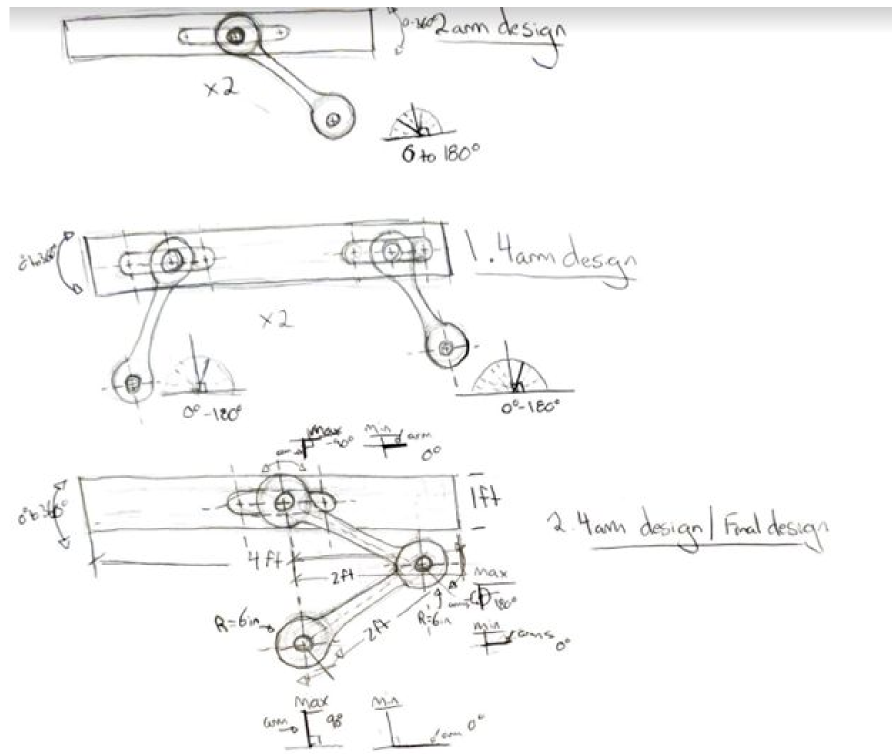


Figure E.3: Sketches of Quantity of arms and Design